WATT.

Engraved from a Drawing by H Corbould, taken with the permission of James Watt Esq

FROM THE STATUE BY CHANTREY.

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# THE STEAM ENGINE, STEAM NAVIGATION, ROADS, AND RAILWAYS,

EXPLAINED AND ILLUSTRATED.

BY

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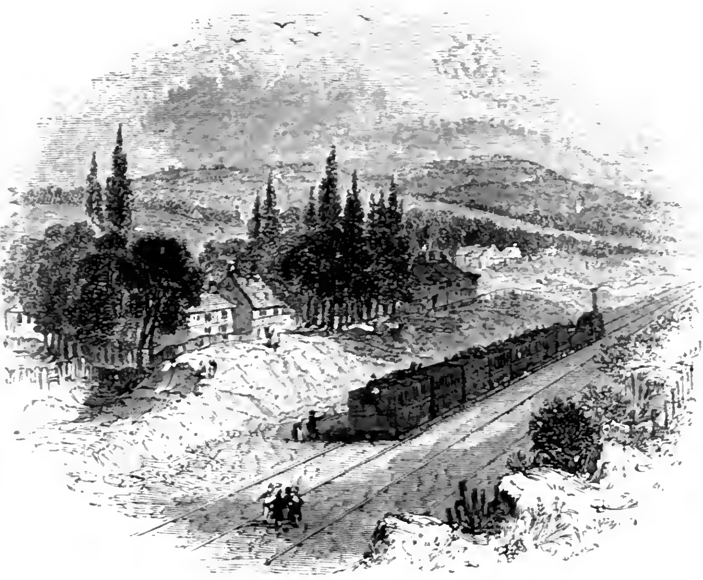

THE present is the eighth edition of a work which appeared more than twenty years ago, and was the earliest attempt to present the history of the invention of the Steam Engine and an exposition of its structure and operation in a form and style which should be intelligible to the public in general. Some time previous to its publication the author had been requested by the Royal Dublin Society to deliver at their theatre a course of popular lectures on this subject. These lectures were very numerously attended, and the Society, considering them as deserving of some mark of their approbation, besides the customary acknowledgment, voted a gold medal to be presented to the author bearing a suitable inscription. These lectures were soon after reduced to a form suited for publication, and supplied the materials for the first edition of the present treatise.

In the successive editions through which the work has passed, it has undergone such modifications as the progressive improvement and extension of steam power rendered necessary. In its present form it is intended to convey to the general reader that degree of information respecting steam power and its principal applications, which well-informed persons desire to possess. It is written in language divested of mathematical and mechanical technicalities, so that the details of the machinery, and the physical principles on which they depend, will be generally intelligible. In former editions, much space was occupied by historical and biographical matter, as well as by the description of engines which have long since become obsolete, and which, not forming a necessary link in the chain of invention, may be considered superfluous. The space has been in the present edition more usefully occupied by other matter.

The Second and Third Parts are for the most part new. In the third chapter of the Second Part will be found a review of the progress of Steam Navigation, from its first establishment in 1812 to the present day. This chapter also contains the refutation of those absurd reports which have been generally circulated, imputing to the author opinions as to the impossibility of the Atlantic voyage, which are precisely the reverse of those he really expressed.

LONDON ENTRANCE TO THE NORTH WESTERN RAILWAY

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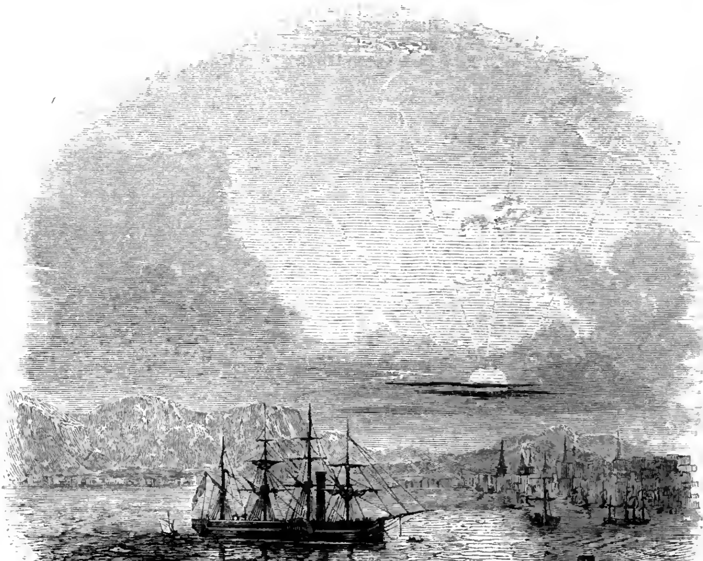


THE GREAT WESTERN, OFF NEW YORK

THE

# STEAM ENGINE, STEAM NAVIGATION, ROADS, AND RAILWAYS.

## PART I.

### THE STEAM ENGINE.

### CHAPTER I.

#### ORIGIN OF THE INVENTION AND EARLIEST ATTEMPTS AT ITS APPLICATION.

(1.) *The steam engine a subject of popular interest.* — The history of the steam-engine offers to our notice a series of contrivances which, for exquisite and refined ingenuity, stand without any parallel in the annals of mechanical science. These admirable inventions, unlike other results of scientific inquiry, have also this peculiarity, that, to understand their excellence and to perceive their beauty, no previous or subsidiary knowledge is necessary, save what may be imparted with facility and clearness in the progress of the explanation and development of the machine itself. A simple and clear exposition, divested of needless technicalities and aided by well-selected diagrams, is all that is required to render the construction and operation of the steam-engine, in all its forms, intelligible to persons of plain understanding and moderate information.

But if the contrivances by which this vast power is brought to bear on the arts and manufactures be rendered attractive by their great mechanical beauty, how much more imposing will the subject become, when the effects which the steam-engine has produced upon the well-being of the human race are considered! It has penetrated the crust of the earth, and drawn from beneath it boundless treasures of mineral wealth, which, without its aid, would have been rendered inaccessible; it has drawn up, in measureless quantity, the fuel on which its own life and activity depend; it has relieved men from many of their most slavish toils, and reduced their labour in a great degree to light and easy superintendence. To enumerate the benefits it has conferred, would be to count almost every comfort and every luxury of life. It has increased the sum of human happiness, not only by calling new pleasures into existence, but by so cheapening former enjoyments as to render them attainable by those who before could never have hoped to share them: the surface of the land and the face of the waters are traversed with equal facility by its power; and by thus stimulating and facilitating the intercourse of nation with nation, and the commerce of people with people, it has knit together remote countries by bonds of amity not likely to be broken. Streams of knowledge and information are kept flowing between distant centres of population; those more advanced diffusing civilisation and improvement among those that are more backward. The press itself, to which mankind owes in so large a degree the rapidity of their improvement in modern times, has had its power and influence increased in a manifold ratio by its union with the steam engine. It is thus that literature is cheapened, and, by being cheapened, diffused; it is thus that Reason has taken the place of Force, and the pen has superseded the sword; it is thus that war has almost ceased upon the earth, and that the differences which inevitably arise between people and people are for the most part adjusted by peaceful negotiation.

Deep as the interest must be with which the steam engine will be regarded in every civilised country, it presents peculiar claims upon the attention of the people of Great Britain. Its invention and progressive improvement are the work of our own time and our own country; it has been produced and matured within the last century, and is the almost exclusive offspring of British genius, fostered and sustained by British enterprise and British capital.

(2.) *Mechanical virtue conferred by it on coals.* — The steam engine is a mechanical contrivance, by which coal, wood, or other fuel, is rendered capable of executing any kind of labour.

Coals are by it made to spin, weave, dye, print and dress silks, cottons, woollens, and other cloths; to make paper, and print books upon it when made; to convert corn into flour; to express oil from the olive, and wine from the grape; to draw up metal from the bowels of the earth; to pound and smelt it, to melt and mould it; to forge it; to roll it, and to fashion it into every desirable form; to transport these manifold products of its own labour to the doors of those for whose convenience they are produced; to carry persons and goods over rivers, lakes, seas, and oceans, in opposition alike to the natural difficulties of wind and water; to carry the wind-bound ship out of port; to take the vessel of war and place her side by side with the enemy; to transport persons and intelligence over the surface of the deep, and to convey them by land from town to town, and from country to country, with a speed as much exceeding that of the ordinary wind as the ordinary wind exceeds that of a common pedestrian.

Such are the virtues, such the powers, which the steam engine has conferred upon COALS.

The means of calling these powers into activity are supplied by a substance which nature has happily provided in unbounded quantity in every part of the earth; and though it has no price, it has inestimable value: this substance is WATER.

(3.) *Mechanical effect produced by evaporating a pint of water.* — A pint of water may be evaporated by about two ounces of coals of average quality. In its evaporation it will swell into seventeen hundred times its volume, exerting a mechanical force equivalent to thirty-five tons weight raised one foot. If, after being evaporated, it be allowed to expand, in virtue of its elasticity, a further mechanical effect will be developed, equivalent to about seventy tons raised one foot. Thus, a pint of water and two ounces of coal become the source of a mechanical power sufficient to raise about one hundred tons weight to the height of one foot.

(4.) *Example of railway transport.* — The circumstances under which the steam engine is worked on a railway are not favourable to the economy of fuel. Nevertheless, a pound of coke burned in a locomotive engine will evaporate about five pints of water. In their evaporation they will exert a mechanical force sufficient to draw three tons weight on a level railway a distance of one mile in two minutes. Four horses working in a stage-coach on a common road are necessary to draw the same weight the same distance in eight minutes.

A train of coaches weighing about eighty tons, and transporting two hundred and forty passengers with their luggage, has been taken from Liverpool to Birmingham, and back from Birmingham to Liverpool, the trip each way taking about four hours and a quarter, stoppages included. The distance between these places by the railway is ninety-five miles. This double journey of one hundred and ninety miles was effected by the mechanical force produced in the combustion of four tons of coke, the value of which is about five pounds. To carry the same number of passengers daily between the same places by stage-coaches on a common road, would require twenty coaches and an establishment of three thousand eight hundred horses, with which the journey in each direction would be performed in about twelve hours, stoppages included.

The circumference of the earth measures twenty-five thousand miles; if it were begirt with an iron railway, such a train as above described, carrying two hundred and forty passengers, would be drawn round it by the combustion of about thirty tons of coke, and the circuit would be accomplished in five weeks.

(5.) *Examples illustrating the mechanical effect produced by steam.* — In the drainage of the Cornish mines the economy of fuel is much attended to, and coals are there made to do more work than elsewhere. A bushel of coals usually raises forty thousand tons of water a foot high; but it has on some occasions raised sixty thousand tons the same height. Let us take its labour at fifty thousand tons raised one foot high. A horse worked in a fast stage-coach pulls against an average resistance of about a quarter of a hundred weight. Against this he is able to work at the usual speed through about eight miles daily; his work is therefore equivalent to one thousand tons raised one foot. A bushel of coals consequently, as used in Cornwall, performs as much labour as a day's work of fifty such horses.

The great pyramid of Egypt stands upon a base measuring seven hundred feet each way, and is five hundred feet high, its weight being twelve thousand seven hundred and sixty millions of pounds. Herodotus states, that in constructing it one hundred thousand men were constantly employed for twenty years. The materials of this pyramid would be raised from the ground to their present position by the combustion of about four hundred and eighty tons of coals.

The Menai Bridge consists of about two thousand tons of iron, and its height above the level of the water is one hundred and twenty feet. Its mass might be lifted from the level of the water to its present position by the combustion of four bushels of coal.

(6.) *Exhaustion of coal mines improbable.* — The enormous consumption of coals produced by the application of the steam engine in the arts and manufactures, as well as to railways and navigation, has of late years excited the fears of many as to the possibility of the exhaustion of our coal-mines. Such apprehensions are, however, altogether groundless. If the present consumption of coal be estimated at sixteen millions of tons annually, it is demonstrable that the coal-fields of this country would not be exhausted for many centuries.

(7.) *Other scientific discoveries may supersede steam.* — But in speculations like these, the probable, if not certain progress of improvement and discovery ought not to be overlooked; and we may safely pronounce that, long before such a period of time shall have rolled away, other and more powerful mechanical agents will supersede the use of coal. Philosophy already directs her finger at sources of inexhaustible power in the phenomena of electricity and magnetism. The alternate decomposition and recomposition of water, by electric action, has too close an analogy to the alternate processes of vaporisation and condensation, not to occur at once to every mind: the development of the gases from solid matter by the operation of the chemical affinities, and their subsequent condensation into the liquid form, has already been essayed as a source of power. In a word, the general state of physical science at the present moment, the vigour, activity, and sagacity with which researches in it are prosecuted in every civilised country, the increasing consideration in which scientific men are held, and the personal honours and rewards which begin to be conferred upon them, all justify the expectation that we are on the eve of mechanical discoveries still greater than any which have yet appeared; that the steam engine itself, with its gigantic powers, will dwindle into insignificance in comparison with the energies of nature which are still to be revealed; and that the day will come when that machine, which is now extending the blessings of civilisation to the most remote skirts of the globe, will cease to have existence except in the page of history.

(8.) *Object of this work.*—The object of the present volume will be to deliver, in an easy and familiar style, an historical view of the invention of the steam engine, and an exposition of its structure and operation in the various forms in which it is now used. It is hoped that the details of these subjects may be rendered easily intelligible to all persons of ordinary information, whether urged by that natural and laudable spirit of inquiry awakened by contemplating effects on the material and social condition of our species, so rapid and so memorable as those which have followed the invention of the steam engine, and by the pleasure which results from the perception of the numerous instances of successful contrivances and beautiful applications of science to art which it unfolds,—or impelled by the exigencies of trade or profession to acquire the acquaintance with a machine on which, more than any other, the prosperity of our commercial and manufacturing interests depends. It will be our aim to afford to the former class all the information which they can require; and, if this work be not as comprehensive in its scope, and as minute in its details, as some of the latter may wish, it will at least serve as an easy and convenient introduction to other works more voluminous, costly, and detailed, but less elementary in their matter, and less familiar in their style.

(9.) *Conflicting claims to the invention of the steam engine.* — The history of the arts and manufactures affords no example of any invention the credit for which has been claimed by so many different nations and individuals as that of the steam engine. The advocates of the competitors for this honour have urged their pretensions, and pressed their claims, with a zeal which has occasionally outstripped the bounds of discretion, and the contest has not unfrequently been tinged with prejudices, national and personal, and characterised by a degree of asperity altogether unworthy of so noble a cause, and beneath the dignity of science.

"When a question is clearly proposed, it is already half resolved." Let us see whether a careful attention to this maxim will aid us in the investigation of the origin of the steam engine. The source of the power of that machine is found in the following natural phenomena.

*First.* When fire is applied to water, the liquid swells into vapour, and in undergoing this change exerts, as has been already stated, a considerable amount of mechanical force. This force may, by proper means, be rendered applicable to any purpose for which labour or power is needful.

*Second.* The vapour so produced is endowed with the property of elasticity, in virtue of which it is capable of swelling or expanding into increased dimensions, exerting, as it expands, a force, the energy of which is gradually diminished as the dimensions of the vapour are increased. This mechanical force is likewise capable of being applied to any useful purpose for which labour or power is necessary.

*Third.* This vapour is capable, by proper means, of being reconverted into water; and when so reconverted, it shrinks into its original dimensions, deserting the large space which it occupied as vapour, and leaving that space a vacuum. It is known in physics, that when a vacuum is produced, surrounding bodies have a tendency to rush into it with a definite amount of force. Consequently, any agent which produces a vacuum becomes a source of a considerable amount of mechanical power. By its reconversion into water, therefore, steam again becomes a mechanical agent.

Such are the natural phenomena in which are found the original sources of all steam power. In some forms of steam engine one of these is used, and in some another, and in some the application of all of them is combined; but in no existing form of steam engine whatever is there any other source of mechanical power.

Neither these nor any other natural forces can be applied *immediately* to any useful purpose. The interposition of mechanism is indispensable; on the invention and contrivance of that mechanism depends altogether the useful application of these natural forces.

The world owes the steam engine then partly to *discovery*, and partly to *invention*.

He that discovered the fact, that mechanical force was produced in the conversion of water into steam, must be justly held to be a sharer in the merit of the steam engine, even though he should never have practically applied his discovery. The like may be said of him who first discovered the source of the mechanical power arising from the expansion of steam. The discoverer of the fact, that steam being reconverted into water greatly contracted its dimensions, and thereby produced a vacuum, is likewise entitled to a share of the credit.

The mechanism by which these natural forces have been rendered so universally available as a moving power, is very various and complicated, and cannot be traced to one inventor. "If a watchmaker," says M. Arago, "well instructed in the history of his art, were required to give a categorical answer to the question, Who has invented watches? he would remain mute; but the question would be divested of much of its difficulty if he were required separately to declare who discovered the use of the main spring, the different forms of escapement, or the balance wheel." So it is with the steam engine. It is a combination of a great variety of contrivances, distinct from each other, which are the production of several inventors. If, however, one name more than the rest be entitled to special notice; if *he* is entitled to the chief credit of the invention who by the powers of his mechanical genius has imparted to the steam engine that form, and conferred upon it those qualities, on which mainly depends its present extensive utility, and by which it has become an agent of transcendant power, spreading its beneficial effects throughout every part of the civilised globe, then the universal voice will, as it were by acclamation, award the honour to one individual, whose pre-eminent genius places him far above all other competitors, and from the application of whose mental energies to this machine may be dated those grand effects which render it a topic of interest to all for whom the progress of civilisation has any attractions. Before the era rendered memorable by the discoveries of James Watt, the steam engine, which has since become an object of such universal interest, was a machine of extremely limited power, inferior in importance and usefulness to most other mechanical agents used as prime movers; but, from that epoch, it is scarcely necessary here to state, that it became a subject not of British interest only, but one having an important connection with the progress of the human race.

(10.) *Hero of Alexandria*, 120 B. C.—The discovery of the fact, that a mechanical force is produced when water is evaporated by the application of heat, must be considered as the first capital step in the invention of the steam engine. It is recorded in a work entitled *Spiritalia seu Pneumatica*, that Hero of Alexandria contrived a machine, 120 years before the Christian era, which was moved by the mechanical force of the vapour of water. The principle of this machine admits of easy explanation: When a fluid issues from any vessel in which it is confined, that vessel suffers a force equal to that with which the fluid escapes from it, and in the opposite direction. If water issues from an orifice, a pressure is produced behind the orifice corresponding to the force with which the water escapes. If a man discharge a gun, the gases produced by the explosion of the powder issue with a certain force from the muzzle, and his shoulder is driven backwards by the recoil with a corresponding force. If the muzzle, instead of being presented forwards, were turned at right angles to the length of the gun, then, as the gases of explosion would escape sideways, the recoil would likewise take place sideways, and the shooter, instead of being driven backward, would be made to spin round as a dancer pirouettes. This was the principle of Hero's steam engine.

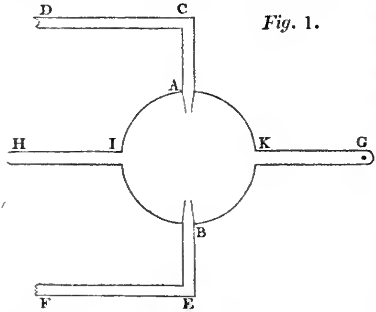



*Fig.* 1.

A small globe or ball was placed on pivots at A and B (*fig.* 1.), on which it was capable of revolving: steam was supplied through one of these pivots from one of the tubes D C E F, which communicated with the boiler. This steam filled the globe A I B K, and also the arms I H and K G. A lateral orifice, represented at G, near the end of these arms, allowed the steam to escape in a jet, and the reaction, producing a recoil, had a tendency to drive the arm round. A small orifice at H, on the other side of the tube, produced a like effect. In the same manner, any convenient number of arms might be provided, surrounding the globe and communicating with its interior like the spokes of a wheel. Thus these arms, having lateral orifices for the escape of the steam, all placed so that the recoil may tend to turn the globe in the same direction, a rotatory motion might be communicated to any machinery which it was desired to move.

(11.) *Force of steam vaguely known to the ancients.*— Although the elastic force of steam was not reduced to numerical measure by the ancients, nor brought under control, nor applied to any useful purpose, yet it appears to have been recognised in vague and general terms. Aristotle, Seneca, and other ancient writers, accounted for earthquakes by the sudden conversion of water into steam within the earth. This change, according to them, was effected by subterranean heat. Such tremendous effects being ascribed to steam, it can scarcely be doubted that the Greeks and Romans were acquainted with the fact, that water in passing into vapour exercises considerable mechanical power. They were aware that the earthquakes, which they ascribed to this cause, exerted forces sufficiently powerful to derange the natural limits of the ocean; to overturn from their foundations the most massive monuments of human labour; to raise islands in the midst of seas; and to heave up the surface of the land of level continents so as to form lofty mountains.

HERO'S STEAM ENGINE.

Such notions, however, resulted not as consequences of any exact or scientific principles, but from vague analogies derived from effects which could not fail to have been manifested in the arts, such as those which commonly occurred in the process of casting in metal the splendid statues which adorned the temples, gardens, and public places of Rome and Athens. The artist was liable to the same accidents to which modern founders are exposed, produced by the casual presence of a little water in the mould into which the molten metal is poured. Under such circumstances, the sudden formation of steam of an extreme pressure produces, as is well known, explosions attended with destructive effects. The Grecian and Roman artisans were subject to such accidents; and the philosopher, generalising such a fact, would arrive at a solution of the grander class of phenomena of earthquakes and volcanoes.

(12.) *Subserved to superstitious purposes.* — Before natural phenomena are rendered subservient to purposes of utility, they are often made to minister to the objects of superstition. The power of steam is not an exception to this rule. It is recorded in the Chronicles, that upon the banks of the Weser the ancient Teutonic gods sometimes marked their displeasure by a sort of thunderbolt, which was immediately succeeded by a cloud that filled the temple. An image of the god *Busterich*, which was found in some excavations, clearly explains the manner in which this prodigy was accomplished by the priests. The head of the metal god was hollow, and contained within it a pot of water: the mouth, and another hole above the forehead, were stopped by wooden plugs; a small stove, adroitly placed in a cavity of the head under the pot, contained charcoal, which, being lighted, gradually heated the liquid contained in the head. The vapour produced from the water, having acquired sufficient pressure, forced out the wooden plugs with a loud report, and they were immediately followed by two jets of steam, which formed a dense cloud round the god, and concealed him from his astonished worshippers.

(13.) *Anecdote of Anthemius, architect of St. Sophia.* — Among other amusing anecdotes showing the knowledge which the ancients had of the mechanical force of steam, it is related that Anthemius, the architect of Saint Sophia, occupied a house next door to that of Zeno, between whom and Anthemius there existed a feud. To annoy his neighbour, Anthemius placed on the ground floor of his own house several close digesters, or boilers, containing water. A flexible tube proceeded from the top of each of these, which was conducted through a hole made in the wall between the houses, and which communicated with the space under the floors of the rooms in the house of Zeno. When Anthemius desired to annoy his neighbour, he lighted fires under his boilers, and the steam produced by them rushed in such quantity and with such force under Zeno's floors, that they were made to heave with all the usual symptoms of an earthquake.

(14.) *Blasco de Garay*, A. D. 1543. — In the year 1826, M. de Navarrete published, in Zach's Astronomical Correspondence, a communication from Thomas Gonzales, director of the royal archives of Simancas, giving an account of an experiment reported to have been made in the year 1543, in which a vessel was propelled by a machine having the appearance of a steam engine.

Blasco de Garay, a sea captain, proposed in that year to the Emperor Charles V. to propel vessels by a machine which he had invented, even in time of calm, without oars or sails. Notwithstanding the apparent improbability attending this project, the Emperor ordered the experiment to be made in the port of Barcelona, and the 17th of June, 1543, was the day appointed for its trial. The commissioners appointed by Charles V. to attend and witness the experiment were Don Henry of Toledo, Don Pedro of Cardona, the treasurer Ravago, the vice-chancellor and intendant of Catalonia, and others. The vessel on which the experiment was made was the Trinity, 200 tons burthen, which had just discharged a cargo of corn at Barcelona. Garay concealed the nature of his machinery, even from the commissioners. All that could be discovered during the trial was, that it consisted of a large boiler containing water, and that wheels were attached to each side of the vessel, by the revolution of which it was propelled. The commissioners having witnessed the experiment made a report to the king, approving generally of the invention, particularly on account of the ease and promptitude with which the vessel could be put about by it.

The treasurer Ravago, who was himself hostile to the project, reported that the machine was capable of propelling a vessel at the rate of two leagues in three hours; but the other commissioners stated that it made a league an hour at the least, and that it put the vessel about as speedily as would be accomplished with a galley worked according to the common method. Ravago reported that the machinery was too complicated and expensive, and that it was subject to the danger of the boiler bursting.

After the experiment was made, Garay took away all the machinery, leaving nothing but the framing of wood in the arsenals of Barcelona.

Notwithstanding the opposition of Ravago, the invention was approved, and the inventor was promoted, and received a pecuniary reward, besides having all his expenses paid.

From the circumstance of the nature of the machinery having been concealed, it is impossible to say in what this machine consisted; but as a boiler was used, it is probable, though not certain, that steam was the agent. There have been various machines proposed, of which a furnace and boiler form a part, and in which the agency of steam is not used. The machine of Amontons furnishes an example of this. It is most probable that the contrivance of Garay was identical with that of Hero. The low state of the arts in Spain in the sixteenth century would be incompatible with the construction of any machine requiring great precision of execution. But the simplicity of Hero's contrivance would have rendered its construction and operation quite practicable. As to the claims to the invention of the steam engine advanced by the advocates of De Garay, founded on the above document, a refutation is supplied by the admission, that though he was rewarded and promoted by the government of the day, in consequence of the experiment, and although the great usefulness of the contrivance in towing ships out of port, &c. was admitted, yet it does not appear that a second experiment was ever tried, much less that the machine was ever brought into practical use.

(15.) *Solomon de Caus*, 1615.—Solomon de Caus was engineer and architect to Louis XIII., king of France, before the year 1612. In that year he entered the service of the Elector Palatine, who married the daughter of King James I., with whom he came to England. He was there employed by the Prince of Wales in ornamenting the gardens of his house at Richmond. During his sojourn in England he composed and published at London, in the same year, a Treatise on

Perspective. This person was the author of a work entitled, "*Les Raisons des Forces Mouvantes, avec diverses Machines tant utiles que plaisantes,*" which was apparently composed at Heidelburg, but published at Frankfort, in 1615. The same work was subsequently republished in Paris in 1623.

The treatise commences with definitions of what were then considered the four elements: earth, air, fire, and water. Air is defined to be a cold, dry, and light element, capable of compression, by which it may be rendered very violent. He says, "The violence will be great when water exhales in air by means of fire, and that the said air is enclosed: as, for example, take a ball of copper of one or two feet diameter, and one inch thick, which being filled with water by a small hole, which shall be strongly stopped with a peg, so that neither air nor water can escape, it is certain that if we put the said ball upon a great fire, so that it will become very hot, that it will cause a compression so violent, that the ball will burst in pieces, with a noise like a petard."

The effect which is here described is due to the combined pressure of the heated air contained in the ball and the high pressure steam raised from the water, but much more to the latter than to the former. It is evident, however, from the language of De Caus, that he ascribes the force entirely to the air, and seems to consider that the force of the air proceeded from the water which exhaled in it.

The first theorem is, "that the parts of the elements mix together for a time, and then each returns to its place" (the elements here referred to being apparently air and water). Upon this subject the following is an example: "Take a round vessel of copper, soldered close on every side, and with a tube, whereof one end approaches nearly to the bottom of the vessel, and the other end, which projects on the outside of the vessel, has a stop-cock; there is also a hole in the top of the vessel, with a plug to stop it. If this vessel will contain three pots of water, then pour in one pot of water, and place the vessel on the fire about three or four minutes, leaving the hole open; then take the vessel off the fire, and a little after pour out the water at the hole, and it will be found that a part of the said water has been evaporated by the heat of the fire. Then pour in one pot of water as before, and stop up the hole and the cock, and put the vessel on the fire for the same time as before; then take it off, and let it cool of itself, without opening the plug, and after it is quite cold pour out the water, and it will be found exactly the same quantity as was put in. Thus we see that the water which was evaporated (the first time that the vessel was put on the fire) is returned into water the second time when that vapour has been shut up in the vessel, and cooled of itself."

In the description of these experiments, the processes of evaporation and condensation are obscurely indicated; but there is no intimation that the author possessed any knowledge of the elastic force of steam. His theorem is, that the parts of the element water mix for a time with the parts of the element air; that fire causes this mixture; and that on removing the fire, and dissipating the heat, then the parts of the water mixed with air return to their proper place, forming again part of the water. There is no indication of a *change of property* of the water in passing into vapour. It is difficult to conceive, if De Caus had been aware that the vapour of water possessed the same violent force which he distinctly and in terms ascribes to air, or if he had been aware that in effect the vapour of the water produced by the fire was a fluid, possessing exactly the same mechanical qualities, and producing the same mechanical effects as air, that he would not have expressed himself clearly on the subject.

He proceeds to give another demonstration that heat will cause the particles of water to mix with those of air.

"After having put the measure of water into the vessel, and shut the vent-hole, and opened the cock, put the vessel on the fire, and put the pot under the cock, then the water of the vessel, raising itself by the heat of the fire, will run out through the cock; but about one sixth or one eighth part of the water will not run out, because the violence of the vapour which causes the water to rise proceeds from the said water; which vapour goes out through the cock after the water with great violence. There is also another example in quicksilver, or mercury, which is a fluid mineral, but being heated by fire, exhales in vapour, and mixes with the air for a time; but after the said vapour is cooled, it returns to its first nature of quicksilver. The vapour of water is much lighter, and therefore it rises higher," &c.

In this second demonstration there appears to be some obscure indication of the force of steam in the words "because of the violence of the vapour which causes the water to rise," &c.

The fifth theorem is the following: —

"*Water will mount by the help of fire higher than its level,*" which is explained and proved in the following terms: —

"The third method of raising water is by the aid of fire. On this principle may be constructed various machines: I shall here describe one. Let a ball of copper marked A; well soldered in every part, to which is attached a tube and stop-cock marked D, by which water may be introduced; and also another tube marked B C, which will be soldered into the top of the ball, and the lower end C of which shall descend nearly to the bottom of the ball without touching it. Let the said ball be filled with water through the tube D, then shutting the stop-cock D, and opening the stop-cock in the vertical tube B C, let the ball be placed upon a fire, the heat acting upon the said ball will cause the water to rise in the tube B C."

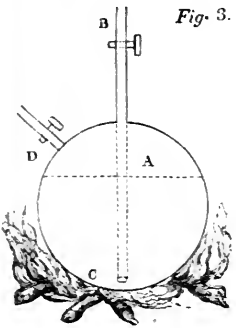


Fig. 3.

In the apparatus as here described, the space enclosed in the boiler above the surface of the water is filled with air. By the action of the fire, two effects are produced: first, the air enclosed above the water, being heated, acquires increased elasticity, and presses with a corresponding force on the surface of the water. By this means a column of water will be driven up the tube A B at such a height as will balance the elasticity of the heated air confined in the boiler; but besides this, the water contained in the boiler being heated, will produce steam, which being mixed with air contained in the boiler, will likewise press with its proper elasticity on the surface of the water, and will combine with the air in raising a column of water in the tube A B. In the above description of the machine, the force which raises the water in the tube A B is ascribed to the fire, no mention being made of the water, or of the vapour or steam produced from it having any agency in raising the water in the tube A B.

Antecedently to the date of this invention, the effect of heat in increasing the elastic force of air was known; and, so far as the above description goes, the whole operation might be ascribed to the air by a person having no knowledge whatever of the elasticity of steam. M. Arago however, who, on the grounds of this passage in the work of De Caus, claims for him a share of the honour of the invention of the steam engine, contends that the agency of steam in this apparatus was perfectly known to De Caus, although no mention is made of steam in the above description, because in the second demonstration above quoted he uses the words, "the violence of the vapour which causes the water to rise proceeds from the said water; which vapour goes out from the cock after the water with great violence." By these words M. Arago considers that De Caus expresses the quality of elasticity proper to the vapour, and that the context justifies the inference, that to this elasticity he ascribed the elevation of the water in the tube C B.

There appears to be some uncertainty attending the birthplace of De Caus. In the *Biographie Universelle* he is said to have been born and to have died in Normandy. M. Arago assigns Dieppe, or its neighbourhood, as his birthplace.

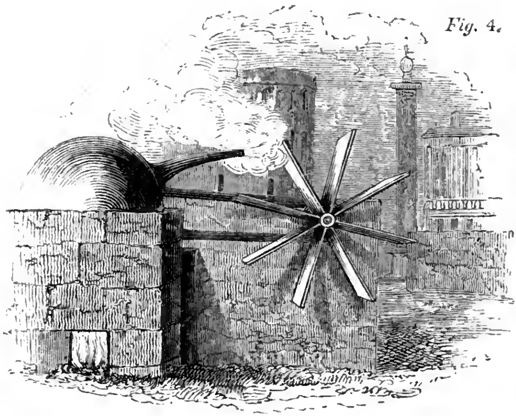
There was another engineer and architect, Isaac De Caus, a native of Dieppe, who published a work in folio, entitled "*Nouvelle Invention de Lever l'Eau plus haut que sa Source, avec quelque Machines mouvantes, par le Moyen de l'Eau, et un Discours de la Conduite d'Icelle.*" This volume is without a date, but from the nature of its contents it would appear to have been published before the work of Solomon De Caus already cited. The drawings and machines described in both are exactly the same; but the definitions and theorems quoted above on raising water by fire are not given in the work of Isaac. It seems, therefore, that Solomon De Caus republished, with additions, the work of Isaac De Caus. From the same birthplace being assigned to both these authors, as well as from the similarity of their pursuits, it is likely they were members of the same family, and from their first names they were probably Jews.

The work cited above was dedicated to Louis XIII., and in the dedication Solomon De Caus calls himself the subject of that monarch; and in the privilege prefixed to the work he is designated, "Our well-beloved Solomon De Caus, master engineer, being at present in the service of our dear and well-beloved cousin, the Prince Elector Palatine, has made known to us," &c. — "we, desiring to gratify the said De Caus, he being our subject," &c.

It is therefore certain, whatever may have been the birthplace of De Caus, that he was at least a subject of France. The circumstance of his work being written in French, though published beyond the Rhine, is also an argument in favour of his being a native of that country.

(16.) *Giovanni Branca*, 1629. — Giovanni Branca of Loretto in Italy, an engineer and architect, proposed to work mills of different kinds by steam issuing from a large æolopile, and blowing against the vanes of a wheel. Branca was the author of many ingenious mechanical inventions, a collection of which he dedicated to M. Cenci, the governor of Loretto. These were published in a work printed at Rome in 1629. It is a thin quarto, entitled "*Le Machine volume nuovo, et di molto artificio da fare effetti maravigliosi tanto Spiritali quanto di Animale Operatione, arichito di bellissime figure. Del Sig. Giovanni Branca, Cittadino Romano. In Roma*, 1629." The work contains sixty-three engravings, accompanied by descriptions in Italian and Latin. Branca's steam engine, represented in the twenty-fifth plate, consists of a wheel furnished with flat vanes upon its rim, like the boards of a paddle wheel. The steam is produced in a close vessel, and made to issue with violence from the extremity of the pipe directed against the vanes, and causes the wheel to revolve. This motion being imparted by the usual mechanical contrivances, any machinery may be impelled by it. Different useful applications of this power are contained in the work, viz. pestles and mortars for pounding materials to make gunpowder, and rolling stones for grinding the same; machines for raising water by buckets, for sawing timbers, for driving piles, &c.

Fig. 4.



BRANCA'S ENGINE.

This method of applying the force of steam has no analogy to any application of steam in modern engines.

(17.) *Edward Somerset, Marquis of Worcester*, 1663.— Of all the names which figure in the early annals of steam by far the most remarkable is that of the Marquis of Worcester, who has left a description of a machine in a work, entitled "The Scantling of One Hundred Inventions," which has been generally in this country considered as giving him a right to the honour of having been the inventor of the steam engine.

Lord Worcester having been engaged on the side of the Royalists in the civil wars of the revolution, lost his fortune and went to Ireland, where he was imprisoned. He escaped from thence, and reached France; from that country he ventured to London, as a secret agent of Charles II., but was detected, and imprisoned in the Tower, where he remained until the Restoration, when he was set at liberty. Tradition has connected the invention of the steam engine with the following anecdote:—One day, during his imprisonment, Lord Worcester observed the lid of the pot in which his dinner was being cooked, suddenly forced upwards by the vapour of the water which was boiling in it. Reflecting on this, it occurred to him that the same force which raised the cover of the pot might be rendered, when properly applied, a useful and convenient moving power. After he recovered his liberty, he accordingly proceeded to carry into effect this conception. The contrivance to which he was ultimately led is described in the following terms in the sixty-eighth invention, in the work above named: —

"I have invented an admirable and forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be, as the philosopher terms it, *infra sphærum activitatis*, which is but at such a distance. But this way hath no bounder if the vessels be strong enough. For I have taken a piece of whole cannon whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it; within twenty-four hours, it burst and made a great crack. So that, having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream forty feet high. One vessel of water rarefied by fire driveth up forty of cold water, and a man that tends the work has but to turn two cocks; that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

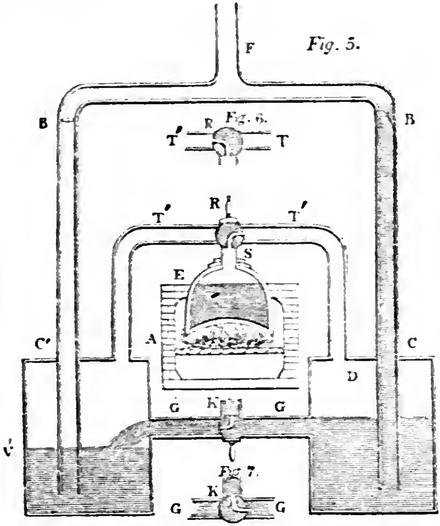
Since the date of the publication of the "Century of Inventions" was the year 1663, the experiments here mentioned must have been made before that year. The description of the machine here given, as well as others in the same work, was intended by the author, not to convey a knowledge of the nature of the mechanism which he used, but only to express the effects produced, and to indicate the physical principle on which they depended. It should also be observed, that an air of mystery was thrown by Worcester over the accounts of all the machines which he described; and therefore any obscurity in the above description ought not to be regarded as an evidence against his claim to the discovery of the mechanical agency of steam, so far as that agency is indicated by the effects said by him to be produced. The above account is, however, sufficiently distinct and explicit to enable any one possessing a knowledge of the mechanical qualities of steam to perceive the general nature of the machine described.

In the apparatus ascribed to *Hero* of Alexandria, the elasticity of the vapour contained in the arms of the revolving ball causes that vapour to issue from the lateral orifices in the arms, such as that of G, *fig.* 1. As these orifices, however, are exposed to the common atmosphere pressing inwards with a force, the mean amount of which is about fifteen pounds per square inch, it follows that the steam cannot escape from these orifices until its pressure or elasticity exceeds this amount, and that when it does, the force with which it will so escape will be the excess of its elasticity above that of the atmosphere; and it is the reaction produced by this difference of pressure, causing the arms to recoil, which will give motion to the machine.

In the case of the apparatus of *De Caus*, the heat of the fire acting on the vessel D C (*fig.* 3.) will raise the temperature of the water contained in it, and also of the air confined within it above the surface of that water. This air as it is increased in temperature, will also increase in elasticity; it will therefore press on the surface of the water with increased force, and will gradually force the water upwards in the tube; and this effect would continue until all the water in the vessel would be forced up the tube.

But at the same time that the heat acting on the vessel increases the temperature of the air above the water, it also produces a partial evaporation of the water, so that more or less steam is mixed with the air in the vessel above the surface of the water; and this steam possessing elasticity, unites with the air in pressing on the surface of the water, and in raising it in the tube.

(18.) *Description of the Marquis of Worcester's steam engine.* Let us now revert to the brief account of the engine of the Marquis of Worcester, described in "The Century of Inventions." We collect from that description that the vessel in which the water was evaporated was separate from those which contained the water to be elevated; also that there were two vessels of the like description, the contents of which were alternately elevated by the pressure of the "water rarefied by the fire;" in other words by steam; and that the water was raised in an uninterrupted stream, by the management of two cocks communicating with these vessels and with the boiler. The following is such an apparatus as would answer this description. Let E (*fig.* 5.) be the vessel containing the water to be evaporated, placed over a proper furnace A; let S be a pipe to allow the steam produced from the boiling water in E to pass into the vessels where its mechanical action is required. Let R




represent a cock or regulator, having in it a curved passage, leading from S to the tube T, when the lever or handle L is in the position represented by the cut; but leading to the tube T′, when the lever L is turned one quarter of a revolution to the right, as represented in *fig.* 6. By the shifting of this lever, therefore, the steam pipe S may be made to communicate alternately with the tubes T and T′. The tubes T and T′ are carried respectively to two vessels V and V′, which are filled with the water required to be raised. In these vessels tubes enter at C and C′, descending nearly to the bottom: these tubes have valves at B and B′, opening upwards, by which water will be allowed to pass into the vertical tube F, but which will not allow it to return downwards, the valves B and B′ being then closed by the weight of the water above them.

Let G G′ be a pipe entering the sides of the vessels V and V′, for the purpose of filling them with the water to be raised: let K be a cock having a curved passage similar to the cock R, and leading to a tube by which water is supplied from the reservoir or other source from which the water to be raised is drawn. When the cock K is placed as represented in *fig.* 5., the water from the reservoir will flow through the curved passage in the cock K into the tube G′, and thence into the vessel V′; but when this cock is turned one quarter round, by shifting the lever to the left, it will take the position represented in *fig.* 7., and the water will flow through the curved passage into the tube G, and thence into the vessel V. Let us now suppose the vessel V already filled with water to be elevated, and the vessel V′ to have discharged its contents. The cock R is turned, so as to allow the steam generated in the boiler E to pass into the tube T, and thence into the upper part of the vessel V, while the cock K is turned so as to allow the water from the reservoir to pass into the tube G′, and thence into the vessel V′. The steam collecting in the upper part of the vessel V presses with its elastic force on the surface of the water therein, and forces the water upwards in the tube C; it passes through the valve B, which it opens by the upward pressure received from the action of the steam, and thence into the tube F, its descent into the tube C′ being prevented by the valve B′, which can only be opened upwards. As the steam is gradually supplied from the boiler E, the water in the vessel V is forced up the tube C, through the valve B, and into the tube F, until all the contents of the vessel V above the lower end of the tube C have been raised. In the meanwhile, the vessel V′ has been filled with water, through the cock K: when this has been accomplished, the man who attends the machine shifts the cocks R and K, so as to give them the position represented in *figs.* 6 and 7. In this position, the steam from the boiler being excluded from the tube T, will be conducted to the tube T′, and thence to the vessel V′, while the water from the reservoir will be excluded from the tube G′, and conducted through the tube G to the vessel V. The vessel V will thus be replenished, and, by a process similar to that already described, the contents of the vessel

(27.) *General description of Newcomen's engine.* — Newcomen resumed the old method of raising the water from the mines by ordinary pumps, but conceived the idea of working these pumps by some moving power less expensive than that of horses. The means whereby he proposed effecting this was by connecting the end of the pump-rod D (*fig.* 13.) by a chain with the arch head A of a working beam A B, playing on an axis C. The other arch head B of this beam was connected by a chain with the rod E of a solid piston P, which moved air-tight in a cylinder F. If a vacuum be created beneath the piston P, the atmospheric pressure acting upon it will press it down with a force of fifteen pounds per square inch; and the end A of the beam being thus raised, the pump-rod D will be drawn up. If a pressure equivalent to the atmosphere be then introduced below the piston, so as to neutralise the downward pressure, the piston will be in a state of indifference as to the rising or falling; and if in this case the rod D be made heavier than the piston and its rod, so as to overcome the friction, it will descend, and elevate the piston again to the top of the cylinder. The vacuum being again produced, another descent of the piston, and consequent elevation of the pump-rod, will take place; and so the process may be continued.

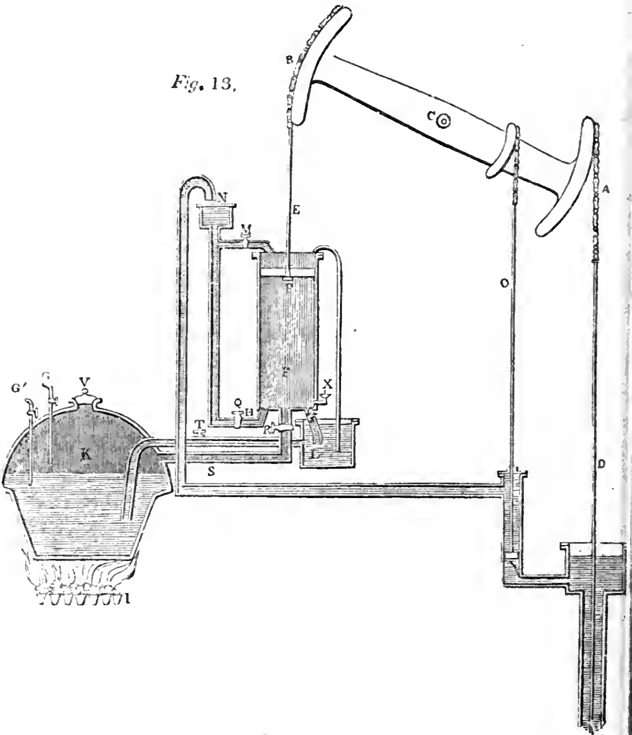
Such was Newcomen's first conception of the *atmospheric engine;* and the contrivance had much, even at the first view, to recommend it. The power of such a machine would depend entirely on the magnitude of the piston; and being independent of highly elastic steam, would not expose the materials to the destructive heat which was necessary for working Savery's engine. Supposing a perfect vacuum to be produced under the piston in the cylinder, an effective downward pressure would be obtained, amounting to fifteen times as many pounds as there are square inches in the section of the piston. Thus, if the base of the piston were 100 square inches, a pressure equal to 1500 lbs. would be obtained.

In order to accomplish this, two things were necessary:— 1. To make a speedy and effectual vacuum below the piston in the descent; and, 2. To contrive a counterpoise for the atmosphere in the ascent.

The condensation of steam immediately presented itself as

the most effectual means of accomplishing the former ; and
the elastic force of the same steam previous to condensation
an obvious method of effecting the latter. Nothing now
remained to carry the design into execution, but the con-
trivance of means for the alternate introduction and con-
densation of the steam ; and Newcomen and Cawley were
accordingly granted a patent in 1707, in which Savery was

*Fig.* 13.




united, in consequence of the principle of condensation fo
which he had previously received a patent being necessary t
the projected machine. We shall now describe the *atmo-
spheric engine,* as first constructed by Newcomen : —

The boiler K (*fig.* 13.) is placed over a furnace I, the flu
of which winds round it, so as to communicate heat to ever

part of the bottom of it. In the top, which is hemispherical, two gauge cocks G G′ are placed, as in Savery's engine, and a *puppet valve* V, which opens upward, and is loaded at one pound per square inch; so that when the steam produced in the boiler exceeds the pressure of the atmosphere by more than one pound on the square inch, the valve V is lifted, and the steam escapes through it, and continues to escape until its pressure is sufficiently diminished, when the valve V again falls into its seat. This valve performs the office of the safety valve in modern engines.

The great steam tube is represented at S, which conducts steam from the boiler to the cylinder; and a feeding pipe T, furnished with a cock, which is opened and closed at pleasure, proceeds from a cistern L to the boiler. By this pipe the boiler may be replenished from the cistern, when the gauge cock G′ indicates that the level has fallen below it. The cistern L is supplied with hot water, by means which we shall presently explain.

To understand the mechanism necessary to work the piston, let us consider how the supply and condensation of steam must be regulated. When the piston has been forced to the bottom of the cylinder by the atmospheric pressure acting against a vacuum, in order to balance that pressure, and enable it to be drawn up by the weight of the pump rod, it is necessary to introduce steam from the boiler. This is accomplished by opening the cock R in the steam pipe S. The steam being thus introduced from the boiler, its pressure balances the action of the atmosphere upon the piston, which is immediately drawn to the top of the cylinder by the weight of the pump-rod D. It then becomes necessary to condense this steam, in order to produce a vacuum. To accomplish this, the further supply of steam must be cut off, which is done by closing the cock R. The supply of steam from the boiler being thus suspended, the application of cold water on the external surface of the cylinder becomes necessary to condense the steam within it. This was done by enclosing the cylinder within another, leaving a space between them.* Into this space cold water was allowed to

* The external cylinder is not represented in the diagram.

flow from a cock M placed over it, supplied by a pipe from the cistern N. This cistern is supplied with water by a pump O, which is worked by the engine.

The cold water supplied from M, having filled the space between the two cylinders, abstracts the heat from the inner one; and condensing the steam, produces a vacuum, into which the piston is forced by the atmospheric pressure. Preparatory to the next descent, the water which thus fills the space between the cylinders, and which is warmed by the heat abstracted from the steam, must be discharged, in order to give room for a fresh supply of cold water from M. An aperture, furnished with a cock, is accordingly provided in the bottom of the cylinder, through which the water is discharged into the cistern L; and being warm, is adapted for the supply of the boiler through T, as already mentioned.

The cock R being now again opened, steam is admitted below the piston, which, as before, ascends, and the descent is again accomplished by closing the cock R, and opening the cock M, admitting cold water between the cylinders, and thereby condensing the steam below the piston.

The condensed steam, thus reduced to water, will collect in the bottom of the cylinder, and resist the descent of the piston. It is therefore necessary to provide an exit for it, which is done by a valve opening *outwards* into a tube which leads to the feeding cistern L, into which the condensed steam is driven.

That the piston should continue to be air-tight, it was necessary to keep a constant supply of water over it; this was done by a cock similar to M, which allowed water to flow from the pipe M on the piston.

Soon after the first construction of these engines, an accidental circumstance suggested to Newcomen a much better method of condensation than the application of cold water on the external surface of the cylinder. An engine was observed to work several strokes with unusual rapidity, and without the regular supply of the condensing water. Upon examining the piston, a hole was found in it, through which the water, which was poured on to keep it air-tight, flowed, and instantly condensed the steam under it.

On this suggestion Newcomen abandoned the external cylinder, and introduced a pipe H, furnished with a cock Q, into the bottom of the cylinder, so that, on turning the cock, the pressure of the water in the pipe H, from the level of the water in the cistern N, would force the water to rise as a jet into the cylinder, and would instantly condense the steam. This method of condensing by injection formed a very important improvement in the engine, and is still used.

(28.) *Its operation.* — Having taken a general view of the parts of the atmospheric engine, let us now consider more particularly its operation.

When the engine is not working, the weight of the pump rod D (*fig.* 13.) draws down the beam A, and draws the piston to the top of the cylinder, where it rests. Let us suppose all the cocks and valves closed, and the boiler filled to the proper depth. The fire being lighted beneath it, the water is boiled until the steam acquires sufficient force to lift the valve V. When this takes place, the engine may be started. For this purpose the regulating valve R is opened. The steam rushes in, and is first condensed by the cold cylinder. After a short time the cylinder acquires the temperature of the steam, which then ceases to be condensed, and mixes with the air which filled the cylinder. The steam and heated air, having a greater force than the atmospheric pressure, will open a valve placed at the end X of a small tube in the bottom of the cylinder, and which opens outwards. From this (which is called the *blowing valve**) the steam and air rush in a constant stream, until all the air has been expelled, and the cylinder is filled with the pure vapour of water. This process is called *blowing* the engine preparatory to starting it.

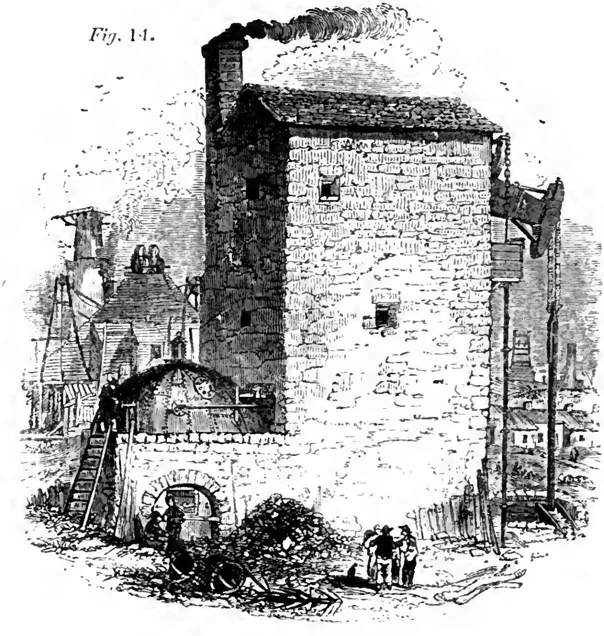
When it is about to be started, the engine-man closes the regulator R, and thereby suspends the supply of steam from the boiler. At the same time he opens the *condensing valve* H†; and thereby throws up a jet of cold water into the cylinder. This immediately condenses the steam contained in the cylinder, and produces the vacuum. (The atmosphere

* Also called the *snifting* valve, from the peculiar noise made by the air and steam escaping from it.

† Also called the *injection valve.*

cannot enter the *blowing* valve, because it opens *outwards,* so that no air can enter to vitiate the vacuum.) The atmospheric pressure above the piston now takes effect, and forces

*Fig.* 14.



ATMOSPHERIC ENGINE.

it down in the cylinder. The descent being completed, the engine-man closes the condensing valve H, and opens the regulator R. By this means he stops the play of the jet within the cylinder, and admits the steam from the boiler. The first effect of the steam is to expel the condensing water and condensed steam which are collected in the bottom of the cylinder, through the tube Y, containing a valve which opens *outwards,* (called the *eduction valve*), which leads to the hot cistern L, into which this water is therefore discharged.

When the steam admitted through R ceases to be condensed, it balances the atmospheric pressure above the piston, and thus permits it to be drawn to the top of the cylinder by the weight of the rod D. This ascent of the piston is also assisted by the circumstance of the steam being somewhat stronger than the atmosphere.

When the piston has reached the top, the regulating valve R is closed, and the condensing valve opened, and another descent produced, as before, and so the process is continued.

The manipulation necessary in working this engine was, therefore, the alternate opening and closing of two valves; the regulating and condensing valves. When the piston reached the top of the cylinder, the former was to be closed, and the latter opened; and, on reaching the bottom, the former was to be opened, and the latter closed.

(29.) *Invention of self-acting mechanism by Humphrey Potter.* — The duty of working the engine requiring no great amount of labour, or skill, was usually entrusted to boys, called *cock boys.* It happened that one of the most important improvements which has ever been made in the working of steam engines was due to the ingenuity of one of these boys. It is said that a lad, named *Humphrey Potter,* was employed to work the cocks of an atmospheric engine, and being tempted to escape from the monotonous drudgery to which his duty confined him, his ingenuity was sharpened so as to prompt him to devise some means by which he might indulge his disposition to play without exposing himself to the consequences of suspending the performance of the engine. On observing the alternate ascending and descending motion of the beam above him, and considering it in reference to the labour of his own hands, in alternately raising and lowering the levers which governed the cocks, he perceived a relation which served as a clue to a simple contrivance, by which the steam engine, for the first time, became an automaton. When the beam arrived at the top of its play, it was necessary to open the steam valve by raising a lever, and to close the injection valve by raising another. This he saw could be accomplished by attaching strings of proper length to these levers, and tying them to some part of the beam. These levers required to be moved in the opposite direction when the beam attained the lowest point of its play. This he saw could be accomplished by strings, either connected with the outer arm of the beam, or conducted over rods or pulleys. In short, he contrived means of so connecting the levers which governed the two cocks by strings with the beam, that the beam opened and closed these cocks with the most perfect regularity and certainty as it moved upwards and downwards.

Besides rendering the machine independent of manual superintendence, this process conferred upon it much greater regularity of performance than any manual superintendence could ensure.

This contrivance of Pötter was very soon improved by the substitution of a bar, called a *plug frame*, which was suspended from the arm of the beam, and which carried upon it pins, by which the arms of the levers governing the cocks were struck as the plug frame ascended and descended, so as to be opened and closed at the proper times.

The engine thus improved required no other attendance except to feed the boiler occasionally by the cock T, and to attend the furnace.

(30.) *Merits of Newcomen's invention.*—However the merit of the discovery of the physical principles on which the mechanical application of steam depends may be awarded, it must be admitted that the engine contrived by Newcomen and his associates, considered as a practical machine, was immeasurably superior to that which preceded it; superior, indeed, to such a degree, that while the one was incapable of any permanently useful application, the other soon became a machine of extensive utility in the drainage of mines; and, even at the present time, the atmospheric engine is not unfrequently used in preference to the modern steam engine, in districts where fuel is abundant and cheap; the expense of constructing and maintaining it being considerably less than that of an improved steam engine. The low pressure of the steam used in working it, rendered it perfectly safe. While Savery's engine, to work with effect, required that the steam confined in the vessels should have a bursting pressure amounting to about thirty pounds per square inch, the pressure of steam in the boiler and cylinder of the atmospheric engine required only a pressure of about one pound per square inch. The high pressure also of the steam used in Savery's engine was necessarily accompanied, as we shall presently explain, by a greatly increased temperature. The effect of this was, to weaken and gradually destroy the vessels, especially those which, like the steam vessels V and V′ (*fig.* 10.), were alternately heated and cooled.

Besides these defects, the power of Savery's engines was also very restricted, both as to the quantity of water raised and as to the height to which it was elevated. On the other hand, the atmospheric engine was limited in its power only by the dimensions of its piston. Another considerable advantage which the atmospheric engine possessed over that of Savery, was the facility with which it was capable of driving machinery by means of the working beam. The merit, however, of Newcomen's engine, regarded as an invention, and apart from merely practical considerations, must be ascribed principally to its mechanism and combinations. We find in it no new principle, and scarcely even a novel application of a principle. The agency of the atmospheric pressure acting against a vacuum, or partial vacuum, had been long known: the method of producing a vacuum by the condensation of steam had been suggested by Papin, and carried into practical effect by Savery. The mechanical power obtained from the direct pressure of the elastic force of steam, used in the atmospheric engine to balance the atmosphere during the ascent of the piston, was suggested by De Caus and Lord Worcester. The boiler, gauge pipes, and the regulator, were all borrowed from the engine of Savery. The idea of using the atmospheric pressure against a vacuum or partial vacuum, to work a piston in a cylinder, had been suggested by Otto Guericke, an ingenious German philosopher, who invented the air pump; and this, combined with the production of a vacuum by the condensation of steam, was subsequently suggested by Papin. The use of a working beam could not have been unknown. Nevertheless, the judicious combination of these scattered principles must be acknowledged to deserve considerable credit. In fact, the mechanism contrived by Newcomen rendered a machine, which was before altogether inefficient, highly efficient: and, as observed by Tredgold, such a result, considered in a practical sense, should be more highly valued than the fortuitous discovery of a physical principle. The method of condensing the steam by the sudden injection of water, and of expelling the air and water from the cylinder by the injection of steam, are two contrivances not before in use, which are quite essential to the effective operation of the engine. These processes, which are still necessary to the operation of the improved steam engine, appear to be wholly due to the inventors of the atmospheric engine.

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## CHAPTER III.

### FIRST INVENTIONS OF WATT.

(31.) *Improvements of the atmospheric engine.* — The atmospheric engine was brought to a state of considerable efficiency and improvement by Mr. Beighton, in 1718. From that time it continued in use without any change in its principle, and with little improvement in its structure, for half a century. Although engines of this kind continued to be extensively constructed, they were usually executed by ordinary mechanics, incapable of applying to them the just principles of practical science; and, consequently, little attention was paid to their proportions. It was not until about the year 1772, that Mr. John Smeaton, the celebrated engineer, applied the powers of his mind to the investigation of this machine, as he had previously done with such success to wind and water mills. Although he did not introduce any new principle into the atmospheric engine, yet it derived greatly augmented power from the proportions which he established for engines of different magnitudes.

In 1759, Mr. James Brindley, whose name is so celebrated as the engineer of the Duke of Bridgewater's canal, obtained a patent for some improvements in the atmospheric engine. He proposed that the boiler should be made of wood and stone, with a stove or fire-place of cast iron within it, so that the fire should be surrounded on every side by water. The chimney was to be an iron pipe or tube, conducted through the boiler; so that the heated air, in passing from the fire, should impart a portion of its heat to the water. He also proposed a method of feeding the boiler, which, by self-acting machinery, would keep the water in the boiler at a fixed level, independently of any attention on the part of the engine-man. This was to be accomplished by a buoy or float upon the surface of the water in the boiler, which should communicate with a valve in the feed pipe, so that when the level of the water in the boiler fell, the float or buoy, falling with it, would open the valve and supply the feed. It is stated, in the *Biographia Britannica*, that Mr. Brindley, in 1756, undertook to erect an engine at Newcastle-under-Lyne; but he is said to have been discouraged by the obstacles which were thrown in his way, and to have abandoned the steam engine.

The interval between the invention of the atmospheric engine, and the amelioration it received at the hands of Smeaton, has been rendered memorable by the advent of one who was destined to work a mighty change in the condition of the human race by the application of his vast genius to the adaptation of steam power to the uses of life.

(32.) *Birth and parentage of James Watt.*—James Watt was born at Greenock, in Scotland, on the nineteenth day of January, in the year 1736.

The great-grandfather of Watt, a farmer in Aberdeenshire, was killed in one of the battles of Montrose. The victorious party, not thinking death a sufficient expiation for the political opinions in support of which he had fought and bled, punished him in the person of his son, by confiscating his little property. Thomas Watt, the son, thus deprived of support, was received by distant relations, and, for a time, applied himself to study, by which he was enabled, after the restoration of tranquillity, to establish himself at Greenock as a teacher of practical mathematics and navigation. He resided in the burgh or barony of Crawford's Dyke, and attained a position of sufficient respectability to be elected to the office of baron-baillie, or chief magistrate, and died in 1734, at the advanced age of ninety-two years.

Thomas Watt had two sons. The elder, John, adopted the profession of his father, and was a teacher of mathematics and navigation at Glasgow: he died in 1737, at the age of fifty years. The second son, James, the father of the celebrated engineer, was, during a quarter of a century, treasurer of the town council of Greenock, and a local magistrate. He was remarked for the ardent zeal and enlightened spirit with which he discharged his public duties. His business was that of a ship-chandler, builder, and general merchant; but, unhappily, notwithstanding his active industry, he lost, in the decline of his life, by unsuccessful commercial speculations, a part of the property which he had so honourably acquired. He died in 1782, at the age of eighty-four years.

James Watt, to whom the world is so largely indebted for the extension and improvement of steam power, had from his birth an extremely delicate constitution. From his mother, whose family name was Muirhead, he received his first lessons in reading, and he learned from his father writing and arithmetic. Although he was entered as a pupil in the grammar school of Greenock, yet such was his delicate state of health, that his attendance there was so interrupted by constant indisposition that he could derive but little benefit from the opportunities of instruction which it afforded. For a great period of the year he was confined to his room, where he devoted himself to study without the aid of instruction. It was in the retirement of the sick chamber that the high intellectual faculties of Watt, which were destined to produce such precious fruits, began to unfold themselves.

(33.) *Is established as a mathematical instrument maker in Glasgow.*—In 1775, at the age of nineteen, at the recommendation of Dr. Dick, professor of natural philosophy in the University of Glasgow, he went to London, where he employed himself in the house of Mr. John Morgan, a mathematical instrument maker, in Finch Lane, Cornhill, to whom he apprenticed himself for three years. He remained, however, only a year, at the expiration of which (probably owing to his delicate state of health) he was released from his apprenticeship, and returned to Glasgow, where he opened a shop for the sale of mathematical instruments.

(34.) *His first experiment on steam.*— In 1762, Watt tried some experiments on the force of steam at a high pressure, confined in a close digester; and he then constructed a small model to show how motion could be obtained from that power. The practicability of what has since been called the *High Pressure Engine*, was demonstrated by him on this occasion; but he did not pursue the inquiry, on account of the supposed danger of working with such compressed steam as was required.

It is usual to provide, in the cabinets of experimental apparatus for the instruction of the students of universities, small working models of the most useful machines. In the collection for the illustration of the lectures delivered to the Natural Philosophy class in the University of Glasgow was a working model of Newcomen's atmospheric engine, applied to a pump for raising water; which, however, had never been found to work satisfactorily. The Professor of Experimental Philosophy of that day, Dr. John Anderson (the founder of the celebrated Andersonian Institution), sent this model in 1763 to Watt's workshop, to be repaired. Its defects soon disappeared, and it was made to work to the satisfaction of the professor and students.

This simple discharge of his duty, however, did not satisfy the artisan; and his wonted activity of mind rendered this model a subject of profound meditation, and led him into a course of practical inquiry respecting it, which formed the commencement of a most brilliant career of mechanical discovery. The improvement — we might almost say the creation — of the steam engine, by this great man, must not therefore be regarded, as so often happens with mechanical discoveries, as the result of fortuitous observation, or even of a felicitous momentary inspiration. Watt, on the other hand, conducted his investigation by a course of deep thought, and of experiments marked by the last refinement of delicacy and address. If he had received a more extended and liberal education, one would have thought that he had adopted for his guide the celebrated maxim of Bacon: —

"To write, speak, meditate, or act, when we are not provided with *facts* to direct our thoughts, is to navigate a coast full of dangers without a pilot, and to launch into the immensity of the ocean without either rudder or compass."

The model which he had repaired had a cylinder of only two inches diameter, and six inches stroke. After he had put it in complete order, he found, that although the boiler was much larger in proportion to the cylinder than those of real engines, yet it was incapable of supplying the cylinder with steam in sufficient quantity to keep it at work. To enable it to continue to move, he found it necessary to lessen the quantity of water raised by its pump, so as to reduce the load on its piston very much below the proper standard according to the common rules for large engines.

He ascribed the great inferiority in the performance of the model, compared with the performance of the large engines, to the small size of the cylinder, and to its material. The cylinder of the model was brass, while those of large engines were of cast iron; and brass being a better conductor of heat than iron, he concluded that more heat in proportion was lost from this cause in the model, than in the larger engines. He observed that the small cylinder was so heated when the steam was admitted into it, that it could not be touched by the hand; but, nevertheless, that this heat contributed nothing to its performance, inasmuch as before the piston descended, the cylinder required to be cooled.

(35.) *His first attempt to improve the steam engine.* — His first attempt to improve the engine, was by using a wooden cylinder instead of an iron one. He accordingly made a model with a cylinder of wood, soaked in linseed oil, and baked to dryness. With this he made numerous experiments, and found that it required a less quantity of water to be thrown into the cylinder to condense the steam, and that it was worked with a less supply of steam from the boiler than was necessary with the metallic cylinder.

Still he found that the force with which the piston descended was considerably less than that which the atmospheric pressure ought to supply, supposing a tolerably perfect vacuum to be produced under the piston. This led him to suspect that the water injected into the cylinder was not perfectly effectual in condensing the steam. The experiments which he had previously made on the increased temperature at which water boils under pressures greater than that of the atmosphere, led him by analogy to the conclusion that it would boil at lower temperatures if it were submitted to a pressure less than the atmosphere, and he was aware that Dr. Cullen and others had then recently discovered that in vacuo, water would boil at so low a temperature as 100°. These notions suggested the probability that the water injected into the cylinder being heated by the condensed steam, might produce vapour of a low temperature and reduced pressure under the piston, which would account for the deficiency he observed in the power of the engine.

No means occurred to him by which he could ascertain, by direct experiment, the temperatures at which water would boil under pressures less than that of the atmosphere. He sought, however, to determine it by the following method. Having ascertained, by repeating and multiplying the experiments which he had tried in 1762, on high-pressure steam, he obtained a table of the temperatures at which water boils at various pressures greater than that of the atmosphere. These results he laid down in a series forming a curve, of which the abscissa represented the temperatures, and the ordinates the pressures. He then continued this curve, backwards as it were, and obtained, by analogy, an approximation to the boiling temperatures, corresponding to pressures less than that of the atmosphere. In other words, having obtained by his experiments a notion, however imperfect, of the law or rule observed by the temperatures at which water boils at different pressures *greater* than that of the atmosphere, he calculated by the same law or rule what the pressures would be at different pressures *less* than that of the atmosphere.

(36.) *His calculation of the waste of steam.* — Applying these results to the interior of the cylinder of the atmospheric engine, he obtained an approximation to the pressure of the vapour which would be produced from the warm water formed by the cold water injected into the cylinder, and the steam condensed by it; and he accordingly found that vapour, having a pressure seriously injurious to the power of the engine, would be produced in the cylinder, unless considerably more water of injection was thrown in than was customary.

It was apparent that the actual quantity of steam usefully employed in the cylinder at each stroke, was only the quantity which filled the cylinder; and therefore, in order to ascertain the quantity of steam lost by the imperfection of the machine, it was necessary to compare the actual quantity of steam transmitted by the boiler to the cylinder at each stroke, with the quantity which would just fill the cylinder. The difference would of course be wasted. But to determine the actual quantity of steam supplied by the boiler to the cylinder, there was no other means than by observing the quantity of water evaporated in the boiler. That being observed, it was necessary to know the quantity of steam which that water formed; and it was therefore necessary to determine the quantity or volume of steam which a given volume of water produced.

(37.) *His investigation of the imperfections of the atmospheric engine* — On considering more attentively the operation of the machine, the following circumstances gradually unfolded themselves to him.

Let us suppose the piston at the top of the cylinder, and the space in the cylinder below it, filled with steam so as to balance the pressure of the atmosphere above the piston. Under such circumstances the steam, as will presently be explained, must have the temperature of boiling water. But that the steam should have, and should maintain, this temperature, it was evidently necessary that the inner surface of the cylinder in contact with it should have the same temperature: for if it had a lower temperature, it would take heat from the steam, and reduce the temperature of the latter. Now the cylinder being a mass of metal, has a quality in virtue of which heat passes freely through its dimensions, so that its inner surface could not be maintained at a temperature more elevated than that of its dimensions extending from the inner surface to the outer surface. Therefore, to maintain the steam contained in the cylinder at the proper temperature, it was essential that the whole of the solid metal composing the cylinder should be itself at that temperature.

Things being in this state, it was required that a vacuum should be produced under the piston to give effect to the atmospheric pressure above it, by relieving it from the pressure below. This indeed, would appear to have been attained by introducing as much cold water within the cylinder as would be sufficient to reconvert the steam contained in it into water; but Watt found, in his experiments on the atmospheric model, that the piston would not descend with the proper force, unless a vastly greater quantity of water were introduced into the cylinder than the quantity which he had ascertained to be necessary for the reconversion of the steam into water. The cause of this he perceived and fully explained.

If we suppose as much, and no more, cold water introduced into the cylinder as would reconvert the steam contained in it into water, then we should have in the bottom of the cylinder a quantity of warm water with a vacuum above it: but the entire mass of metal composing the cylinder itself, which was previously at the temperature of boiling water, would still be at the same temperature. The warm water, resting in contact with this metal in the bottom of the cylinder, would be immediately heated by it, and would rise in its temperature, while the metal of the cylinder itself would be somewhat lowered in temperature by the heat which it would thus impart to the warm water contained in it. Under these circumstances, as we shall presently explain, steam would be produced from the water, which would fill the cylinder; and although such steam would not have a mechanical pressure equal in amount to the atmosphere, and therefore would not altogether prevent the piston from descending if it had no load to move, yet it would deprive the engine of so great a portion of its legitimate power as to render it altogether inefficient. But this defect would be removed by throwing into the cylinder a sufficient quantity of cold water, not only to destroy the steam contained in it, but also to cool the entire mass of metal composing the cylinder itself, until it would be reduced to such a temperature that the vapour proceeding from the water contained in it would have so small a pressure that it would not seriously or injuriously obstruct the descent of the piston.

The piston being made to descend with such force as to render the machine practically efficient, it would then be necessary again to make it ascend; and to accomplish this, Watt found that the boiler should supply a quantity of steam many times greater than was necessary to fill the cylinder. Mature reflection on the circumstances which have been just explained, enabled him to discover how this undue quantity of steam was rendered necessary.

Let it be recollected, that when the piston has reached the bottom of the cylinder, the whole mass of the cylinder, and the piston itself, are reduced to so low a temperature that the vapour of water, having the same temperature, has no pressure sufficiently great to obstruct the action of the machine. When, in order to make the piston ascend, steam is introduced from the boiler into the cylinder under the piston, this steam encounters, in the first instance, the cold surfaces of the metal forming the bottom of the cylinder and the bottom of the piston. The first effect of this is to convert the steam which comes from the boiler into water, an effect which is produced by that steam imparting its heat to the metal with which it comes into contact. This destruction of steam continues until the metal exposed to contact with it has been heated up to the temperature of boiling water. Then, and not till then, the steam below the piston will have a pressure equal to that of the atmosphere above it, and the piston will begin to ascend. As it ascends, however, the sides of the cylinder which it exposes to the contact of the steam are cold, and partially destroy the steam. Steam, therefore, must be supplied from the boiler to replace the steam thus destroyed; nor can the piston reach the top of the cylinder until such a quantity of steam shall have flowed from the boiler into the cylinder, as shall be sufficient not only to fill the cylinder under the piston, but likewise, by its condensation, to raise the whole mass of the cylinder and piston to the temperature of boiling water.

Such were the circumstances which forced themselves upon the attention of Watt, in the course of repairing, and subsequently trying, the model of the atmospheric engine, at Glasgow. Being informed generally of the uses of the engine in the drainage of mines, and of the vast expense attending its operation, by reason of the quantity of fuel which it consumed, he saw how important any improvement would be by which the extensive sources of waste which had thus presented themselves could be removed. He saw also, that all that portion of steam which was expended, not in filling the cylinder under the piston, but in raising the great mass of metal composing the cylinder and piston, from a low temperature to that of boiling water, upon each stroke of the piston, was so much heat lost, and that the proportion of the fuel expended in producing the steam thus wasted would be saved, if by any expedient *he could make the piston descend without cooling the cylinder.* But in order to estimate the full amount of this waste, and to discover the most effectual means of preventing it, it was necessary to investigate the quantity of heat necessary for the evaporation of a given quantity of water; also, the quantity of steam which a given quantity of water would produce, as well as other circumstances connected with the temperature and pressure of steam. He therefore applied himself to make experiments with a view to elucidate these questions; and succeeded in obtaining results which led to the discovery of some of the most important of those physical phenomena, on the due application of which, the efficacy of the steam engine, which he afterwards invented, depended, and which also form striking facts in the general physics of heat.

(38.) *His investigation of the properties of steam.*—The first question to which he directed his experiments, was the determination of the extent to which water enlarged its volume, or magnitude, when it passed into steam. To ascertain this, he filled a thin Florence flask with steam, of a pressure equal to the atmosphere, and weighed it accurately. The same flask was then filled with water, and weighed again. Finally, the weight of the flask itself was ascertained. It is evident, that by such means, the exact weight of the steam which filled the flask, and of the same bulk of water, would be obtained. He found that the water weighed about eighteen hundred times more than the steam; from whence he inferred that the steam which filled the flask contained about eighteen hundred times less water than the flask would contain.

Having once ascertained this point, he was able, by observing the quantity of water evaporated in the boiler of the atmospheric model, to compute the volume of steam which was supplied to the cylinder. It was evident, that for every cubic inch of water evaporated in the boiler, eighteen hundred cubic inches of steam were supplied to the cylinder.

Having accurately observed the evaporation of the boiler for a short time, and the number of strokes made by the piston in the same time, he found that the quantity of water evaporated in the boiler would supply about four times as much steam as the cylinder would require. He consequently inferred, that about three-fourths of the steam produced was wasted.

The next question to which he directed his experiments, was to ascertain the quantity of cold water necessary to be injected into the cylinder, in order to condense the steam contained in it. To ascertain this, he attached a pipe to a boiler, by which he was enabled to conduct the steam from the boiler into a glass jar containing cold water at fifty-two degrees of temperature. The steam, as it passed from the boiler through the pipe, was condensed by the cold water, and continued to be so condensed, until, by the heat which it imparted to the water, the latter began to boil, and would then condense no more steam. On comparing the water in the glass jar, when boiling, with the water originally contained in it at fifty-two degrees, the quantity was found to be increased in the proportion of six to seven, very nearly; from which he inferred, that to reduce one ounce of steam to water, it was necessary to mix about six ounces of cold water with it.

He was further led to the conclusion, that steam contains a vast quantity of heat, by the following experiment. He heated, in a close digester, a quantity of water several degrees above the common boiling point. When thus heated, by opening a stop-cock, he allowed the compressed steam to escape into a cold vessel; in three or four seconds, he found that the heat of the water in the digester was reduced from a very high temperature to the common boiling point; yet, that all the steam which escaped from it, and which carried off with it the superabundant heat, formed only a few drops of water when condensed; from which he inferred, that this small quantity of water, in the form of steam, contained as much heat as was sufficient to raise all the water in the digester from the boiling point to the temperature at which it was before the steam was allowed to escape.

Having thus ascertained the exact quantity of cold water which ought to be injected into the cylinder in order to condense the steam which filled the cylinder, he found, on comparing the quantity necessary to be injected in order to enable the piston to descend, that this quantity was about four times as great as that which was necessary to condense the steam. This led him to the conclusion, that about four times as much heat was destroyed in the cylinder as needed to be destroyed, if the object were the mere condensation of the steam. This result fully corroborated the other conclusion deduced from the proportion which he found between the quantity of steam supplied by the boiler and the actual contents of the cylinder.

Watt was forcibly struck with these circumstances, not only on account of their importance in an economical point of view, when their relation to steam power was considered, but still more so, as indicating phenomena in the physics of heat altogether novel to him.

He, therefore, eagerly sought his friend Dr. Black, to whom he communicated these results. Then, for the first time, he was informed, by Black, of the theory of LATENT HEAT, which had recently been discovered by him, and of which these very phenomena formed the basis.

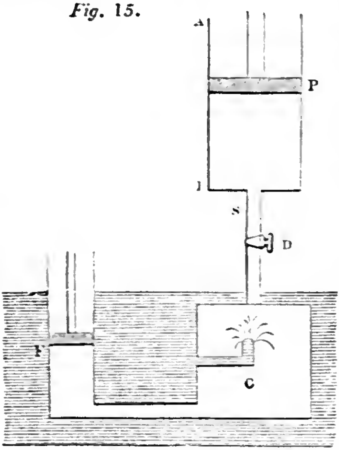
At the period to which we have now brought the history of the invention of the steam engine, Watt had obtained, chiefly by his own experiments, a sufficient knowledge of the phenomena which have been just explained, to enable him to arrive at the conclusion that a very small proportion of the whole mechanical effect attending the evaporation was really rendered available by the atmospheric engine; and that, therefore, extensive and injurious sources of waste existed in its machinery.

He perceived that the principal source of this wasteful expenditure of power consisted in the quantity of steam which was condensed at each stroke of the piston, in heating the cylinder previous to the ascent of the piston. Yet, as it was evident that that ascent could not be accomplished in a cold cylinder, it was apparent that this waste of power must be inevitable, unless some expedient could be devised, by which *a vacuum could be maintained in the cylinder, without cooling it.* But, to produce such a vacuum, the steam must be condensed; and, to condense the steam, its temperature must be lowered to such a point that the vapour proceeding from it shall have no injurious pressure; yet, if condensed steam be contained in a cylinder at a high temperature, it will return to the temperature of the cylinder, recover its elasticity, and resist the descent of the piston.

(39.) *His discovery of separate condensation.*—Having reflected on these circumstances, it became apparent to Watt, that a vice was inherent in the structure of the atmospheric engine, which rendered a large waste of power inevitable; this vice arising from the fact, that the condensation of the steam was incompatible with the condition of maintaining the elevated temperature of the cylinder in which that condensation took place. It followed, therefore, either that the steam must be imperfectly condensed, or that the condensation could not take place in the cylinder. It was in 1765, that, pondering on these circumstances, the happy idea occurred to him, that the production of a vacuum could be equally effected, though *the place* of the condensation of the steam were not the cylinder itself. He saw, that if a vessel in which a vacuum was produced were put into communication with another containing an elastic fluid, the elastic fluid would rush into the vacuum, and diffuse itself through the two vessels; but if, on rushing into such vacuum, this elastic fluid, being vapour, were there condensed, and restored to the liquid form, that then the space within the two vessels would be equally rendered a vacuum;—that, under such circumstances, one of the vessels might be maintained at any temperature, however high, while the other might be kept at any temperature, however low. This felicitous conception formed the first step in that splendid career of invention and discovery which has conferred immortality on the name of Watt. He used to say, that the moment the idea of separate condensation occurred to him,—that is, of condensing, in one vessel kept cold, the steam coming from another vessel kept hot,—all the details of his improved engine rushed into his mind in such rapid succession, that, in the course of a day, his invention was so complete that he proceeded to submit it to experiment.

To explain the first conception of this memorable invention; let a tube or pipe, S (*fig.* 15.), be imagined to proceed from the bottom of the cylinder A B to a vessel, C, having a stop-cock, D, by which the communication between the cylinder and the vessel C may be opened or closed at pleasure. Let us suppose the piston P at the top of the cylinder, and the space below it filled with steam, the cylinder and steam being at the usual temperature, while the vessel C is a vacuum, and maintained at a low temperature. Then, on opening the cock D, the steam will rush from the cylinder A B through the tube S, and, passing into the cold vessel C, will be condensed by contact with its cold sides. This process of condensation will be rendered instantaneous if a jet of cold water is allowed to play in the vessel C. When the steam thus rushing into C, has been destroyed, and the space in the cylinder A B becomes a vacuum, then the pressure of the atmosphere being unobstructed, the piston will descend with the force due to the excess of the pressure of the atmosphere above the friction. When it has descended, suppose the stop-cock D closed, and steam admitted from the boiler through a proper cock or valve below the piston, the cylinder and piston being still at the same temperature as before. The steam on entering the cylinder, not being exposed to contact with any surface below its own temperature, will not be condensed, and therefore will immediately cause the piston to rise, and the piston will have attained the top of the cylinder when as much steam shall have been supplied by the boiler as will fill the cylinder. When this has taken place, suppose the communication with the boiler cut off, and the cock D once more opened: the steam will again rush through the pipe S into the vessel C, where encountering the cold surface and the jet of cold water, it will be condensed, and the vacuum, as before,

*Fig.* 15.



will be produced in the cylinder A B; that cylinder still maintaining its temperature, the piston will again descend, and so the process may be continued.

(40.) *Invention of the air-pump.* — Having carried the invention to this point, Watt saw that the vessel C would gradually become heated by the steam which would be continually condensed in it. To prevent this, as well as to supply a constant jet of cold water, he proposed to keep the vessel C, submerged in a cistern of cold water, from which a pipe should conduct a jet to play within the vessel, so as to condense the steam as it would pass from the cylinder.

But here a difficulty presented itself, against which it was necessary to provide. The cold water admitted through the jet to condense the steam, mixed with the condensed steam itself, would gradually collect in the vessel C, and at length choke it. To prevent this, Watt proposed to put the vessel C in communication with a pump F, which might be wrought by the engine itself, and by which the water, which would collect in the bottom of the vessel C, would be constantly drawn off. This pump would be evidently rendered the more necessary, since more or less atmospheric air, always combined with water in its common state, would enter the vessel C by the condensing jet. This air would be disengaged in the vessel C by the heat of the steam condensed therein; and it would rise through the tube S, and vitiate the vacuum in the cylinder;— an effect which would be rendered the more injurious inasmuch as, unlike steam, this elastic fluid would be incapable of being condensed by cold. The pump F, therefore, by which Watt proposed to draw off the water from the vessel C, might also be made to draw off the air, or the principal part of it.

The vessel C was subsequently called a *condenser;* and, from the circumstances just adverted to, the pump F has been called the *air-pump.*

These—namely, the cylinder, the condenser, and the air pump—were the three principal parts in the invention, as it first presented itself to the mind of Watt—and even before it was reduced to a model, or submitted to experiment. But, in addition to these, other two improvements offered themselves in the very first stage of its progress.

(41.) *Substitutes steam pressure for the atmosphere.*—In the atmospheric engine, the piston was maintained steam-tight in the cylinder by supplying a stream of cold water above it, by which the small interstices between the piston and cylinder would be stopped. It is evident that the effect of this water as the piston descended would be to cool the cylinder, besides which any portion of it which might pass between the piston and cylinder and which would pass below the piston, would boil the moment it would fall into the cylinder, which itself would be maintained at the boiling temperature. This water, therefore, would produce steam, the pressure of which would resist the descent of the piston.

Watt perceived, that even though this inconvenience were removed by the use of oil or tallow upon the piston, still, that as the piston would descend in the cylinder, the cold atmosphere would follow it; and would, to a certain extent, lower the temperature of the cylinder. On the next ascent of the piston, this temperature would have to be again raised to 212° by the steam coming from the boiler, and would entail upon the machine a proportionate waste of power.

If the atmosphere of the engine house could be kept heated to the temperature of boiling water, this inconvenience would be removed. The piston would then be pressed down by air as hot as the steam to be subsequently introduced into it. On further consideration, however, it occurred to Watt that it would be still more advantageous if the cylinder itself could be worked in an atmosphere of steam, having only the same pressure as the atmosphere. Such steam would press the piston down as effectually as the air would; and it would have the further advantage over air, that if any portion of it leaked through between the piston and cylinder, it would be condensed, which could not be the case with atmospheric air.

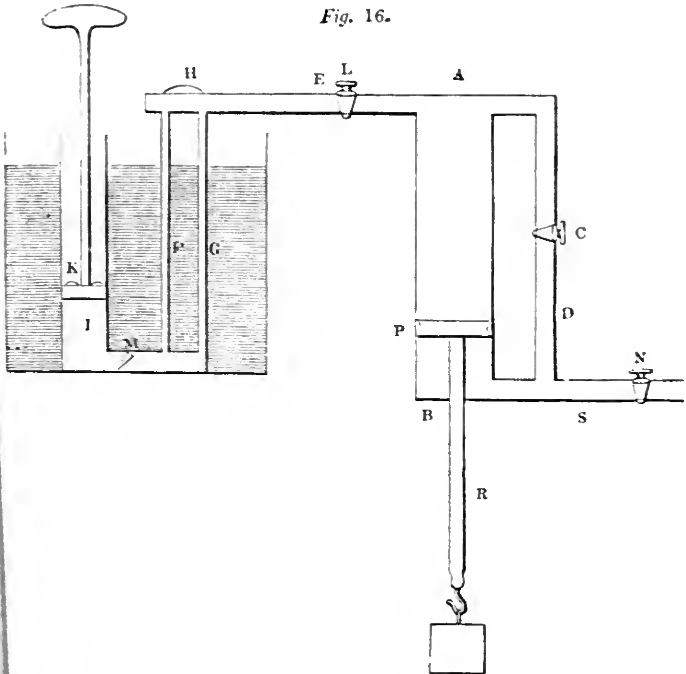
(42.) *Invention of the steam jacket.*—He therefore determined on surrounding the cylinder by an external casing, the space between which and the cylinder he proposed to be filled with steam supplied from the boiler. The cylinder would thus be enclosed in an atmosphere of its own, independent of the external air, and the vessel so enclosing it would only require to be a little larger than the cylinder, and to have a close cover at the top, the centre of which might be perforated with a hole to admit the rod of the piston to pass through, the rod being made smooth, and so fitted to the perforation that no steam should escape between them. This method would be attended also with the advantage of keeping the cylinder and piston always heated, not only inside but outside; and Watt saw that it would be further advantageous to employ the pressure of steam to drive the piston in its descent instead of the atmosphere, as its intensity or force would be much more manageable; for, by increasing or diminishing the heat of the steam in which the cylinder was enclosed, its pressure might be regulated at pleasure, and it might be made to urge the piston with any force that might be required. The power of the engine would therefore be completely under control, and independent of all variations in the pressure of the atmosphere.

This was a step which totally changed the character of the machine, and which rendered it a STEAM ENGINE instead of an ATMOSPHERIC ENGINE. Not only was the vacuum below the piston now produced by the property of steam, in virtue of which it is reconverted into water by cold; but the pressure which urged the piston into this vacuum was due to the elasticity of steam.

The external cylinder, within which the working cylinder was enclosed, was called THE JACKET, and is still very generally used.

(43.) *Practical realisation of these inventions.*—The first experiment in which Watt attempted to realise, on a small scale, his conceptions, was made in the following manner. The cylinder of the engine was represented by a brass syringe A B (*fig.* 16.) an inch and a third in diameter, and ten inches in length, to which a top and a bottom of tin plate was fitted. Steam was conveyed by a pipe S, from a small boiler into the lower end of this syringe, a communication being made with the upper end by a branch pipe D. For the greater convenience of the experiment, it was found desirable to invert the position of the cylinder, so that the steam should press the piston P upwards instead of downwards. The piston rod R therefore was presented downwards. An eduction pipe E was also inserted in the top of the cylinder, which was carried to the condenser. The piston rod was made hollow, or rather a hole was drilled longitudinally through it, and a valve was fitted at its lower

*Fig.* 16.




end, to carry off the water produced by the steam, which would be condensed in the cylinder in the commencement of the process. The condenser used in this experiment operated without injection, the steam being condensed by the contact of cold surfaces. It consisted of two thin pipes, F G, of tin, ten or twelve inches in length, and the sixth of an inch in diameter, standing beside each other perpendicularly, and communicating at the top with the eduction pipe, which was provided with a valve opening upwards. At the bottom these two pipes communicated with another tube I of about an inch in diameter, by a horizontal pipe, having in it a valve, M, opening towards I, fitted with a piston K, which served the office of the air-pump, being worked by the hand. This piston, K, had valves in it opening upwards. These condensing pipes and air-pump were immersed in a small cistern, filled with cold water. The steam was conveyed by the steam pipe S to the bottom of the cylinder, a communication between the top and bottom of the cylinder being occasionally opened by a cock, C, placed in the branch pipe. The eduction pipe leading to the condenser also had a cock, L, by which the communication between the top of the cylinder and the condenser might be opened and closed at pleasure. In the commencement of the operation, the cock N admitting steam from the boiler, and the cock L opening a communication between the cylinder and the condenser, and the cock C opening a communication between the top and bottom of the cylinder, being all open, steam rushed from the boiler, passing through all the pipes, and filling the cylinder. A current of mixed air and steam was thus produced through the eduction pipe E, through the condensing pipes F and G, and through the air-pump I, which issued from the valve H in the eduction pipe, and from the valve in the air-pump piston, all of which opened upwards. The steam also in the cylinder passed through the hole drilled in the piston rod, and escaped, mixed with air, through the valve in the lower end of that rod. This process was continued until all the air in the cylinder, pipes, and condenser was blown out, and all these spaces filled with pure steam. The cocks L, C, and N were then closed, and the atmospheric pressure closed the valve H and the valves in the air-pump piston. The cold surfaces condensing the steam in the pipes F and G, and in the lower part of the air-pump, a vacuum was produced in these spaces. The cock C being now closed, and the cocks L and N being open, the steam in the upper part of the cylinder rushed through the pipe E into the condenser, where it was reduced to water, so that a vacuum was left in the upper part of the cylinder. The steam from the boiler passing below the piston, pressed it upwards with such force, that it lifted a weight of eighteen pounds hung from the end of the piston rod. When the piston reached the top of the cylinder, the cocks L and N were closed, and the cock C opened. All communication between the cylinder and the boiler, as well as between the cylinder and the condenser, were now cut off, and the steam in the cylinder circulated freely above and below the piston, by means of the open tube D. The piston, being subject to equal forces upwards and downwards, would therefore descend by its own weight, and would reach the bottom of the cylinder. The air-pump piston meanwhile being drawn up, the air and the condensed steam in the tubes F and G were drawn into the air-pump I, through the open horizontal tube at the bottom. Its return was stopped by the valve M. By another stroke of the air-pump, this water and air were drawn out through valves in the piston, which opened upwards. The cock C was now closed, and the cocks L and N opened, preparatory to another stroke of the piston. The steam in the upper part of the cylinder rushed, as before, into the tubes F and G, and was condensed by their cold surfaces, while steam from the boiler coming through the pipe S, pressed the piston upwards. The piston again ascended with the same force as before, and in the same manner the process was continually repeated.

The quantity of steam expended in this experimental model in the production of a given number of strokes of the piston was inferred from the quantity of water evaporated in the boiler; and on comparing this with the magnitude of the cylinder and the weight raised by the pressure of the steam, the contrivance was proved to affect the economy of steam, as far as the imperfect conditions of such a model could have permitted. A larger model was next constructed, having an outer cylinder, or steam case, surrounding the working cylinder, and the experiments made with it fully realised Watt's expectations, and left no doubt of the great advantages which would attend his invention. The weights raised by the piston proved that the vacuum in the cylinder produced by the condensation was almost perfect; and he found that when he used water in the boiler which by long boiling had been well cleared of air, the weight raised was not much less than the whole amount of the pressure of the steam upon the piston. In this larger model, the cylinder was placed in the usual position, with a working lever and other apparatus similar to that employed in the Atmospheric Engine.

(44.) *Becomes a civil engineer.*—It was in the beginning of the year 1765, Watt being then in the twenty-ninth year of his age, that he arrived at these great discoveries. The experimental models just described, by which his invention was first reduced to a rude practical test, were fitted up at a place called Delft House, in Glasgow. It will doubtless, at the first view, be a matter of surprise that improvements of such obvious importance in the economy of steam power, and capable of being verified by tests so simple, were not immediately adopted wherever atmospheric engines were used. At the time, however, referred to, Watt was an obscure artisan, in a provincial town, not then arrived at the celebrity to which it has since attained, and the facilities by which inventions and improvements became public were much less than they have since become. It should also be considered that all great and sudden advances in the useful arts are necessarily opposed by the existing interests with which their effects are in conflict. From these causes of opposition, accompanied with the usual influence of prejudice and envy, Watt was not exempt, and was not therefore likely suddenly to revolutionise the arts and manufactures of the country by displacing the moving powers employed in them, and substituting an engine, the efficacy and power of which depended mainly on physical principles, then altogether new and but imperfectly understood.

Not having the command of capital, and finding it impracticable to inspire those who had, with the same confidence in the advantages of his invention which he himself felt, he was unable to take any step towards the construction of engines on a large scale. Soon after this, he gave up his shop in Glasgow, and devoted himself to the business of a Civil Engineer. In this capacity he was engaged to make a survey of the river Clyde, and furnished an elaborate and valuable Report upon its projected improvements. He was also engaged in making a plan of the canal, by which the produce of the Monkland Colliery was intended to be carried to Glasgow, and in superintending the execution of that work. Besides these, several other engineering enterprises occupied his attention, among which may be mentioned, the navigable canal across the isthmus of Crinan, afterwards completed by Rennie; improvements proposed in the ports of Ayr, Glasgow, and Greenock; the construction of the bridges at Hamilton, and at Rutherglen; and the survey of the country through which the celebrated Caledonian canal was intended to be carried.

(45.) *His connection with Dr. Roebuck.*—Although Watt was thus attracted by pursuits foreign to his recent investigations respecting the improvement of steam power, he never lost sight of that object. It was not until the year 1768, three years after his great discoveries, that any step was taken to enable him to carry them into effect on a large scale. At that time his friends brought him into communication with Dr. Roebuck, the proprietor of the Carron Iron Works, who rented extensive coal works at Kinneal from the Duchess of Hamilton. Watt was first employed by Roebuck as a civil engineer; but when he made known to him the improvements he had projected in the steam engine, Roebuck proposed to take out a patent for an engine on the principle of the model which had been fitted up at Delft House, and to join Watt in a partnership for the construction of such engines. Sensible of the advantages to be derived from the influence of Roebuck, and from his command of capital, Watt agreed to cede to him two thirds of the advantages to be derived from the invention. A patent was accordingly taken out on the fifth of January, 1769, nearly four years after the invention had been completed; and an experimental engine on a large scale was constructed by him, and fitted up at Kinneal House. In the first trial this machine more than fulfilled Watt's anticipations. Its success was complete. In the practical details of its construction, however, some difficulties were still encountered, the greatest of which consisted in packing the piston, so as to be steam-tight. The principle of the new engine did not admit of water being kept upon the piston, to prevent leakage, as in the old engines; he was therefore obliged to have his cylinders much more accurately bored, and more truly cylindrical, and to try a great variety of soft substances for packing the piston, which would make it steam-tight without great friction, and maintain it so in a situation perfectly dry, and at the temperature of boiling water.

While Watt was endeavouring to overcome these and other difficulties in the construction of the machine, his partner, Dr. Roebuck, became embarrassed, by the failure of his undertaking in the Borrowstowness coal and salt works; and he was unable to supply the means of prosecuting with the necessary vigour the projected manufacture of the new engines.

(46.) *Is associated with Matthew Boulton.* — The important results of Watt's labours having happily at this time become more publicly known, Mr. Matthew Boulton, whose establishment at Soho, near Birmingham, was at that time the most complete manufactory for metal work in England, and conducted with unexampled enterprise and spirit, proposed to purchase Dr. Roebuck's interest in the patent. This arrangement was effected in the year 1773, and in the following year Mr. Watt removed to Soho, where a portion of the establishment was allotted to him, for the erection of a foundery, and other works necessary to realise his inventions on a grand scale.

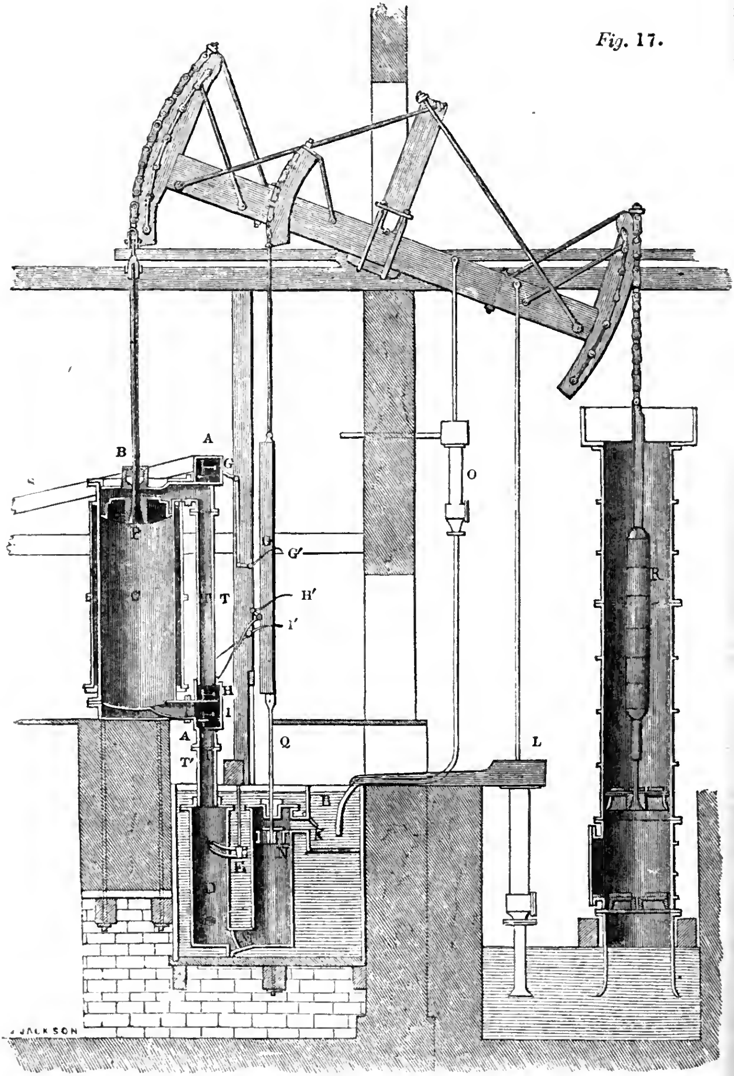
The patent which had been granted in 1769 was limited to a period of fourteen years, and would consequently expire about the year 1783. From the small progress which had hitherto been made in the construction of engines upon the new principle, and from the many difficulties still to be encountered, and the large expenditure of capital which must obviously be incurred before any return could be obtained, it was apparent that unless an extension of the patent right could be obtained, Boulton and Watt could never expect any advantage adequate to the risk of their great enterprise. In the year 1774 an application was accordingly made to parliament for an extension of the patent, which was supported by the testimony of Dr. Roebuck, Mr. Boulton, and others, as to the merits and probable utility of the invention. An Act was accordingly passed, in 1775, extending the term of the patent until the year 1800.

(47.) *Description of Watt's single acting steam engine.*— Thus protected and supported, Watt now directed the whole vigour of his mind to perfect the practical details of his invention, and the result was, the construction on a large scale of the engine which has since been called his SINGLE-ACTING STEAM ENGINE.

It is necessary to recollect, that notwithstanding the extensive and various application of steam power in the arts and manufactures, at the time to which our narrative has now reached, the steam engine had never been employed for any other purpose save that of raising water by working pumps. The motion, therefore, which was required was merely an upward force, such as was necessary to elevate the piston of a pump, loaded with the column of water which it raised. The following, then, is a description of the improved engine of Watt, by which such work was proposed to be performed: —

In the cylinder represented at C (*fig.* 17.), the piston P moves steam-tight. It is closed at the top, and the piston rod, being accurately turned, runs in a steam-tight collar, B, furnished with a stuffing box, and is constantly lubricated with melted tallow. A funnel is screwed into the top of the cylinder, through which, by opening a stop-cock, melted tallow is permitted from time to time to fall upon the piston within the cylinder, so as to lubricate it, and keep it steam-tight. Two boxes, A A, called the upper and lower steam boxes, contain valves by which steam from the boiler may be admitted and withdrawn. These steam boxes are connected by a tube T, and they communicate with the cylinder at the top and bottom by short tubes represented in the figure. The upper steam box A contains one valve, by which a communication with the boiler may be opened or closed at pleasure. The lower valve box contains two valves. The lower valve I communicates with the tube T′, leading to the condenser D, which being opened or closed, a communication is made or cut off at pleasure, between the cylinder C and the condenser D. A second valve, H, which is represented closed in the figure, may be opened so as to make a free communication between the cylinder C and the tube T, and by that means between the cylinder C, below the piston and the space above the piston. The condenser D is submerged in a cistern of cold water. At the side there enters it a tube, E, governed by a cock, which being opened or closed to any required extent, a jet of cold water may be

*Fig.* 17.



allowed to play in the condenser, and may be regulated or stopped, at pleasure. This jet, when playing, throws the water upwards in the condenser towards the mouth of the tube T′, as water issues from the rose of a watering pot. The tube S proceeds from the boiler, and terminates in the steam box A, so that the steam supplied from the boiler constantly fills that box. The upper steam valve G is governed by levers, whose pivots are attached to the framing of the engine, and is opened or closed at pleasure, by raising or lowering the lever G′. The valve G, when open, will therefore allow steam to pass from the boiler through the short tube to the top of the piston, and this steam will also fill the tube T. If the lower valve H be closed, its circulation beyond that point will be stopped; but if the valve H be open, the valve I being closed, then the steam will circulate equally in the cylinder, above and below the piston. If the valve I be open, then steam will rush through the tube T′ into the condenser; but this escape of the steam will be stopped, if the valve I be closed. The valve H is worked by the lever H′, and the valve I by the lever I′.

The valve G is called the upper steam valve, H the lower steam valve, I the exhausting valve, and E the condensing valve.

From the bottom of the condenser D proceeds a tube leading to the air-pump, which is also submerged in the cistern of cold water. In this tube is a valve M, which opens outwards from the condenser towards the air-pump. In the piston of the air-pump N is a valve which opens upwards. The piston rod Q of the air-pump is attached to a beam of wood called a plug frame, which is connected with the working beam by a flexible chain playing on the small arch-head immediately over the air-pump. From the top of the air-pump barrel above the piston proceeds a pipe or passage leading to a small cistern, called the hot well. The pipe which leads to this well is supplied with a valve K, which opens outwards from the air-pump barrel towards the well. From the nature of its construction, the valve M admits the flow of water from the condenser towards the air-pump, but prevents its return; and, in like manner, the valve K admits the flow of water from the upper part of the air-pump barrel into the hot well, but obstructs its return.

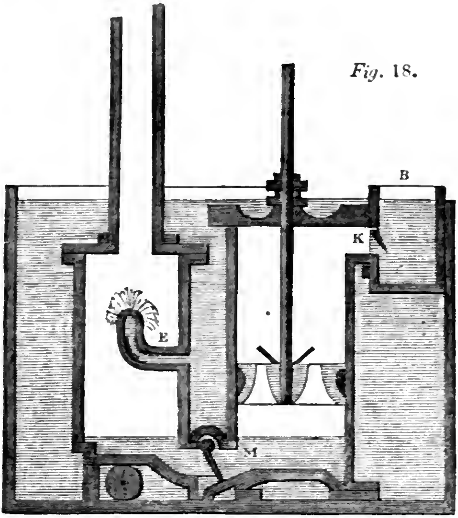
Let us now consider how these valves should be worked in order to move the piston upwards and downwards with the necessary force. It is in the first place necessary that all the air which fills the cylinder, the tubes, and the condenser, shall be expelled. To accomplish this it is only necessary to open at once the three valves G, H, and I. The steam then rushing from the boiler through the steam-pipe S and the open valve G, will pass into the cylinder above the piston, will fill the tube T, pass through the lower steam valve H, will fill the cylinder C below the piston, and will pass through the open valve I into the condenser. If the valve E be closed, so that nó jet shall play in the condenser, the steam rushing into it will be partially condensed by the cold surfaces to which it will be exposed; but if the boiler supply it through the pipe S in sufficient abundance, it will rush with violence through the cylinder and all the passages, and its pressure in the condenser D, combined with that of the heated air with which it is mixed, will open the valve M, and it will rush through mixed with the air into the air-pump barrel N. It will press the valves in the air-pump piston upwards, and, opening them, will rush through, and will collect in the air-pump barrel above the piston. It will then, by its pressure, open the valve K, and will escape into the cistern B.

Throughout this process the steam, which mixed with the air fills the cylinder, condenser, and air-pumps, will be only partially condensed in the last two, and it will escape mixed with air through the valve K, and this process will continue until all the atmospheric air which at first filled the cylinder, tubes, condenser, and air-pump barrel, shall be expelled through the valve K, and these various spaces shall be filled with pure steam. When that has happened, let us suppose all the valves closed. In closing the valve I, the flow of steam to the condenser will be stopped, and the steam contained in it will speedily be condensed by the cold surface of the condenser, so that a vacuum will be produced in the condenser, the condensed steam falling in the form of water to the bottom. In like manner, and for like reasons, a vacuum will be produced in the air-pump. The valve M, and the valves in the air-pump piston will be closed by their own weight.

By this process, which is called *blowing through*, the atmospheric air, and other permanent gases, which filled the cylinder, tubes, condenser, and air-pump, are expelled, and these spaces will be a vacuum. The engine is then prepared to be started, which is effected in the following manner: — The upper steam valve G is opened, and steam allowed to flow from the boiler through the passage leading to the top of the cylinder. This steam cannot pass to the bottom of the cylinder, since the lower steam valve H is closed. The space in the cylinder below the piston being therefore a vacuum, and the steam pressing above the piston, it will be pressed downwards with a corresponding force. When it has arrived at the bottom of the cylinder, the steam valve G must be closed, and at the same time the valve H opened. The valve I leading to the condenser being also closed, the steam which fills the cylinder above the piston is now admitted to circulate through the open valve H below the piston, so that the piston is pressed equally upwards and downwards by steam, and there is no force to resist its movement save its friction with the cylinder. The weight of the pump rods on the opposite end of the beam being more than equivalent to this, the piston is drawn to the top of the cylinder, and pushes before it the steam which is drawn through the tube T, and the open valve H, and passes into the cylinder C below the piston.

When the piston has thus arrived once more at the top of the cylinder, the valve H is closed, and at the same time the valves G and I opened, and the condensing cock E also opened, so as to admit the jet to play in the condenser. The steam which fills the cylinder C below the piston, will now rush through the open valve I into the condenser which has been hitherto a vacuum, and there encountering the jet, will be instantly converted into water, and a mixture of condensed steam and injected water will collect in the bottom of the condenser. At the same time, the steam proceeding from the boiler by the steam pipe S to the upper steam box A, will pass through the open steam valve G to the top of the piston, but cannot pass below it because of the lower steam valve H being closed. The piston thus acted upon above by the pressure of the steam, and the space in the cylinder below it being a vacuum, its downward motion is resisted by no force but the friction, and it is therefore driven to the bottom of the cylinder. During its descent the valves G, I, and E remained open. At the moment it arrives at the bottom of the cylinder, all these three valves are closed, and the valve H opened. The steam which fills the cylinder above the piston is now permitted to circulate below it by the open valve H, and the piston being consequently pressed equally upwards and downwards will be drawn upwards as before by the preponderance of the pump rods at the opposite end of the beam. The weight of these rods must be sufficiently great to draw the air-pump piston N upwards. As this piston rises in the air-pump, it leaves a vacuum below it into which the water and air collected in the condenser will be drawn through the valve M, which opens outwards. When the air-pump piston has arrived at the top of the barrel, which it will do at the same time that the steam piston arrives at the top of the cylinder, the water and the chief part of the air or other fluids which may have been in the condenser will be drawn into the barrel of the air-pump, and the valve M being closed by its own weight, assisted by the pressure of these fluids, they cannot return into the condenser. At the moment the steam piston arrives at the top of the cylinder, the valve H is closed, and the three valves G, I, and E are opened. The effect of this change is the same as was already described in the former case, and the piston will in the same manner and from the same causes be driven downwards. The air-pump piston will at the same time descend by the force of its own weight, aided by the weight of the plug frame attached to its rod. As it descends, the air below it will be gradually compressed above the surface of the water in the bottom of the barrel, until its pressure becomes sufficiently great to open the valves in the air-pump piston. When this happens, the valves in the air-pump piston, as represented on a larger scale in *fig.* 18., will be opened, and the air will pass through them above the piston. When the piston comes in contact with the water in the bottom of the barrel, this water will likewise pass through the open valves. When the piston has arrived at the bottom of the air-pump barrel, the valves in it will be closed by the pressure of the fluids above them. The

*Fig.* 18.




next ascent of the steam piston will draw up the air-pump piston, and with it the fluids in the pump barrel above it. As the air-pump piston approaches the top of its barrel, the air and water above it will be drawn through the valve K into the hot cistern B. The air will escape in bubbles through the water in that cistern, and the warm water will be deposited in it.

The magnitude of the opening in the condensing valve E, must be regulated by the quantity of steam admitted to the cylinder. As much water ought to be supplied through the injection valve as will be sufficient to condense the steam contained in the cylinder, and also to reduce the temperature of the water itself, when mixed with the steam, to a sufficiently low degree to prevent it from producing vapour of a pressure which would injuriously affect the working of the piston. It has been shown, that five and a half cubic inches of ice-cold water mixed with one cubic inch of water in the state of steam, would produce six and a half cubic inches of water at the boiling temperature. If then the cylinder contained one cubic inch of water in the state of steam, and only five and a half cubic inches of water were admitted through the condensing jet, supposing this water, when admitted, to be at the temperature of 32°, then the consequence would be that six and a half cubic inches of water at the boiling temperature would be produced in the condenser. Steam would immediately arise from this, and at the same time the temperature of the remaining water would be lowered by the amount of the latent heat taken up by the steam so produced. This vapour would rise through the open exhausting valve I, would fill the cylinder below the piston, and would impair the efficiency of the steam above pressing it down. The result of the inquiries of Watt respecting the pressure of steam at different temperatures showed, that to give efficiency to the steam acting upon the piston it would always be necessary to reduce the temperature of the water in the condenser to 100°.

Let us then see what quantity of water at the common temperature would be necessary to produce these effects.

If the latent heat of steam be taken at 1000°, a cubic inch of water in the state of steam may be considered, for the purposes of this computation, as equivalent to one cubic inch of water at 1212°. Now the question is, how many cubic inches of water at 60° must be mixed with this, in order that the mixture may have the temperature of 100°? This will be easily computed. As the cubic inch of water at 1212° is to be reduced to 100°, it must be deprived of 1112° of its temperature. On the other hand, as many inches of water at 60° as are to be added, must be raised in the same mixture to the temperature of 100°, and therefore each of these must receive 40° of temperature. The number of cubic inches of water necessary to be added will therefore be determined by finding how often 40 are contained in 1112. If 1112 be divided by 40, the quotient will be 27·8. Hence it appears, that to reduce the water in the condenser to the temperature of 100°, supposing the temperature of the water injected to be 60°, it will be necessary to supply by the injection cock very nearly twenty-eight times as much water as passes through the cylinder in the state of steam; and therefore if it be supposed that all the water evaporated in the boiler passes through the cylinder, it follows that about twenty-eight times as much water must be thrown into the condenser as is evaporated in the boiler.

(48.) *Cold water pump and waste pipe.*—From these circumstances it will be evident that the cold cistern in which the condenser and air-pump are submerged, must be supplied with a considerable quantity of water. Independently of the quantity drawn from it by the injection valve, as just explained, the water in the cistern itself must be kept down to a temperature of about 60°. The interior of the condenser and air-pump being maintained by the steam condensed in them at a temperature not less than 100°, the outer surfaces of these vessels consequently impart heat to the water in the cold cistern, and have therefore a tendency to raise the temperature of that water. To prevent this, a pump called the *cold pump*, represented at L in *fig.* 17., is provided. By this pump, water is raised from any convenient reservoir, and driven through proper tubes into the cold cistern. This cold pump is wrought by the engine, the rod being attached to the beam. Water being, bulk for bulk, heavier the lower its temperature, it follows that the water supplied by the cold pump to the cistern will have a tendency to sink to the bottom, pressing upwards the warmer water contained in it. A waste pipe is provided, by which this water is drained off, and the cistern therefore maintained at the necessary temperature

From what has been stated it is also evident, that the hot well B, into which the warm water is thrown by the air-pump, will receive considerably more water than is necessary to feed the boiler. A waste pipe to carry off this is also provided; and the quantity necessary to feed the boiler is pumped up by a small pump O, the rod of which is attached to the beam, as represented in *fig.* 17., and which is worked by the engine. The water raised by this pump is conducted to a reservoir from which the boiler is fed, by means which will be hereafter explained.

(49.) *Method of working the valves.*—We shall now explain the manner in which the machine is made to open and close the valves at the proper times. By referring to the explanation already given, it will be perceived that at the moment the piston reaches the top of the cylinder, the upper steam valve G must be open, to admit the steam to press it down, while the exhausting valve I must be opened, to allow the steam below the piston to pass to the condenser; and the condensing valve E must be opened, to let in the water necessary for the condensation of the steam; and at the same time the lower steam valve H must be closed, to prevent the passage of the steam which has been admitted through G. The valves G, I, and E must be kept open, and the valve H kept closed, until the piston arrives at the bottom of the cylinder, when it will be necessary to close all the three valves G, I, and E, and to open the valve H, and the same effects must be produced each time the piston arrives at the top and bottom of the cylinder. All this is accomplished by a system of levers, which are exhibited in *fig.* 17. The pivots on which these levers play are represented on the framing of the engine, and the arms of the levers G′, H′, and I′, communicating with the corresponding valves G, H, and I, are represented opposite a bar attached to the rod of the air-pump, called the *plug frame*. This bar carries certain pegs and detents, which act upon the arms of the several levers in such a manner that, on the arrival of the beam at the extremities of its play upwards and downwards, the levers are so struck that the valves are opened and closed at the proper times. It is needless to explain all the details of this arrangement. Let it be sufficient, as an example of all, to explain the method of working the upper steam valve G. When the piston reaches the top of the cylinder, a pin strikes the arm of the lever G′, and throws it upwards: this, by means of the system of levers, pulls the arm of the valve G downwards, by which the upper steam valve is raised out of its seat, and a passage is opened from the steam pipe to the cylinder. The valve is maintained in this state until the piston reaches the bottom of the cylinder, when the arm G′ is pressed downwards, by which the arm G is pressed upwards, and the valve restored to its seat. By similar methods the levers governing the other three valves, H, I, and E, are worked.

The valves used in these engines were of the kind called *spindle valves.* They consisted of a flat circular plate of bell metal, A B, *fig.* 19., with a round spindle passing perpendicularly through its centre, and projecting above and below it. This valve, having a conical form, was fitted very exactly, by grinding into a corresponding circular conical seat, A B C D, *fig.* 20., which forms the passage which it is the office of the valve to open and close. When the valve falls into its seat, it fits the aperture like a plug, so as entirely to stop it. The spindle plays in sockets or holes, one above and the other below the aperture which the valve stops; these holes keep the valve in its proper position, so as to cause it to drop exactly into its place.

*Fig.* 19.

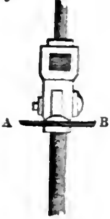
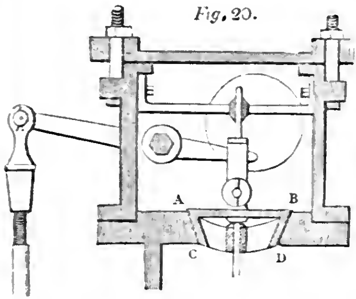



*Fig.* 20.



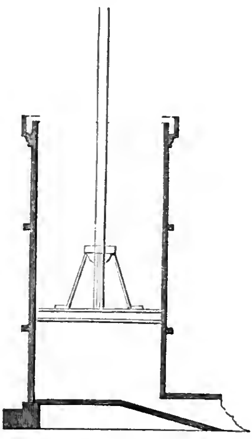

In the experimental engine made by Mr. Watt at Kinneal, he used cocks, and sometimes sliding covers, like the regulator described in the old engines; but these he found very soon to become leaky. He was, therefore, obliged to change them for the spindle valves just described, which, being truly ground, and accurately fitted in the first instance, were not so liable to go out of order. These valves are also called *puppet clacks*, or *button valves.*

In the earlier engines constructed by Watt, the condensation was produced by the contact of cold surfaces, without injection. The reason of rejecting the method of condensing by injection was, doubtless, to avoid the injurious effects of the air, which would always enter the condenser, in combination with the water of condensation, and vitiate the vacuum. It was soon found, however, that a condenser acting by cold surfaces without injection, being necessarily composed of narrow pipes or passages, was liable to incrustation from bad water, by which the conducting power of the material of the condenser was diminished; so that, while its outer surface was kept cold by the water of the cold cistern, the inner surface might, nevertheless, be so warm that a very imperfect condensation would be produced.

Independently of this, however, *surface condensation* as it has been called, in contradistinction to condensation by *injection*, has always been found inefficient, the vacuum not being produced with sufficient promptitude, so that the piston continues to be resisted by the uncondensed steam during a part of the stroke.

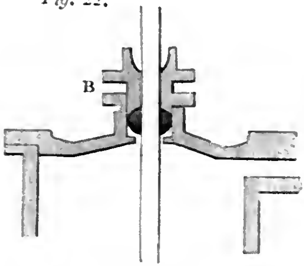
(50.) *Construction of piston.*—The necessity of constructing the piston and cylinder with greater precision than had been usual in the old engines was a consequence of these improvements. To fit the cover to the cylinder so as to be steam-tight; to construct the piston rod so as to move through it without allowing the escape of steam, and yet at the same time without injurious friction; to connect the piston rod with the piston, so as to drive the latter through the cylinder with a perfectly straight and parallel motion; to make such connection perfectly centrical and firm, and yet to allow the piston in its ascent to come nearly into contact with the cover of the cylinder — were all difficulties peculiar to the new engine. In the atmospheric engine the shank of the piston rod was rough and square, and the rod was secured to the piston by branches or stays, as represented in *fig.* 21. It is evident that such a construction would be inadmissible in an engine in which the piston in its ascent must be brought nearly into contact with the close cover of the cylinder. Besides this the piston rod of an atmospheric engine might throughout its whole length have any form which was most convenient, and required no other property than the strength necessary to work the beam. In the new engine, on the contrary, it

*Fig.* 21.



was necessary that it should be accurately turned and finely polished, so as to pass through the hole in the top of the cylinder, and be maintained in it steam-tight. This was effected by a contrivance called a *stuffing box* B, represented in *fig.* 22. A hole is made in the cover of the cylinder very little greater in magnitude than the diameter of the piston rod. Above this hole is a cup in which, around the piston, is placed a stuffing of hemp or tow, which is saturated with oil or melted tallow. This collar of hemp is pressed down by another piece, also perforated with a hole through which the piston rod plays, and which is screwed down on the said collar of hemp.

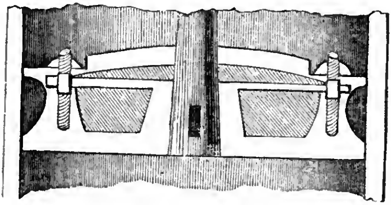
*Fig.* 22.




Although the imperfect manner in which the interior of the cylinders was then formed impaired the efficiency of the new engines, yet such imperfections were not so injurious as in the old atmospheric engines. Any imperfection of form of the inner surface of the cylinder would necessarily cause more or less steam or air to escape between the piston and cylinder. In the improved engine this steam passing into the vacuum below the piston would rush into the condenser, and be there condensed, so that its effect in resisting the motion of the piston would necessarily be trifling. But, on the other hand, any escape of air between the piston and cylinder of an atmospheric engine would introduce an elastic fluid under the piston, which would injuriously affect the action of the machine.

To make the pistons move sufficiently steam-tight in these early imperfect cylinders, Watt contrived a packing formed of a collar of hemp, or tow, as represented in *fig.* 23. The bottom of the piston was formed of a circular plate of a diameter nearly, but not altogether, equal to the interior diameter of the cylinder. The part of the piston above this was considerably less in diameter, so that the piston was surrounded by a circular groove or channel two inches wide, into which hemp or soft rope, called *gasket*, was run, so as to form the packing. The top of the piston was placed over

*Fig.* 23.



this, having a rim or projecting part, which entered the circular groove and pressed upon the packing, the cover being pressed downwards by screws passing through the piston. The lower part of the groove round the piston was rounded with a curve, so that the pressure on the packing might force the latter against the inner surface of the cylinder. This packing was kept supplied with melted tallow, as already described, from the funnel, screwed into the top of the cylinder. The metallic edges of the piston were by this means prevented from coming into contact with the surface of the cylinder, which was only pressed upon by the stuffing or packing projecting beyond these.

Improved methods of boring soon, however, relieved the engine from a part of these imperfections.

(51.) *Construction of cylinder and piston rod.* — When the inner surface of the cylinder is perfectly true and smooth, the packing of the piston is soon rendered solid and hard, being moulded to the cylinder by working, so as to fit it exactly. When by wear it became loose, it was only necessary to tighten the screws by which the top and bottom of the piston were held together. The packing being compressed by those means, was forced outwards towards the surface of the cylinder so as to be rendered steam-tight.

(52.) *Great economy of these engines.* — It was not until about the year 1778, nine years after the date of the patent, and thirteen after the invention of separate condensation, that any impression was produced on the mining interests by the advantages which were presented to them by these vast improvements. This long interval, however, had not elapsed without considerable advantage; for although all the great leading principles of the contrivance were invented so early as the year 1765, yet the details of construction had been in a state of progressive and continued improvement from the time Watt joined Dr. Roebuck, in 1769, to the period now adverted to.

The advantages which the engine offered in the form in which it has been just described, were numerous and important, as compared even with the most improved form of the atmospheric engine; and it should be remembered, that that machine had also gone on progressively improving, and was probably indebted for some of its ameliorations to hints derived from the labours of Watt, and to the adoption of such of his expedients as were applicable to that imperfect machine, and could be adopted without an infraction of his patent.

In the most improved forms to which the atmospheric engine had then attained, the quantity of steam wasted at each stroke of the piston was equal to the contents of the cylinder. Such engines, therefore, consumed twice the fuel which would be requisite, if all sources of waste could have been removed. In Watt's engines, the steam consumed at each stroke of the piston amounted only to $1\frac{1}{4}$ times the contents of the cylinder. The waste steam, therefore, per stroke, was only a quarter of what was usefully employed. The absolute waste, therefore, of the best atmospheric engines was four times that of the improved engine, and consequently the saving of fuel in the improved engines amounted to about three eighths of all the fuel consumed in atmospheric engines of the same power.

But independently of this saving of steam, the power of Watt's engine, as compared with the atmospheric engine, was so much augmented that the former would work against a resistance of ten pounds on the square inch under the same circumstances in which the latter would not move against more than seven pounds. The cause of this augmentation of power is easily explained. In the atmospheric engine the temperature of the condensed steam could not be reduced below 152° without incurring a greater loss than would be compensated by the advantage to be obtained from any higher degree of condensation. Now steam raised from water at 152° has a pressure of nearly four pounds per square inch. This pressure, therefore, acted below the piston resisting the atmospheric pressure above. In Watt's engine, however, the condenser was kept at a temperature of about 100°, at which temperature steam has a pressure of less than one pound per square inch. A resisting force upon the piston of three pounds per square inch was therefore saved in Watt's engine as compared with the atmospheric engine.

Besides these direct sources of economy, there were other advantages incidental to Watt's engine. An atmospheric engine possessed very limited power of adaptation to a varying load. The moving power being the atmospheric pressure, was not under control, and, on the other hand, was subject to variations from day to day, and from hour to hour, according to the changes of the barometer. In the first construction of such an engine, therefore, its power being necessarily adapted to the greatest load which it would have to move, whenever the load upon its pumps was diminished, the motion of the piston in descending would be rapidly accelerated in consequence of the moving power exceeding the resistance. By this the machinery would be subject to sudden shocks, productive of rapid wear and danger of fracture. To remedy this inconvenience, the following expedient was provided in the atmospheric engine: whenever the load on the engine was materially diminished, the quantity of water admitted through the injection valve to condense the steam was proportionally diminished. An imperfect condensation being therefore produced, vapour remained in the cylinder under the piston, the pressure of which resisted the atmosphere, and mitigated the force of the machine. Besides this, a cock was provided in the bottom of the cylinder, called an *air cock,* by which atmospheric air could be admitted to resist the piston whenever the motion was too rapid.

These expedients, however, were all attended with a waste of fuel in relation to the work done by the engine; for it is evident that the consumption of steam was necessarily the same, whether the engine was working against its full load, or against a reduced resistance.

(53.) *Throttle valve.*—On the other hand, in the improved engine of Watt, when the load was diminished, a cock or valve was provided in the steam pipe leading from the boiler, which was called a *throttle valve*, by adjusting which the passage in that pipe could be more or less contracted. By regulating this cock the supply of steam from the boiler was checked, and the quantity transmitted to the cylinder diminished, so that its effect upon the piston might be rendered equal to the amount of the diminished resistance. By this means the quantity of steam transmitted to the cylinder was rendered exactly proportional to the work which the engine had to perform. If, under such circumstances, the boiler was worked to its full power, so as to produce steam as fast as it would when the engine was working at full power, then no saving of fuel would be effected, since the surplus steam produced in the boiler would necessarily escape at the safety valve. But in such case the fireman was directed to limit the fuel of the furnace until the discharge at the safety valve ceased.

By these expedients, the actual consumption of fuel in one of these improved engines was always in the exact proportion of the work which it performed, whether it worked at full power, or at any degree under its regular power.

(54.) *Difficulty of getting the improved engines into use.*— Notwithstanding these and other advantages attending the new engines, Boulton and Watt experienced difficulties all but insurmountable in getting them into use. No manufactory existed in the country possessing machinery capable of executing with the necessary precision the valves and other parts which required exact execution, and the patentees were compelled to construct machinery at Soho for this purpose; and even after they succeeded in getting the cylinders properly bored, the piston rods exactly turned and polished, the spindle valves constructed so as to be steam-tight, and every other arrangement completed which was necessary for the efficiency of the machine, the novelty of the engine, and the difficulty which was supposed to attend its maintenance in good working order, formed strong objections to its adoption.

To remove such objections, great sacrifices were necessary on the part of Boulton and Watt; and they accordingly resolved to undertake the construction of the new engines without any direct profit, giving them to the parties requiring their use at first cost, on the condition of being remunerated by a small share of what they would save in fuel.

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## CHAPTER IV.

### INVENTION OF THE EXPANSIVE ENGINE.

(55.) *First application of expansion.* — At the time that Watt, in conjunction with Dr. Roebuck, obtained the patent for his improved engine, the idea occurred to him, that the steam which had impelled the piston in its descent rushed from the cylinder with a mechanical force much more than sufficient to overcome any resistance which it had to encounter in its passage to the condenser; and that such force might be rendered available as a moving power, in addition to that already obtained from the steam during the stroke of the piston. This notion involved the whole principle of the expansive action of the steam, which subsequently proved to be of such importance in the performance of steam engines. Watt was, however, so much engrossed at that time, and, subsequently, by the difficulties he had to encounter in the construction of his engines, that he did not attempt to bring this principle into operation. It was not until after he had organised that part of the establishment at Soho which was appropriated to the manufacture of steam engines, that he proceeded to apply the expansive principle.

In 1776 the engine, which had been then recently erected at Soho, was adapted to act upon the principle of expansion. When the piston had been pressed down in the cylinder for a certain portion of the stroke, the further supply of steam from the boiler was cut off, by closing the upper steam valve, and the remainder of the stroke was accomplished by the expansive power of the steam which had already been introduced into the cylinder.

(56.) *Principle of expansion explained.* — To make this method of applying the force of steam intelligible, some previous explanation of mechanical principles will be neeessary.

If a body which offers a certain resistance be urged by a certain moving force, the motion which it will receive will depend on the relation between the energy of the moving force and the amount of the resistance opposed to it. If the moving force be precisely equal to the resistance, the motion which the body will receive will be perfectly uniform.

If the energy of the moving foree be greater than the resistance, then its surplus or excess above the amount of resistance will be expended in imparting momentum to the mass of the body moved, and the latter will, consequently, continually acquire augmented speed. The motion of the body will, therefore, be in this case accelerated.

If the energy of the moving force be less in amount than the resistance, then all that portion of the resistance which exeeeds the amount of the moving force will be expended in depriving the mass of the body of momentum, and the body will therefore be moved with continually diminished speed until it be brought to rest.

Whenever, therefore, a uniform motion is produced in a body, it may be taken as an indication of the equality of the moving force to the resistance; and, on the other hand, according as the speed of the body is augmented or diminished, it may be inferred that the energy of the moving force has been greater or less than the resistance.

It is an error to suppose that rest is the only condition possible for a body to assume when under the operation of two or more mechanical forces which are in equilibrium. By the laws of motion the state of a body which is not under the operation of any external force must be either a state of rest or of uniform motion. Whichever be its state, it will suffer no change if the body be brought under the operation of two or more forces which are in equilibrium; for to suppose such forces to produce any change in the state of the body, whether from rest to motion, or *vice versâ*, or in the velocity of the motion which the body may have previously had, would be equivalent to a supposition that the forces applied to the body being in equilibrium were capable of producing a dynamical effect, which would be a contradiction in terms. This, though not always clearly understood by mere practical men, or by persons superficially informed, is, in fact, among the fundamental principles of mechanical science.*

When the piston is at the top of the cylinder, and about to commence its motion downwards, the steam acting upon it will have not only to overcome the resistance arising from the friction of the various parts of the engine, but will also have to put in motion the whole mass of matter of the piston pump rods, pump pistons, and the column of water in the pump barrels. Besides imparting to this mass the momentum corresponding to the velocity with which it will be moved, it will also have to encounter the resistance due to the preponderance of the weight of the water and pump rods over that of the steam piston. The pressure of steam, therefore, upon the piston at the commencement of the stroke must, in accordance with the mechanical principles just explained, have a greater force than is equal to all the resistances which it would have to overcome, supposing the mass to be moving at a uniform velocity. The moving force, therefore, being greater than the resistance, the mass, when put in motion, will necessarily move with a gradually augmented speed, and the piston of the engine which has been described in the last chapter would necessarily move from the top to the bottom of the cylinder with an accelerated motion, having at the moment of its arrival at the bottom a greater velocity than at any other part of the stroke. As the piston and all the matter which it has put in motion must at this point come to rest, the momentum of the moving mass must necessarily expend itself on some part of the machinery, and would be so much mechanical force lost. It is evident, therefore, independently of any consideration of the expansive principle, to which we shall presently refer, that the action of the moving power in the descent of the piston ought to be suspended before the arrival of the piston at the bottom of the

* Handbook of Natural Philosophy and Astronomy, First Course, p. 186, *et seq.*

cylinder, in order to allow the momentum of the mass which is in motion to expend itself, and to allow the piston to come gradually to rest at the termination of the stroke.

Thus, if we were to suppose that after the piston had descended through three-fourths of the whole length of the cylinder, and had acquired a certain velocity, the steam above it were suddenly condensed, so as to leave a vacuum both above and below it, the piston, being then subject to no impelling force, would still move downwards, in virtue of the momentum it had acquired, until the resistance would deprive it of that momentum, and bring it to rest; and if the remaining fourth part of the cylinder were necessary for the accomplishment of this, then it is evident that that part of the stroke would be accomplished without further expenditure of the moving power.

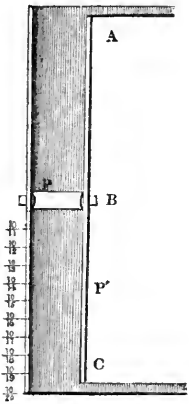
In fact, this part of the stroke would be made by the expenditure of that excess of moving power, which, at the commencement of the stroke, had been employed in putting the machinery and its load in motion, and in subsequently accelerating that motion.

Although under such circumstances the resistance, during the operation of the moving power, shall not have been at any time equal to the moving power, since while the motion was accelerated it was less, and while retarded greater than that power, yet as the whole moving power has been expended upon the resistance, the mechanical effect which has produced under such circumstances will be equal to the actual amount of that power. If, in an engine of this kind, the steam was not cut off till the conclusion of the stroke, a part of the moving power would be lost upon those fixed points in the machinery which would sustain the shock produced by the instantaneous cessation of motion at the end of the stroke.

Independently, therefore, of any consideration of the expansive principle, it appears that, in an engine of this kind, the steam ought to be cut off before the completion of the stroke.

(57.) *Calculation of the mechanical effect of expanding steam.*—To render the expansive action of steam intelligible, let A B (*fig.* 24.) represent a cylinder whose area we will suppose, for the sake of illustration, to be a square foot, and whose length, A B, shall also be a foot. If steam of a pressure equal to the atmosphere be supplied to this cylinder, it will exert a pressure of about one ton on the piston; and if such steam be uniformly supplied from the boiler, the piston will be moved from A to B with the force of one ton, and that motion will be uniform if the piston be opposed throughout the same space by a resistance equal to a ton. When the piston has arrived at B, let us suppose that the further supply of steam from the boiler is stopped by closing the upper steam valve, and let us also suppose the cylinder to be continued downwards, so that B C shall be equal to A B, and suppose that B C has been previously in communication with the condenser, and is therefore a vacuum. The piston at B will then be urged with a force of one ton downwards, and, as it descends, the steam above it will be diffused through an increased volume, and will consequently acquire a diminished pressure. We shall, for the present, assume that this diminution of pressure follows the law of elastic fluids in general; and that it will be decreased in the same proportion as the volume of the steam is augmented. While the piston, therefore, moves from B downwards, it will be urged by a continually decreasing force. Let us suppose, that by some expedient it is also subject to a continually decreasing resistance, and that this resistance decreases in the same proportion as the force which urges the piston. In that case the motion of the piston would continue uniform. When the piston would arrive at P′, the middle of the second cylinder, then the space occupied by the steam being increased in the proportion of 2 to 3, the pressure on the piston would be diminished in the proportion of 3 to 2, and the pressure at B being one ton, it would be two-thirds of a ton at P′. In like manner, when the piston would arrive at C, the space occupied by the steam being double that which it occupied when

*Fig. 24.*



the piston was at B, the pressure of the steam would be half its pressure at B, and therefore, at the termination of the stroke, the pressure on the piston would be half a ton.

If the space from B to C, through which the steam is here supposed to act expansively, be divided into ten equal parts, the pressure on the piston at the moment of passing each of those divisions would be calculated upon the same principle as in the cases now mentioned. After moving through the first division, the volume of the steam would be increased in the proportion of 10 to 11, and therefore its pressure would be diminished in the proportion of 11 to 10. The pressure, therefore, driving the piston at the end of the first of these ten divisions would be $\frac{10}{11}$ths of a ton. In like manner, its pressure at the second of the divisions would be $\frac{10}{12}$ths of a ton, and the third $\frac{10}{13}$ths of a ton; and so on, as indicated in the figure.

Now if the pressure of the steam through each of these divisions were to continue uniform, and, instead of gradually diminishing, to suffer a sudden change in passing from one division to another, then the mechanical effect produced from B to C would be obtained by taking a mean or average of the several pressures throughout each of the ten divisions. In the present case it has been supposed that the force on the piston at B was 2240 pounds. To obtain the pressure in pounds corresponding to each of the successive divisions, it will therefore only be necessary to multiply 2240 by 10, and to divide it successively by 11, 12, 13, &c. The pressures, therefore, in pounds, at each of the 10 divisions, will be as follows: —

| | |
|---|---|
| 1st - - - - - | 2036·3 |
| 2nd - - - - - | 1866·6 |
| 3rd - - - - - | 1723·1 |
| 4th - - - - - | 1600·0 |
| 5th - - - - - | 1493·3 |
| 6th - - - - - | 1400·0 |
| 7th - - - - - | 1317·6 |
| 8th - - - - - | 1244·4 |
| 9th - - - - - | 1179·0 |
| 10th - - - - - | 1120·0 |

If the mean of these be taken by adding them together and dividing by 10, it will be found to be 1498 pounds. It appears, therefore, that the pressures through each of the ten divisions being supposed to be uniform (which however, strictly, they are not), the mechanical effect of the steam from B to C would be the same as if it acted uniformly throughout that space upon the piston with a force of about 1500 pounds, being rather less than three-fourths of its whole effect from A to B.

But it is evident that this principle will be equally applicable if the second cylinder had any other proportion to the first. Thus it might be twice the length of the first; and, in that case, a further mechanical effect would be obtained from the expansion of the steam.

The more accurate method of calculating the effect of the expansion from B to C would involve more advanced mathematical principles than could properly be introduced here; but the result of such a computation would be, that the actual average effect of the steam from B to C would be equal to a uniform pressure through that space, amounting to 1545 pounds, being greater than the result of the above computation, the difference being due to the expansive action through each of the ten divisions, which was omitted in the above computation.

(58.) *Methods of equalising the varying pressure.*—It is evident that the expansive principle, as here explained, involves the condition of a variation in the intensity of the moving power. Thus, if the steam act with a uniform energy on the piston so long as its supply from the boiler continues, the moment that supply is stopped, by closing the steam valve, the steam contained in the cylinder will fill a gradually increasing volume by the motion of the piston, and therefore will act above the piston with a gradually decreasing energy. If the resistance to the moving power produced by the load, friction, &c. be not subject to a variation corresponding precisely to such variation in the moving power, then the consequence must be that the motion imparted to the load will cease to be uniform. If the energy of the moving power at any part of the stroke be greater than the resistance, the motion produced will be accelerated; if it be less, the motion will be retarded; and if it be at one time greater, and another time less, as will probably happen, then the motion will be alternately accelerated and retarded. This variation in the speed of the body moved will not, however, affect the mechanical effect produced by the power, provided that the momentum imparted to the moving mass be allowed to expend itself at the end of the stroke, so that the piston may be brought to rest as nearly as possible by the resistance of the load, and not by any shock on any fixed points in the machine. This is an object which, consequently, should be aimed at with a view to the economy of power, independently of other considerations connected with the wear and tear of the machinery. So long as the engine is only applied to the operation of pumping water, great regularity of motion is not essential, and, therefore, the variation of speed which appears to be an almost inevitable consequence of any extensive application of the expansive principle, is of little importance.

In the patent which Watt took out for the application, of the expansive principle, he specified several methods of producing a uniform effect upon a uniform resistance, notwithstanding the variation of the energy of the power which necessarily attended the expansion of the steam. This he proposed to accomplish by various mechanical means, some of which had been previously applied to the equalisation of a varying power. One consisted in causing the piston to act on a lever, which should have an arm of variable length, the length increasing in the same proportion as the energy of the moving power diminished. This was an expedient which had been already applied in mechanics for the purpose of equalising a varying power. A well-known example of it is presented in the main-spring and fuzee of a watch. According as the watch goes down, the main-spring becomes relaxed, and its force is diminished; but, at the same time, the chain by which it drives the fuzee acts upon a wheel or circle, having a diameter increased in the same proportion as the energy of the spring is diminished.*

Another expedient consisted in causing the moving power, when acting with greatest energy, to lift a weight which should be allowed to descend again, assisting the piston when the energy of the moving force was diminished.

* Handbook of Natural Philosophy, First Course, p. 244.

Another method consisted in causing the moving force, when acting with greatest energy, to impart momentum to a mass of inert matter, which should be made to restore the same force when the moving power was more enfeebled. We shall not more than allude here to these contrivances proposed by Watt, since their application has never been found advantageous in cases where the expansive principle is used.

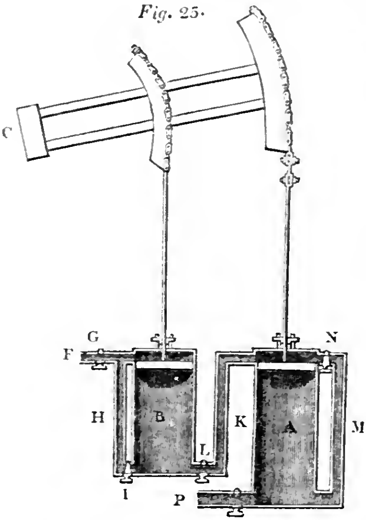
(59.) *Expansion requires high pressure.* — The application of the expansive principle in the engines constructed by Boulton and Watt was always very limited, by reason of their confining themselves to the use of steam having a pressure not much exceeding that of the atmosphere. If the principle of expansion, as above explained, be attentively considered, it will be evident that the extent of its application will mainly depend on the density and pressure of the steam admitted from the boiler. If the density and pressure be not considerable when the steam is cut off, the extent of its subsequent expansion will be proportionally limited. It was in consequence of this, that this principle from which considerable economy of power has been derived, was applied with much less advantage by Mr. Watt than it has since been by others, who have adopted the use of steam of much higher pressure. In the engines of Boulton and Watt, where the expansive principle was applied, the steam was cut off after the piston had performed from one half to two thirds of the stroke, according to the circumstances under which the engine was worked. The decreasing pressure produced by expansion was, in this case, especially with the larger class of engines, little more than would be necessary to allow the momentum of the mass moved to spend itself, before the arrival of the piston at the end of the stroke.

Subsequently, however, boilers producing steam of much higher pressure were applied, and the steam was cut off when the piston had performed a much smaller part of the whole stroke. The great theatre of these experiments and improvements has been the mining districts in Cornwall, where, instead of working with steam of a pressure not much exceeding that of the atmosphere, it has been found advantageous to use steam whose pressure is at least four times as great as that of the atmosphere; and instead of limiting its expansion to the last half or fourth of the stroke, it is cut off after the piston has performed one fourth part of the stroke or less, all the remainder of the stroke being accomplished by the expansive power of the steam, and by momentum.

(60.) *Hornblower's double cylinder.* — One of the methods of equalising the varying force of expanding steam would be to work it at the same time in two cylinders connected with the same beam; so that while its force in one would be augmented, its force in the other would be diminished, the combination of the two producing a uniform effect. Soon after the expansive principle was promulged by Mr. Watt, this expedient was accordingly resorted to by an engineer named Hornblower.

In the year 1781, Hornblower conceived the notion of working an engine with two cylinders of different sizes, by allowing the steam to flow freely from the boiler until it fills the smaller cylinder and then permitting it to expand into the greater one, employing it thus to press down two pistons in the following manner.

*Fig.* 25.



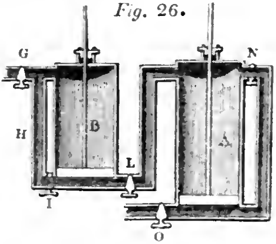

Let C, *fig.* 25., be the centre of the great working-beam, carrying two arch heads, on which the chains of the piston rods play. The distances of these arch heads from the centre C must be in the same proportion as the length of the cylinders, in order that the same play of the beam may correspond to the play of both pistons. Let F be the steam-pipe from the boiler, and G a valve to admit the steam above the lesser piston. H is a tube by which a communication may be opened by the valve I, between the top and bottom of the lesser cylinder B. K is a tube communicating by the valve L, between the bottom of the lesser cylinder B and the top of the greater cylinder A. M is a tube communicating, by the valve N, between the top and bottom of the greater cylinder A; and P a tube leading to the condenser by the exhausting valve O.

At the commencement of the operation, suppose all the valves opened, and steam allowed to flow through the engine until the air be completely expelled, and then let all the valves be closed. To start the engine, let the exhausting valve O and the steam valves G and L be opened, as in *fig.* 25. The steam will flow freely from the boiler, and press upon the lesser piston, and at the same time the steam below the greater piston will flow into the condenser, leaving a vacuum in the greater cylinder. The valve L being opened, the steam which is under the piston in the lesser cylinder will flow through K, and press on the greater piston, which, having a vacuum beneath it, will consequently descend. At the commencement of the motion, the lesser piston is as much resisted by the steam below it, as it is urged by the steam above it; but after a part of the descent has been effected, the steam below the piston, in the lesser cylinder, passing into the greater, expands into an increased space, and therefore loses part of its elastic force. The steam above the lesser piston retaining its full force by having a free communication with the boiler by the valve G, the lesser piston will be urged by a force equal to the excess of the pressure of this steam above the diminished pressure of the expanded steam below it. As the pistons descend, the steam which is between them is continually increasing in its bulk, and therefore decreasing in its pressure, from whence it follows, that the force which resists the lesser piston is continually decreasing, while that which presses it down remains the same, and therefore the effective force which impels it must be continually increasing.

On the other hand, the force which urges the greater piston is continually decreasing, since there is a vacuum below it, and the steam which presses it is continually expanding into an increased bulk.

Impelled in this way, let us suppose the pistons to have arrived at the bottoms of the cylinders, and let the valves

*Fig.* 26.




G, L, and O, be closed, and the valves I and N opened, as in *fig.* 26. No steam is allowed to flow from the boiler, G being closed, nor any allowed to pass into the condenser, since O is closed, and all communication between the cylinders is stopped by closing L. By opening the valve I, a free communication is made between the top and bottom of the lesser cylinder through the tube H, so that the steam which presses above the lesser piston will exert the same pressure below it, and the piston is in a state of indifference. In the same manner the valve N being open, a free communication is made between the top and bottom of the greater cylinder, and the steam circulates above and below the piston, and leaves it free to rise. A counterpoise attached to the pump-rods, in this case, draws up the piston, as in Watt's single engine; and when they arrive at the top, the valves I and N are closed, and G, L, and O opened, and the next descent of the pistons is produced in the manner already described, and so the process is continued.

The valves are worked by the engine itself, by means similar to some of those already described. By computation, we find the power of this engine to be nearly the same as a similar engine on Watt's expansive principle. It does not, however, appear, that any adequate advantage was gained by this modification of the principle, since no engines of this construction are now made.

(61.) *Woolf's double cylinder.* — The use of two cylinders was revived by Arthur Woolf in 1804, who, in this and the succeeding year, obtained patents for the application of steam raised under a high pressure to double-cylinder engines. The specification of his patent states, that he has proved by experiment that steam raised under a safety valve loaded with any given number of pounds upon the square inch will, if allowed to expand into as many times its bulk as there are pounds of pressure on the square inch, have a pressure equal to that of the atmosphere. Thus, if the safety valve be loaded with four pounds on the square inch, the steam, after expanding into four times its bulk, will have the atmospheric pressure; if it be loaded with 5, 6, or 10 lbs. on the square inch, it will have the atmospheric pressure when it has expanded into 5, 6, or 10 times its bulk, and so on. It was, however, understood in this case, that the vessel into which it was allowed to expand should have the same temperature as the steam before it expands.

It is very unaccountable how a person of Mr. Woolf's experience in the practical application of steam could be led into errors so gross as those involved in the averments of this patent; and it is still more unaccountable how the experiments could have been conducted which led him to conclusions not only incompatible with all the established properties of elastic fluids, but even involving in themselves palpable contradiction and absurdity. If it were admitted that every additional pound avoirdupois which should be placed upon the safety valve would enable steam, by its expansion into a proportionally enlarged space, to attain a pressure equal to the atmosphere, the obvious consequence would be, that a physical relation would subsist between the atmospheric pressure and the pound avoirdupois! It is wonderful that it did not occur to Mr. Woolf, that, granting his principle to be true at any given place, it would necessarily be false at another place, where the barometer would stand at a different height! Thus, if the principle were true at the foot of a mountain, it would be false at the top of it; and if it were true in fair weather, it would be false in foul weather, since these circumstances would be attended by a change in the atmospheric pressure, without making any change in the pound avoirdupois.*

(62.) *Ericsson's double cylinder.* — A patent has lately been obtained by Captain Ericsson, for an improved method of applying the principle of expansion by means of two cylinders of different magnitudes. This engine is now under trial on a large scale, and much advantage is expected from it.†

* It is strange that this absurdity has been repeatedly given, without question or comment, in various encyclopædias, as well as in by far the greater number of treatises expressly on the subject.

† See Lardner's Railway Economy, p. 374.

## CHAPTER V.

### DOUBLE-ACTING ENGINE.

(63.) *General application of steam as a moving power suggested.*—For several years after the extension of Watt's first patent had been obtained from parliament, he was altogether engrossed by the labour of bringing to perfection the application of the steam engine to the drainage of mines, and in surmounting the numerous difficulties which presented themselves to its general adoption, even after its manifold advantages were established and admitted. When, however, these obstacles had been overcome, and the works for the manufacture of engines for pumping water, at Soho, had been organised and brought into active operation, he was relieved from the pressure of these anxieties, and was enabled to turn his attention to the far more extensive and important uses of which he had long been impressed with the conviction that the engine was capable. His sagacious mind enabled him to perceive that the machine he had created was an infant force, which by the fostering influence of his own genius would one day extend a vast power over the arts and manufactures, the commerce and the civilisation of the world. Filled with such aspirations, he addressed his attention, about the year 1779, to the adaptation of the steam engine to move machinery, and thereby to supersede animal power, and the natural agents, wind and water.

The idea that steam was capable of being applied extensively as a prime mover, had prevailed from a very early period; and now that we have seen its powers so extensively brought to bear, it will not be uninteresting to revert to the faint traces by which its agency was sketched in the crude speculations of the early mechanical inventors.

(64.) *Early suggestion of steam navigation by Papin.*—Papin, to whom the credit of discovering the method of producing a vacuum by the condensation of steam is due, was the earliest and most remarkable of those projectors.

With very limited powers of practical application, he was, nevertheless, peculiarly happy in his mechanical conceptions ; and had his experience and opportunities been proportionate to the clear sighted character of his mind, he would doubtless have anticipated some of the most memorable of his successors in the progressive improvement of the steam engine.

In his work already cited, after describing his method of imparting an alternate motion to a piston by the atmospheric pressure acting against a vacuum produced by the condensation of steam, he stated that his invention, besides being applicable to pumping water, could be available for rowing vessels against wind and tide, which he proposed to accomplish in the following manner.

Paddle wheels, such as have since been brought into general use, were to be placed at the sides, and attached to a shaft extending across the vessel. Within the vessel, and under this shaft, he proposed to place several cylinders supplied with pistons, to be worked by the atmospheric pressure. On the piston rods were to be constructed racks furnished with teeth: these teeth were to work in the teeth of wheels or pinions, placed on the shaft of the paddle wheels. These pinions were not to be fixed on the shaft, but to be connected with it by a ratchet; so that when they turned in one direction, they would revolve without causing the shaft to revolve; but when driven in the other direction, the catch of the ratchet wheel would act upon the shaft so as to compel the shaft and paddle wheels to revolve with the motion of the pinion or wheel upon it. By this arrangement, whenever the piston of any cylinder was forced down by the atmospheric pressure, the rack descending would cause the corresponding pinion of the paddle shaft to revolve; and the catch of the ratchet wheel, being thus in operation, would cause the paddle shaft and paddle wheels also to revolve; but whenever the piston would rise, the rack driving the pinion in the opposite direction, the catch of the ratchet wheel would merely fall from tooth to tooth, without driving the paddle shaft.

It is evident that by such an arrangement a single cylinder and piston would give an intermitting motion to the paddle shaft, the motion of the wheel being continued only during the descent of the piston; but if several cylinders were provided, then their motion might be so managed, that when one would be performing its ascending stroke, and therefore giving no motion to the paddle shaft, another should be performing its descending stroke, and therefore driving the paddle shaft. As the interval between the arrival of the piston at the bottom of the cylinder and the commencement of its next descent would have been, in the imperfect machine conceived by Papin, much longer than the time of the descent, it was evident that more than two cylinders would be necessary to insure a constantly acting force on the paddle shaft, and accordingly Papin proposed to use several cylinders.

In addition to this, Papin proposed to construct a boiler having a fireplace surrounded on every side by water, so that the heat might be imparted to the water with such increased rapidity as to enable the piston to make four strokes per minute. These projects were promulged in 1690, but it does not appear that they were ever reduced to experiment.

(65.) *Savery, in 1698, conceived the idea of using steam generally as a prime mover.* — Savery proposed, in his original patent, in 1698, to apply his steam engine as a general prime mover for all sorts of machinery, by causing it to raise water, to make an artificial fall, by which overshot water wheels might be driven. This proposal was not acted on during the lifetime of Savery, but it was at a subsequent period partially carried into effect. Mr. Joshua Rigley erected several steam engines on this principle at Manchester, and other parts of Lancashire, to impel the machinery of some of the earliest manufactories and cotton mills in that district. The engines generally raised the water from sixteen to twenty feet high, from whence it was conveyed to an overshot wheel, to which it gave motion. The same water was repeatedly elevated by the engine, so that no other supply was necessary, save what was sufficient to make good the waste. These engines continued in use for some years, until superseded by improved machines.

(66.) *Jonathan Hulls' project of towing ships* (1736).— In 1736, Jonathan Hulls obtained a patent for a method of towing ships into or out of harbour against wind and tide. This method was little more than a revival of that proposed by Papin in 1690. The motion, however, was to be communicated to the paddle shaft by a rope passing over a pulley fixed on an axis, and was to be maintained during the returning stroke of the piston by the descent of a weight which was elevated during the descending stroke. There is no record, however, of this plan, any more than that of Papin, ever having been reduced to experiment.

(67.) *Early attempts to apply the atmospheric engine as a general mover.*— During the early part of the last century the manufactures of this country had not attained to such an extent as to render the moving power supplied by water insufficient or uncertain to any inconvenient degree; and accordingly mills, and other works in which machinery required to be driven by a moving power, were usually built along the streams of rivers. About the year 1750 the general extension of manufactures, and their establishment in localities where water power was not accessible, called the steam engine into more extensive operation. In the year 1752, Mr. Champion, of Bristol, applied the atmospheric engine to raise water, by which a number of overshot wheels were driven. These were applied to move extensive brass-works in that neighbourhood, and this application was continued for about twenty years, but ultimately given up on account of the expense of fuel and the improved applications of the steam engine.

About this time Smeaton applied himself with great activity and success to the improvement of wind and water mills, and succeeded in augmenting their useful effect in a twofold proportion with the same supply of water. From the year 1750 until the year 1780 he was engaged in the construction of his improved water mills, which he erected in various parts of the country, and which were imitated so extensively that the improvement of such mills became general. In cases where a summer drought suspended the supply of water, horse machinery was provided, either to work the mill, or to throw back the water. These improvements necessarily obstructed for a time the extension of steam power to mill work; but the increase of manufactures soon created a demand for power greatly exceeding what could be supplied by such limited means.

In the manufacture of iron, it is of great importance to keep the furnaces continually blown, so that the heat may never be abated by day or night. In the extensive iron works at Colebrook Dale, several water wheels were used in the different operations of the manufacture of iron, especially in driving the blowers of the iron furnaces. These wheels were usually driven by the water of a river, but in the summer months the supply became so short that it was insufficient to work them all. Steam engines were accordingly erected to return the water for driving these wheels. This application of the engine as an occasional power for the supply of water wheels having been found so effectual, returning engines were soon adopted as the permanent and regular means of supplying water wheels. The first attempt of this kind is recorded to have been made by Mr. Oxley, in 1762, who constructed a machine to draw coals out of a pit at Hartley Colliery, in Northumberland. It was originally intended to turn the machine by a continuous circular motion received from the beam of the engine; but that method not being successful, the engine was applied to raise water for a wheel by which the machine was worked. This engine was continued in use for several years, and though it was at length abandoned, on account of its defective construction, it nevertheless established the practicability of using steam power as a means of driving water wheels.

(68.) *Stewart's project* (1777) *for obtaining a rotatory motion.*— In the year 1777, Mr. John Stewart read a paper before the Royal Society, describing a method for obtaining a continued circular motion for turning all kinds of mills from the reciprocating motion of a steam engine. He proposed to accomplish this by means of two endless chains passing over pulleys, which should be moved upwards and downwards by the motion of the engine, in the manner of a window sash. The joint pins of the links of the two chains worked in teeth at the opposite sides of a cog-wheel, to which they imparted a circular motion, first by one chain, and then by the other, acting alternately on opposite sides of the wheel. One chain impelled it during the descent of the piston, and the other during the ascent; but one of these chains always passed over its pulleys so as to produce no effect on one side of the cog-wheel, whilst the other chain worked on the opposite side to turn it round. For this purpose each chain was provided with a catch, to prevent its sliding over its pulleys in one direction, but to allow it free motion in the other. The cog-wheel thus kept in revolution might be applied to the axis of any mill which the engine was required to work. Thus, if it were applied to a flour mill, the millstone itself would perform the office of a fly-wheel to regulate the intermission of the power, and in other mills a fly-wheel might be added for this purpose.

The hints obtained by Mr. Stewart from Papin's contrivance, before mentioned, will not fail to be perceived. In Mr. Stewart's paper he notices indirectly the method of obtaining a continued circular motion from a reciprocating motion by means of a crank or winch, which, he says, occurs naturally in theory, but in practice would be impossible, from the nature of the motion of the engine. Such an opinion, pronounced by a man of considerable mechanical knowledge and ingenuity, against a contrivance which, as will presently appear, proved in practice, not less than in theory, to be the most effectual means of accomplishing the end here pronounced to be impossible, is sufficiently remarkable. It might cast some doubt on the extent of Mr. Stewart's practical knowledge, if it did not happen to be in accordance with a judgment so generally unimpeachable as that of Mr. Smeaton. This paper of Mr. Stewart's was referred by the council of the Royal Society to Mr. Smeaton, who remarked upon the difficulty arising from the absolute stopping of the whole mass of moving power, whenever the direction of the motion is changed; and observed, that although a fly-wheel might be applied to regulate the motion, it must be such a large one as would not be readily controlled by the engine itself; and he considered that the use of such a fly-wheel would be a greater incumbrance to a mill than a water-wheel to be supplied by water pumped up by the engine. This engineer, illustrious as he was, not only fell into the error of Mr. Stewart in respect of the crank, but committed the further blunder of condemning the very expedient which has since rendered the crank effectual. It will presently appear that the combination of the crank and fly-wheel have been the chief means of establishing the dominion of the steam engine over manufactures.

(69.) *Wasbrough engines* (1779).—In 1779, Mr. Matthew Wasbrough, an engineer at Bristol, took out a patent for the application of a steam engine to produce a continuous circular motion by means of ratchet wheels, similar to those previously used by Mr. Oxley, at Hartley Colliery; to which, however, Mr. Wasbrough added a fly-wheel to maintain and regulate the motion. Several machines were constructed under this patent; and, among others, one was erected at Mr. Taylor's saw-mills and block manufactory at Southampton. In 1780, one was erected at Birmingham, where the ratchet work was found to be subject to such objections, that one of the persons about the works substituted for it the simple crank, which has since been invariably used. A patent was taken out for this application of the crank in the same year, by Mr. James Pickard, of Birmingham. It will presently appear, however, that the suggestions of this application of the crank was derived from the proceedings of Watt, who was at the same time engaged in similar experiments.

(70.) *Defects of Watt's single-acting engine as a general mover.* — The single-acting steam engine, as constructed by Watt, was not adapted to produce continuous uniform motion of rotation, for the following reasons: —

*First.* The effect required was that of an uniformly acting force. The steam engine, on the other hand, supplied an intermitting force. Its operation was continued during the descending motion of the piston, but it was suspended during the ascent of the piston. To produce the continued effect now required, either its principle of operation should be altered, or some expedient should be devised for maintaining the motion of the revolving shaft during the ascent of the piston, and the consequent suspension of the moving power.

*Secondly.* The action of the steam engine was rectilinear. It was a power which acted in a straight line, viz. in the direction of the cylinder. The motion, however, required to be produced, was a circular motion — a motion of rotation around the axis or shaft of a mill.

(71.) *Watt's first attempts to obtain a continuous rotatory motion.* — The steps by which Watt proceeded to accomplish these objects have been recorded by himself as follows, in his notes upon Dr. Robison's article on the steam engine: —

"I had very early turned my mind to the producing of continued motion round an axis; and it will be seen by reference to my first specification in 1769, that I there described a steam wheel, moved by the force of steam, acting in a circular channel against a valve on one side, and against a column of mercury, or some other fluid metal, on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly, but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines, which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet wheels.

"Having made my single reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank, in the manner of the common turning lathe; but as the rotative motion is produced in that machine by impulse given to the crank in the descent of the foot only, it requires to be continued in its ascent by the energy of the wheel, which acts as a fly; being unwilling to load my engine with a fly-wheel heavy enough to continue the motion during the ascent of the piston (or with a fly-wheel heavy enough to equalise the motion, even if a counterweight were employed to act during that ascent), I proposed to employ two engines, acting upon two cranks fixed on the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly-wheel at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and only a very light fly-wheel would be requisite.

"This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 1789, when Mr. Wasbrough erected one of his ratchet wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated by a workman employed to make the model, to some of the people about Mr. Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam engines. This fact the said workman confessed, and the engineer who directed the works acknowledged it; but said, nevertheless, that the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time; which might be a fact, as the application to a single crank was sufficiently obvious.

"In these circumstances, I thought it better to endeavour to accomplish the same end by other means, than to enter into litigation; and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones; amongst which was the method of the sun-and-planet wheels. This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly-wheel; but is perhaps more subject to wear, and to be broken under great strains, than a simple crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered the counterweight unnecessary, and produced a more regular motion."

(72.) *Watt's second patent* (1781).—Watt's second patent here referred to was dated 25th Oct. 1781, and was entitled

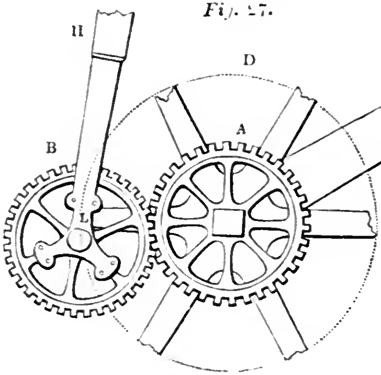
"A patent for certain new methods of applying the vibrating or reciprocating motions of steam or fire engines to produce a continued rotative or circular motion round an axis or centre, and thereby to give motion to the wheels of mills and other machines."

All the methods specified in this patent were intended to be worked by the single-acting engine, already described, a counterweight being applied to impel the machinery during the returning stroke of the engine, which weight would be elevated during the descent of the piston. There were five different expedients proposed in the specification for producing a rotatory motion; but, of these five, two only were ever applied in practice.

(73.) *Methods of producing continuous rotatory motion.— Sun-and-planet wheel.*—Suppose a rod or bar attached by a pin or joint at the upper extremity to the working end of the beam of the engine, and by a similar pin or joint at the lower extremity to an iron wheel fixed on the extremity of the axis of the fly-wheel. One half of this wheel is formed of a solid semicircle of cast iron, while the other half is constructed of open spokes, so as to be as light as is consistent with strength. The position of the wheel on the axis is such that, during the returning stroke of the piston, when the operation of the steam is suspended, the heavy semicircle of the wheel will be descending, and by its weight will draw down the connecting bar, and thereby draw down the working end of the beam, and draw up the piston in the cylinder. When the piston descends and is driven by the power of the steam, the heavy semicircle of the above-mentioned wheel will be drawn upwards, and in the same way the motion will be continued.

The second method of producing a rotatory motion, which was subsequently continued for many years in practical operation, was that which was called the *Sun-and-planet Wheels*. A toothed wheel A (*fig.* 27.), called the sun wheel, was fixed on the axle of the fly-wheel, to which rotation was to be imparted. The wheel B, called the planet wheel, having an equal diameter, was fastened on the end I of the connecting rod H I, so as to be incapable of revolving. During the descent of the piston, the working end of the beam was drawn upwards, and the end I of the connecting rod travelled from C to D, through the dotted semicircle C I D. The wheel B not being capable of revolving on the centre I, would, during

*Fig. 27.*




this motion, drive the sun wheel A. During the ascent of the steam piston, the working end of the beam would descend, and the centre I of the planet wheel B would be driven downwards from D to C, through the other dotted semicircle, and would consequently continue to drive the sun wheel round in the same direction.

This contrivance, although in the main inferior to the more simple one of the crank, is not without some advantages; among others, it gives to the sun wheel double the velocity which would be communicated by the crank; for in the crank one revolution only on the axle is produced by one revolution of the crank, but in the sun-and-planet wheel two revolutions of the sun wheel are produced by one of the planet wheel; thus a double velocity is obtained from the same motion of the beam. This will be evident from considering that when the planet wheel is in its highest position, its lowest tooth is engaged with the highest tooth of the sun wheel; as the planet wheel passes from the highest position, its teeth drive those of the sun wheel before them, and when it comes into the lowest position, the highest tooth of the planet wheel is engaged with the lowest of the sun wheel: but then half of the sun wheel has *rolled off* the planet wheel, and, therefore, the tooth which was engaged with it in its highest position, must now be distant from it by half the circumference of the wheel, and must, therefore, be again in the highest position; so that while the planet wheel has been carried from the top to the bottom, the sun wheel has made a complete revolution.

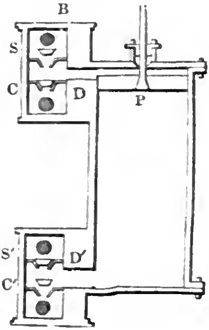
This advantage of giving an increased velocity may be obtained also by the crank, by placing toothed wheels on its axle. Independently of the greater expense attending the construction of the sun-and-planet wheel, its liability to go out of order, and the rapid wear of the teeth, and other objections, rendered it inferior to the crank, which has entirely superseded it.

(74.) *Invention of double-acting piston.*—Although by these contrivances Watt succeeded in obtaining a continuous circular motion from the reciprocating motion of the steam engine, the machine was still one of intermitting, instead of continuous, action. The expedient of a counterweight, elevated during the descending stroke, and giving back the power expended on it in the interval of the returning stroke, did not satisfy the fastidious mechanical taste of Watt. He soon perceived that all which he first proposed to accomplish by the application of two cylinders and pistons working alternately, could be attained with greater simplicity and effect by a single cylinder, if he could devise means by which the piston might be impelled by steam upwards as well as downwards. To accomplish this, it was only necessary to throw each end of the cylinder into alternate communication with the boiler and condenser. If, for example, during the descent of the piston, the upper end of the cylinder communicated with the boiler, and the lower end with the condenser; and, on the other hand, during the ascent of the piston, the lower end communicated with the boiler, and the upper end with the condenser, then the piston would be driven continually, whether upwards or downwards, by the power of steam acting against a vacuum. Watt obtained his third patent for this contrivance, on the 12th of March, 1782.

This change in the principle of the machine involved several other changes in the details of its mechanism.

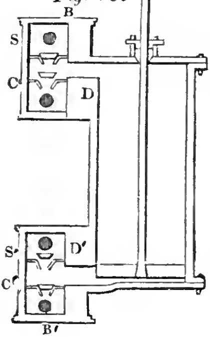
(75.) *Valves for regulating the admission of steam to the cylinder.* — It was necessary, in the first place, to provide means for admitting and withdrawing the steam at either end of the cylinder. For this purpose let B and B′ (*fig.* 28.) be two steam boxes, B the upper, and B′ the lower, communicating respectively with the top and bottom of the cylinder by proper passages D D′. Let two valves be placed in B, one, S, above the passage D, and the other, C, below it; and in like manner two other valves in the lower valve box B′, one, S′, above the passage D′, and the other, C′, below it. Above the valve S in the upper steam box is an opening at which the steam pipe from the boiler enters, and below the valve C is another opening, at which enters the exhausting pipe leading to the condenser. In like manner, above the valve S′ in the lower steam box enters a steam pipe leading from the boiler, and below the valve C′ enters an exhausting pipe leading to the condenser. It is evident, therefore, that steam can always be admitted above the piston by opening the valve S, and below it by opening the valve S′; and, in like manner, steam can be withdrawn from the cylinder above the piston, and allowed to pass to the condenser by opening the valve C, and from below it by opening the valve C′.

*Fig.* 28.




Supposing the piston P to be at the top of the cylinder, and the cylinder below the piston to be filled with pure steam, let the valves S and C′ be opened, the valves C and S′ being closed, as represented in *fig.* 28. Steam from the boiler will, therefore, flow in through the open valve S, and will press the piston downwards, while the steam that has filled the cylinder below the piston will pass through the open valve C′ into the exhausting pipe leading to the condenser, and being condensed will leave the cylinder below the piston a vacuum. The piston will, therefore, be pressed downwards by the action of the steam above it, as in the single-acting engine. Having arrived at the bottom of the cylinder, let the valves S and C′ be both closed, and the valves S′ and C be opened, as represented in *fig.* 29. Steam will now be admitted through the open valve S′ and through the passage D′ below the piston, while the steam which has just driven the piston downwards, filling the cylinder above the piston, will be drawn off through the open valve C, and the exhausting pipe, into the condenser, leaving the cylinder above the piston, a vacuum. The piston will, therefore, be pressed upwards by the action of the steam below it, against the vacuum above it, and will ascend with the same force as that with which it had descended.

*Fig.* 29.




This alternate action of the piston upwards and downwards may evidently be continued by opening and closing the valves alternately in pairs. Whenever the piston is at the top of the cylinder, as represented in *fig.* 28., the valves S and C′, that is, the upper steam valve and the lower exhausting valve, are opened; and the valves C and S′, that is, the upper exhausting valve and the lower steam valve, are closed; and when the piston has arrived at the bottom of the cylinder, as represented in *fig.* 29., the valves C and S′, that is, the upper exhausting valve and the lower steam valve, are opened, and the valves S and C′, that is, the upper steam valve and the lower exhausting valve, are closed.

If these valves, as has been here supposed, be opened and closed at the moments at which the piston reaches the top and bottom of the cylinder, it is evident that they may be all worked by a single lever connected with them by proper mechanism. When the piston arrives at the top of the cylinder, this lever would be made to open the valves S and C′, and at the same time to close the valves S′ and C; and when it arrives at the bottom of the cylinder, it would be made to close the valves S and C′, and to open the valves S′ and C.

If, however, it be desired to cut off the steam before the arrival of the piston at the termination of its stroke, whether upwards or downwards, then the steam valves must be closed before the arrival of the piston at the end of its stroke; and as the exhausting valve ought to be left open until the stroke is completed, these valves ought to be moved at different times. In that case separate levers should be provided for the different valves. We shall, however, return again to the subject of the valves which regulate the admission of steam to the cylinder and its escape to the condenser.

(76.) *Modification of the condensing jet.* — It will be remembered that in the single-acting engine the process of condensation was suspended while the piston ascended in the cylinder, and therefore the play of the jet of cold water in the condenser was stopped during this interval. In the double-acting engine, however, the flow of steam from the cylinder to the condenser is continued, whether the piston ascends or descends, and therefore a constant condensation of steam must be produced. The condensing jet, therefore, does not in this case, as in the former, play with intervals of intermission. A constant jet of cold water must be maintained in the condenser.

It will presently appear that in the double-acting engine applied to manufactures, the motion of the piston was subject to more or less variation of speed, and the quantity of steam admitted to the cylinder was subject to a corresponding change. The quantity of steam, therefore, drawn into the condenser was subject to variation, and required a considerable change in the quantity of cold water admitted through the jet to condense it. To regulate this, the valve or cock by which the water was admitted into the condenser was worked in the double-acting engine by a lever furnished with an index, by which the quantity of condensing water admitted into the condenser could be regnlated. This index played upon a graduated arch, by which the engine-man was enabled to regulate the supply.

(77.) *Invention of parallel motion.* — In the single-acting engine, the force of the piston acted on the beam only during its descent; and this force was transmitted from the piston to the beam, as we have seen, by a flexible chain, extending from the end of the piston rod, and playing upon the arch head of the beam. In the double-acting engine, however, the force of the steam pressing the piston upwards must likewise be transmitted to the beam, so as to drive the latter upwards while the piston ascends. This action could not be accomplished by a chain connecting the piston with the arch head of the beam.

Where the mechanical action to be transmitted is a *pull*, and not a *push*, a flexible chain, cord, or strap, is sufficient; but if a *push* or *thrust* is required to be transmitted, then the flexibility of the medium of mechanical communication afforded by a chain renders it inapplicable. In the double-acting engine, during the descent, the piston rod still pulls the beam down; and so far a chain connecting the piston rod with the beam would be sufficient to transmit the action of the one to the other; but in the ascent, the beam no longer pulls up the piston rod, but is pushed up by it. A chain from the piston rod to the arch head, as described in the single-acting engine, would fail to transmit this force. If such a chain were used with the double engine, where there is no counterweight on the opposite end of the beam, the consequence would be, that in the ascent of the piston the chain would slacken, and the beam would still remain depressed. It is therefore necessary that some other mechanical connection be contrived between the piston rod and the beam, of such a nature that in the *descent* the piston rod may *pull* the beam down, and may *push* it up in the *ascent*.

Watt first proposed to effect this by attaching to the end of the piston rod a straight rack, faced with teeth, which should work in corresponding teeth raised on the arch head of the beam, as represented in *fig.* 30. If his improved

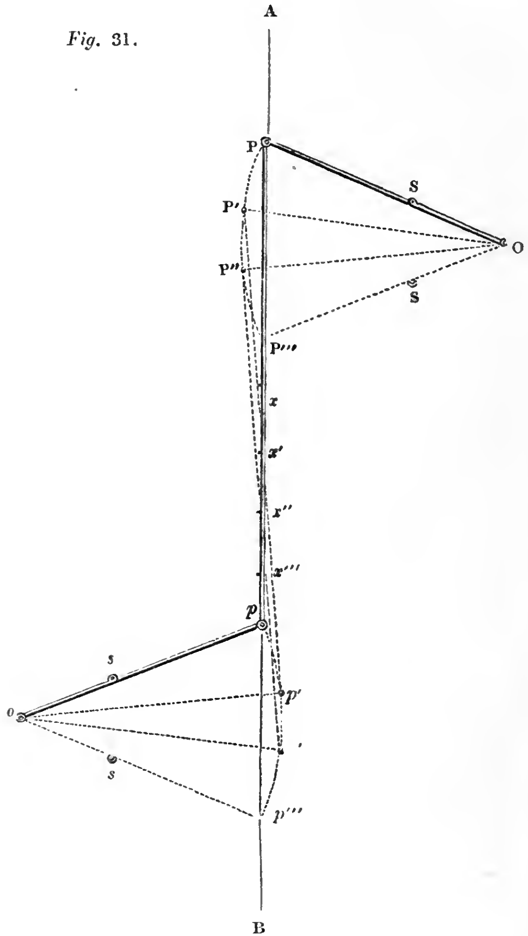
*Fig.* 30.

steam engines required no further precision of operation and construction than the atmospheric engines, this might have been sufficient; but in these engines it was indispensably necessary that the piston rod should be guided with a smooth and even motion through the stuffing box in the top of the cylinder, otherwise any shake or irregularity would cause it to work loose in the stuffing box, and either to admit the air, or to let the steam escape. Under these circumstances, the motion of the rack and toothed arch head were inadmissible, since it was impossible by such means to impart to the piston rod that smooth and equable motion which was requisite. Another contrivance which occurred to Watt was, to attach to the top of the piston rod a bar, which should extend above the beam, and to use two chains or straps, one extending from the top of the bar to the lower end of the arch head, and the other from the bottom of the bar to the upper end of the arch head. By such means the latter strap would pull the beam down when the piston would descend, and the former would pull the beam up when the piston would ascend. These contrivances, however, were superseded by the celebrated mechanism since called the *Parallel Motion*, one of the most ingenious mechanical combinations connected with the history of the steam engine.

(78.) *Explanation of its mechanism.*—It will be observed that the object was to connect by some inflexible means the end of the piston rod with the extremity of the beam, and so to contrive the mechanism, that while the end of the beam would move alternately up and down in part of a circle, the end of the piston rod connected with the beam should move up and down in a straight line. If the end of the piston rod were fastened upon the end of the beam by a pivot without any other connection, it is evident that, being moved up and down in the arc of a circle, it would be drawn to the left and the right alternately, and would consequently either be broken or bent, or would work loose in the stuffing box. Instead of connecting the end of the rod immediately with the end of the beam by a pivot, Watt proposed to connect them by certain moveable rods, so arranged that, as the end of the beam would move up and down in the circular arc, the rods would so accommodate themselves to that motion, that the end connected with the piston rod should not be disturbed from its rectilinear course.

To explain the principle of the mechanism called the parallel motion, let us suppose that O P (*fig.* 31.) is a rod or lever moveable on a centre O, and that the end P of this rod shall move through a circular arc $P\ P'\ P''\ P'''$ in a vertical plane, and let its play be limited by two stops S, which shall prevent its ascent above the point P, and its descent below the point $P'''$. Let the position of the rod and the limitation of its play be such that the straight line A B drawn through P and $P'''$, the extreme positions of the lever O P, shall be a vertical line.

*Fig.* 31.




Let *o* be a point on the other side of the vertical line A B, and let the distance of O to the right of A B be the same as the distance of *o* to the left of A B. Let *o p* be a rod equal in length to O P, moving like O P on the centre *o*, so that its extremity *p* shall play upwards and downwards through the arc $p\ p'\ p''\ p'''$, its play being limited in like manner by stops *s*.

Now, let us suppose that the ends P *p* of these two rods are joined by a link P *p*, the connection being made by a pivot, so that the angles formed by the link and the rods shall be capable of changing their magnitude. This link will make the motion of one rod depend on that of the other, since it will preserve their extremities P *p* always at the same distance from each other. If, therefore, we suppose the rod O P to be moved to the position O P‴, its extremity P tracing the arc P P′ P″ P‴, the link connecting the rods will at the same time drive the extremity *p* of the rod *o p* through the arc $p\ p'\ p''\ p'''$, so that when the extremity of the one rod arrives at P‴, the extremity of the other rod will arrive at $p'''$. By this arrangement, in the simultaneous motion of the rods, whether upwards or downwards, through the circular arcs to which their play is limited, the extremities of the link joining them will deviate from the vertical line A B in opposite directions. At the limits of their play, the extremities of the link will always be in the line A B; but, in all intermediate positions, the lower extremity of the link will be to the right of A B, and its upper extremity to the left of A B. So far as the derangement of the lower extremity of the link is concerned, the matter composing the link would be transferred to the right of A B, and so far as the upper extremity of the link is concerned, the matter composing it would be transferred to the left of A B.

By the combined effects of these contrary derangements of the extremities of the link from the vertical line, it might be expected that a point would exist, in the middle of the link, where the two contrary derangements would neutralise each other, and which point would therefore be expected to be disturbed neither to the right nor to the left, but to be moved upwards and downwards in the vertical line A B. Such is the principle of the parallel motion; and in fact the middle point of the link will move for all practical purposes accurately in the vertical line A B, provided that the angular play of the levers O P and *o p* do not exceed a certain limit, within which, in practice, their motion may always be restrained.

To trace the motion of the middle point of the link more minutely, let P P′ P″ P‴ be four positions of the lever O P, and let *p p′ p″ p‴* be the four corresponding positions of the lever *o p*. In the positions O P, *o p*, the link will take the position P *p*, in which the entire link will be vertical, and its middle point *x* will therefore be in the vertical line A B.

When the one rod takes the position O P′, the other rod will have the position *o p′*; and the link will have the position P′ *p′*. The middle point of the link will be at *x′*, which will be found to be on the vertical line A B. Thus one half of the link P′ *x′* will be to the left of the vertical line A B; while the other half, *p′ x′*, will be to the right of the vertical line; the derangement from the vertical line affecting each half of the link in contrary directions.

Again, taking the one rod in the position O P″, the corresponding position of the other rod will be *o p″*, and the position of the link will be P″ *p″*. If the middle point of the link in this position be taken, it will be found to be at *x″*, on the vertical line A B; and, as before, one half of the link P″ *x″* will be thrown to the left of the vertical line, while the other half *p″ x″* will be thrown to the right of the vertical line.

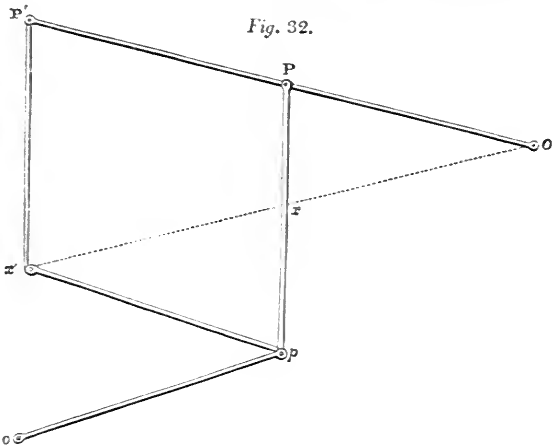
Finally, let the one rod be in its lowest position, O P‴, while the other rod shall take the corresponding position, *o p‴*. The direction of the link P‴ *p‴* will now coincide with the vertical line; and its middle point *x‴* will therefore be upon that line. The previous derangement of the extremities of the rod, to the right and to the left, are now redressed, and all the parts of the rod have assumed the vertical position.

It is plain, therefore, that by such means the alternate motion of a point such as P or *p*, upwards and downwards in a circular arc, may be made to produce the alternate motions of another point *x*, upwards and downwards in a straight line.

(79.) *How it guides the air-pump rod.*—Although the guidance of the air-pump rod in a true vertical line is not so necessary as that of the steam piston, since the air-pump piston is always brought down by its own weight and that of its rod; nevertheless, by a slight addition to the mechanical contrivance which has been just described, Watt obtained the means of at once preserving the true rectilinear motion of both piston rods.

Let the lever represented by O P in *fig.* 31. be conceived to be prolonged to twice its length, as represented in *fig.* 32.,

*Fig.* 32.




so that O P′ shall be twice O P. Let the points P $p$ be connected by a link as before. Let a link P′ $x'$, equal in length to the link P $p$, be attached to the point P′, and let the extremity $x'$ of this link be connected with the point $p$ by another link $x'$ $p$, equal in length to P P′, by pivots at $x'$ and $p$, so that the figure P P′ $x'$ $p$ shall be a jointed parallelogram, the angles of which will be capable of altering their magnitude with every change of position of the rods $o$ $p$ and O P. Thus, when the rod O P descends, the angles of the parallelogram at P and $x'$ will be diminished in magnitude, while the angles at P′ and $p$ will be increased in magnitude. Now, let a line be conceived to be drawn from O to $x'$. It is evident that that line will pass through the middle point of the link $p$ P, for the triangle

O P $x$ is in all respects similar to the greater triangle O P′ $x'$ only on half the scale, so that every side of the one is half the corresponding side of the other. Therefore P $x$ is half the length of P′ $x'$; but P′ $x'$ was made equal to P $p$, and therefore $p$ $x$ is half of P $p$, that is to say, $x$ is the middle point of P $p$.

It has been already shown, that in the alternate motion of the rods $o$ $p$, O P in ascending and descending, the point $x$ is moved upwards and downwards in a true vertical line. Now since the triangle O P $x$ is in all respects similar to O P′ $x'$, and subject to a similar motion during the ascent and descent of the rods, it is apparent that the point $x'$ must be subject to a motion in all respects similar to that which affects the point $x$, except that the point $x'$ will move through double the space. In fact, the principle of the mechanism is precisely similar to that of the common pantograph, where two rods are so connected as that the motion of the one governs the motion of the other, so that whatever line or figure may be described by one, a similar line or figure must be described by the other. Since, then, the point $x$ is moved upwards and downwards in a vertical straight line, the point $x'$ will also be moved in a vertical straight line of double the length.

If such an arrangement of mechanism as has been here described can be connected with the beam of the steam engine, so that while the point $x'$ is attached to the top of the steam piston, and the space through which it ascends and descends shall be equal to the length of the stroke of that piston, the point $x$ shall be attached to the rod of the air-pump piston, the stroke of the latter being half that of the steam piston, then the points $x'$ and $x$ will guide the motion of the two pistons so as to preserve them in true vertical straight lines.

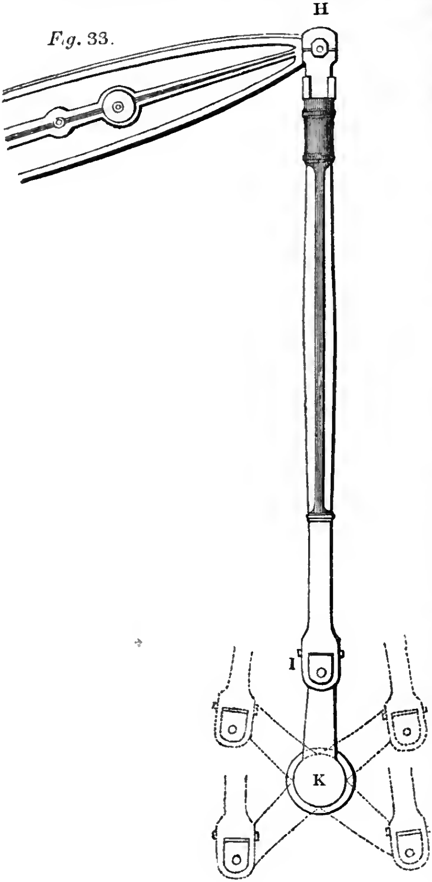
The manner in which these ideas are reduced to practice admits of easy explanation: let the point O be the centre of the great working beam, and let O P′ be the arm of the beam on the side of the steam cylinder. Let P be a pivot upon the beam, at the middle point between its centre O and its extremity P′; and let the links P $p$, P′ $x'$, and P $p$ be jointed together, as already described. Let the point or pivot O be attached to some part of the fixed framing of the engine or engine-house, and let the rod $o\ p$, equal to half the arm of the beam, be attached by a pivot to the corner of the parallelogram at $p$. Let the end of the steam piston rod be attached to the corner of the parallelogram $x'$, and let the end of the air-pump be attached to the middle point $x$ of the link $P\ p$; by which arrangement it is evident that the rectilinear motion of the two piston rods will be rendered compatible with the alternate circular motions of the points $P'$ and $P$ on the beam.

(80.) *Extreme beauty of this mechanism.* — Among the many mechanical inventions produced by the fertile genius of Watt, there is none which has excited such universal, such unqualified, and such merited admiration as that of the parallel motion. It is indeed impossible, even for an eye unaccustomed to view mechanical combinations, to behold the beam of a steam engine moving the pistons, through the instrumentality of the parallel motion, without an instinctive feeling of pleasure at the unexpected fulfilment of an end by means having so little apparent connection with it. When this feeling was expressed to Watt himself, by those who first beheld the performance of this exquisite mechanism, he exclaimed with his usual vivacity, that he himself, when he first beheld his own contrivance in action, was affected by the same sense of pleasure and surprise at its regularity and precision. He said that he received from it the same species of enjoyment that usually accompanies the first view of the successful invention of another person.

"Among the parts composing the steam engine, you have doubtless," says M. Arago, "observed a certain articulated parallelogram. At each ascent and descent of the piston, its angles open and close with the sweetness — I had almost said with the grace — which charms you in the gestures of a consummate actor. Follow with your eye alternately the progress of its successive changes, and you will find them subject to the most curious geometrical conditions. You will see, that of the four angles of the jointed parallelogram, three describe circular arcs, but the fourth, which holds the piston rod, is moved nearly in a straight line. The immense utility of this result strikes mechanicians with even less force than the simplicity of the means by which Watt has attained it."

(81.) *Operation of the crank.* — By the contrivance which has been explained above, the force of the piston in ascending and descending would be conveyed to the working end of the beam; and the next problem which Watt had to solve was, to produce by the force exerted by the working end of the beam in ascending and descending a continuous motion of rotation. In the first instance he proposed to accomplish this by a crank placed upon the axle to which rotation was to be imparted, and driven by a rod connecting it with the working end of the beam. Let K (*fig.* 33.) be the centre, to which motion is to be imparted by the working end H of the beam. On the axle K suppose a short lever K I to be fixed, so that when K I is turned round the centre K, the axle must turn with it. Let

*Fig.* 33.



an iron rod, the weight of which shall balance the piston and piston rod at the other end of the beam, be connected by joints with the working end H of the beam, and the extremity I of the lever K I. As the end H of the beam is moved upwards and downwards, the lever K I will be turned round the centre K, taking successively the positions represented by faint lines in the figure ; and thus a motion of continued rotation will be imparted to the axle K.

This simple and effectual expedient of producing a continued rotatory motion by a crank was abandoned by Watt, as already explained, by reason of a patent having been obtained upon information of his experiments surreptitiously procured. To avoid litigation, he therefore substituted for the crank the sun-and-planet wheel already described ; but at the expiration of the patent, which restricted the use of the crank, the sun-and-planet wheel was discontinued in Watt's engine, and the crank restored.

(82.) *Inconvenience arising from the inequality of its action.*—Whether the crank or the sun-and-planet wheel be used, there is still a difficulty in the maintenance of a regular motion of rotation. In the various positions which the crank and connecting rod assume throughout a complete revolution, there are two in which the moving power loses all influence in impelling the crank. These positions are those which the crank assumes when the piston is at the top and bottom of the cylinder, and is just about to change the direction of its motion. When the piston is at the bottom of the cylinder, the pivot I (*fig.* 33.), by which the connecting rod H I is attached to the end of the crank, is immediately over the axle K of the crank, and under the pivot H, which joins the upper end of the connecting rod with the beam. In fact, in this position the connecting rod and crank are in the same straight line, extending from the end of the beam to the axle of the crank. The steam, on entering the cylinder below the piston, and pressing it upwards, would produce a corresponding downward force on the connecting rod at H, which would be continued along the connecting rod and crank to the axle K. It is evident that such a force could have no tendency to turn the crank round, but would expend its whole energy in pressing the axle K downwards.

The other position in which the power loses its effect upon the crank is when the piston is at the top of the cylinder. In this case, the working end of the beam will be at the lowest point of its play, and the crank pin I will be immediately below the axle K; so that K will be placed immediately between H and I. When the steam presses on the top of the piston, it will expend its force in drawing the end H of the connecting rod upwards, by which the crank pin I will likewise be drawn upwards. It is evident that this force can have no effect in turning the crank round, but will expend its whole energy in producing an upward strain on the axle K.

If the crank were absolutely at rest in either of the positions above described, it is apparent that the engine could not be put in motion by the steam; but if the engine has been previously in motion, then the mass of matter forming the crank, and the axle on which the crank is formed, having already had a motion of rotation, will have a tendency to preserve the momentum it has received, and this tendency will be sufficient to throw the crank K I out of either of those critical positions which have been described. Having once escaped these dead points, then the connecting rod forming an angle, however obtuse or acute, with the crank, the pressure or pull upon the former will have a tendency to produce rotation in the latter. As the crank revolves, however, the influence of the connecting rod upon it will vary according to the angle formed by the connecting rod and crank. When that angle is a right angle, then the effect of the connecting rod on the crank is greatest, since the force upon it has the advantage of the whole leverage of the crank; but according as the angle formed by the crank and connecting rod becomes more or less acute or obtuse in the successive attitudes which they assume in the revolution of the crank, the influence of the connecting rod over the crank varies, changing from nothing at the two dead points already described, to the full effect produced in the two positions where they are at right angles. In consequence of this varying leverage, by which the force with which the connecting rod is driven by the steam is transmitted to the axle on which the crank revolves, a corresponding variation of speed would necessarily be produced in the motion imparted to the crank. The speed at the dead points would be least, being due altogether to the momentum already imparted to the revolving mass of the crank and axle; and it would gradually increase and be greatest at the points where the effect of the crank on the connecting rod is greatest. Although this change of speed would not affect the actual mechanical efficacy of the machine, and although the same quantity of steam would perform the same work at the varying velocity as it would do if the velocity were regulated, yet this variation of speed would be incompatible with the purposes to which it was now proposed that the steam engine should be applied in manufactures. In these a regular uniform motion should be imparted to the main axle.

(83.) *Application of the fly-wheel.* — One of the expedients which Watt proposed for the attainment of this end was, by placing two cranks on the same axle, in different positions, to be worked by different cylinders, so that while one crank should be at its dead points, the other should be in the attitude most favourable for its action. This expedient has since, as we shall see, been carried into effect in steam vessels; but one more simple and efficient presented itself in the use of a *fly-wheel.*

On the main axle driven by the crank Watt placed a large wheel of metal, as represented in *fig.* 39., called a *fly-wheel.* This wheel being well constructed, and nicely balanced on its axle, was subject to very little resistance from friction; any moving force which it would receive it would, therefore, retain, and would be ready to impart such moving force to the main axle whenever that axle ceased to be driven by the power. When the crank, therefore, is in those positions in which the action of the power upon it is most efficient, a portion of the energy of the power is expended in increasing the velocity of the mass of matter composing the fly-wheel. As the crank approaches the dead points, the effect of the moving power upon the axle and upon the crank is gradually enfeebled, and at these points vanishes altogether. The momentum which has been imparted to the fly-wheel then comes into play, and carries forward the axle and crank out of the dead points with a velocity very little less than that which it had when the crank was in the most favourable position for receiving the action of the moving power.

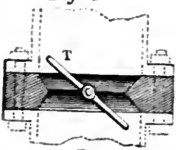
By this expedient, the motion of revolution received by the axle from the steam piston is subject to no other variation than just the amount of change of momentum in the great mass of the fly-wheel, which is sufficient to extricate the crank twice in every revolution from the mechanical dilemma to which its peculiar form exposes it ; and this change of velocity may be reduced to as small an amount as can be requisite by giving the necessary weight and magnitude to the fly-wheel.

(84.) *Method of varying the intensity of the moving power.* —*Throttle valve.* — By such arrangements the motion imparted to the main axle K would be uniform, provided that the moving power of the engine be always proportionate to the load which it drives. But in the general application of the steam engine to manufactures, it was evident that the amount of the resistance to which any given machine would be subject must be liable to variation. If, for example, the engine drive a cotton-mill, it will have to impart motion to all the spinning frames in that mill. The operation of one or more of these may from time to time be suspended, and the moving power would be relieved from a corresponding amount of resistance. If, under such circumstances, the energy of the moving power remained the same, the velocity with which the machines would be driven would be subject to variation, being increased whenever the operation of any portion of the machines usually driven by it is suspended; and, on the other hand, diminished when any increased number of machines are brought into operation. In fine, the speed would vary nearly in the inverse proportion of the load driven, increasing as the load is diminished, and *vice versâ.*

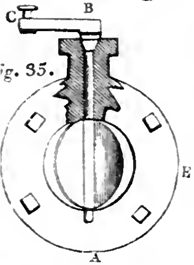
On the other hand, supposing that no change took place in the amount of the load driven by the engine, and that the same number of machines of whatever kind would have to be continually driven, the motion imparted to the main axle would still be subject to variation by the changes inevitable to the moving power. The piston of the engine being subject to an unvaried resistance, a uniform motion could only be imparted to it, by maintaining a corresponding uniformity in the impelling power. This would require a uniform supply f steam from the boiler, which would further imply a uniform ıte of evaporation in the boiler, unless means were provided ı the admission of steam from the boiler to the cylinder to revent any excess of steam which might be produced in the oiler from reaching the cylinder.

This end was attained by a contrivance afterwards called ıe *throttle valve.* An axis A B (*figs.* 34, 35.) was placed across the steam pipe in a ring of cast iron D E, of proper thickness. On this axis was fastened a thin circular plate T, of nearly the same diameter as the steam pipe. On the outer end B of this axle was placed a short lever or handle B C, by which it could be turned. When the circular plate T was turned into such a position as to be at right angles to the length of the tube, it stopped the passage within the tube altogether, so that no steam could pass from the boiler to the engine. On the other hand, when the handle was turned through a fourth of a revolution from this position, then the circular plate T ad its plane in the direction of the length of the tube, so ıat its edge would be presented towards the current of eam flowing from the boiler to the cylinder. In that position the passage within the tube would be necessarily unostructed by the throttle valve. In intermediate positions f the valve, as that represented in *figs.* 34, 35., the passage ıight be left more or less opened, so that steam from ıe boiler might be admitted to the cylinder in any regulated uantity according to the position given to the lever B C.

*Fig.* 34.




ig. 35.




A view of the throttle valve taken by a section across the eam pipe is exhibited in *fig.* 35., and a section of it through ıe axis of the steam pipe is represented in *fig.* 34. The orm of the valve is such, that, if accurately constructed, the eam in passing from the boiler would have no effect by its ressure to alter any position which might be given to the alve; and any slight inaccuracy of form which might give tendency to the steam to alter the position would be easily counteracted by the friction of the valve upon its axle. The latter might be regulated at pleasure.

By this expedient, however the evaporation of water in the boiler might vary within practical limits, the supply of steam to the cylinder would be rendered regular and uniform. If the boiler became too active, and produced more steam than was necessary to move the engine with its load at the requisite speed, then the throttle valve was shifted so as to contract the passage and limit the supply of steam. If, on the other hand, the process of evaporation in the boiler was relaxed, then the throttle valve was placed with its edge more directed towards the steam. Independently of the boiler, if the load on the engine was lightened, then the same supply of steam to the cylinder would unduly accelerate the motion. In this case, likewise, the partial closing of the throttle valve would limit the supply of steam and regulate the motion; and if, on the other hand, the increase of load upon the engine rendered necessary an increased supply of steam, then the opening of the throttle valve would accomplish the purpose. By these means, therefore, a uniform motion might be maintained, provided the vigilance of the engine-man was sufficient for the due management of the lever B C, and provided that the furnace under the boiler was kept in sufficient activity to supply the greatest amount of steam which would be necessary for the maintenance of a uniform motion with the throttle valve fully opened.

(85.) *Contrivance to render the throttle valve self-acting.* —*The governor.*—Watt, however, soon perceived that the proper manipulation of the lever B C would be impracticable with any degree of vigilance and skill which could be obtained from the persons employed to attend the engine. He, therefore, adapted to this purpose a beautiful application of a piece of mechanism, which had been previously used in the regulation of mill-work, and which has since been well known by the name of the *governor*, and has always been deservedly a subject of much admiration.

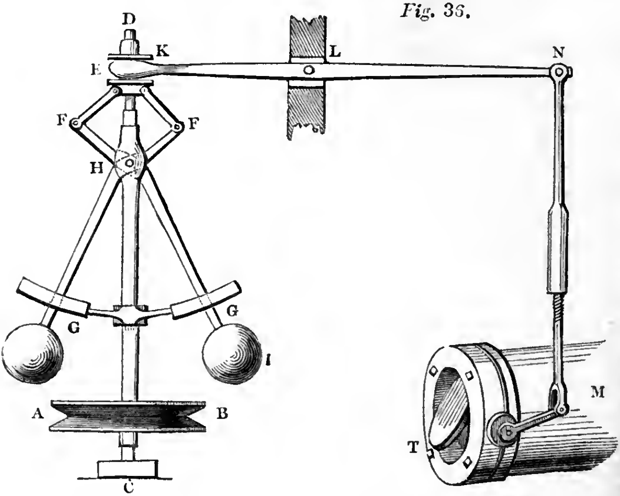
The governor is an apparatus by which the axle of the fly-wheel is made to regulate the throttle valve, so that the moment that the axle begins to increase its velocity, it shifts the position of the throttle valve so as to limit the supply of team from the boiler, and thereby to check the increase of peed. And on the other hand, whenever the velocity of the xle is diminished, the lever B C is moved in the contrary irection, so as to open more fully the passage for the steam, nd accelerate the motion of the engine.

A small grooved wheel A B (*fig.* 36.) is attached to a vertial spindle supported in pivots or sockets C and D, in which it s capable of revolving. An endless cord works in the groove . B, and is carried over proper pulleys to the axle of the flyheel, where it likewise works in a groove. When this cord s properly tightened, the motion of the fly-wheel will give notion to the wheel A B, so that the velocity of the one will e subject to all the changes incidental to the velocity of he other. By this means the speed of the grooved wheel . B may be considered as representing the speed of the flyheel, and of the machinery which the axle of the fly-wheel rives.

It is evident that the same end might be attained by subtituting for the grooved wheel A B a toothed wheel, which night be connected by other toothed wheels, and proper hafts, and axles with the axle of the fly-wheel.

A ring or collar E is placed on the upright spindle, so as o be capable of moving freely upwards and downwards. To his ring are attached by pivots two short levers, E F, the ivots or joints at E allowing these levers to play upon them. At F these levers are joined by pivots to other levers F G, which cross each other at H, where an axle or pin passes hrough them, and attaches them to the upright spindle C D. These intersecting levers are capable, however, of playing on his axle or pin H. To the ends G of these levers are ttached two heavy balls of metal I. The levers F G pass hrough slits in a metallic arc attached to the upright pindle, so as to be capable of revolving upon it. If the balls are drawn outwards from the vertical axis, it is evident that he ends F of the levers will be drawn down, and therefore the ivots E likewise drawn down. In fact, the angles E F H will ecome more acute, and the angle F E F more obtuse. By hese means the sliding ring E will be drawn down. To this liding ring E, and immediately above it, is attached a grooved collar, which slides on the vertical spindle upwards and downwards with the ring E. In the grooved collar are inserted the prongs of a fork K, formed at the end of the lever K L, the

*Fig. 35.*




fulcrum or pivot of the lever being at L. By this arrangement, when the divergence of the balls I causes the collar E to be drawn down, the fork K, whose prongs are inserted in the groove of that collar, is likewise drawn down; and, on the other hand, when by reason of the balls I falling towards the vertical spindle, the collar E is raised, the fork K is likewise raised.

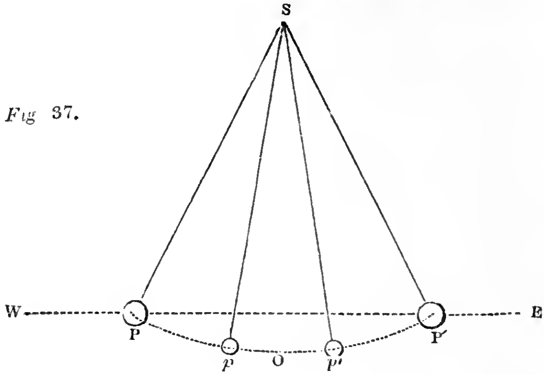
The ascent and descent of the fork K necessarily produce a contrary motion in the other end N of the lever. This end is connected by a rod, or system of rods, with the end M of the short lever which works the throttle valve T. By such means the motion of the balls I, towards or from the vertical spindle, produces in the throttle valve a corresponding motion; and they are so connected that the divergence of the balls I will cause the throttle valve to close, while their descent towards the vertical spindle will cause it to open.

These arrangements being comprehended, let us suppose that, either by reason of a diminished load upon the engine or an increased activity of the boiler, the speed has a tendency to increase. This would impart increased velocity to the grooved wheel A B, which would cause the balls I to revolve with an accelerated speed. The centrifugal force which attends their motion would therefore give them a tendency to move from the axle, or to diverge. This would cause, by the means already explained, the throttle valve T to be partially closed, by which the supply of steam from the boiler to the cylinder would be diminished, and the energy of the moving power, therefore, mitigated. The undue increase of speed would thereby be prevented.

If, on the other hand, either by an increase of the load, or a diminished activity in the boiler, the speed of the machine was lessened, a corresponding diminution of velocity would take place in the grooved wheel A B. This would cause the balls I to revolve with less speed, and the centrifugal force produced by their circular motion would be diminished. This force being thus no longer able fully to counteract their gravity, they would fall towards the spindle, which would cause, as already explained, the throttle valve to be more fully opened. This would produce a more ample supply of steam to the cylinder, by which the velocity of the machine would be restored to its proper amount.

(86.) *Principle of the governor explained.* — The principle which renders the governor so perfect a regulator of the velocity of the machine is difficult to be explained without having recourse to the aid of the technical language of mathematical physics. As, however, this instrument is of such great practical importance, and has attracted such general admiration, it may be worth while here to attempt to render intelligible the mechanical principles which govern its operation. Let S (*fig.* 37.) be the point of suspension of a common pendulum S P, and let P O P′ be the arc of its vibration, so that the ball P shall swing or vibrate alternately to the east and to the west of the lowest point O, through the arcs O P′ and O P. It is a property of such an instrument that, provided the arc in which it vibrates be not considerable in magnitude, the time of its vibration will be the same whether the arc be long or short. Thus, for example, if the pendulum, instead of vibrating in the arc P P′, vibrated in the arc $p$ $p'$, the time which it would take to

*Fig* 37.




perform its vibrations would be the same. If however, the magnitude of the arc of vibration be increased, then a variation will take place in the time of vibration; but unless the arc of vibration be considerably increased, this variation wiil not be great.

Now let it be supposed that while the pendulum P P′ continues to vibrate east and west through the arc P P′, it shall receive such an impulse from north and south as would, if it were not in a state of previous vibration, cause it to vibrate between north and south, in an arc similar to the arc P P′. This second vibration between north and south would not prevent the continuance of the other vibration between east and west; but the ball P would be at the same time affected by both vibrations. While, in virtue of the vibration from east and west, the ball would swing from P to P′, it would, in virtue of the other vibration, extend its motion towards the north to a distance from the line W E equal to half a vibration, and will return from that distance again to the position P′. While returning from P′ to P, its second vibration will carry it towards the south to an equal distance on the southern side of W E, and it will return again to the position P. If the combination of these two motions or vibrations be attentively onsidered, it will be perceived that the effect on the ball ʼill be a circular motion, precisely similar to the circular ıotion of the balls of the governor already described.

Now the time of vibration of the pendulum S P between ast and west will not in any way be affected by the second ibration, which it is supposed to receive between north nd south, and therefore the time the pendulum takes in ıoving from P to P′ and back again from P′ to P will be ıe same whether it shall have simultaneously or not the ther vibration between north and south. Hence it follows hat the time of revolution of the circular pendulum will e equal to the time of similar vibrations of the same pen-ulum, if, instead of having a circular motion, it were allowed ɔ vibrate in the manner of a common pendulum.

If this point be understood, and if it also be remembered hat the time of vibration of a common pendulum is neces-arily the same whether the arc of vibration be small or reat, it will be easily perceived that the revolving pen-ulum or governor will have nearly the same time of re-olution, whether it revolve in a large circle or a small ne; in other words, whether the balls revolve at a greater r a less distance from the central spindle or axis. This, owever, is to be understood only approximately. When he angle of divergence of the balls is as considerable as t usually is in governors, the time of revolution at different istances from the axis will therefore be subject to some ariation, but to a very small one.

The centrifugal force (which is the name given in me-hanics to that influence which makes a body revolving in a ircle fly from the centre) depends conjointly on the velocity f revolution, and on the distance of the revolving body from he centre of the circle.* If the velocity of revolution be the ame, then the centrifugal force will increase in the same roportion as the distance of the revolving body from the entre. If, on the other hand, the distance of the revolving ody from the centre remain the same, the centrifugal force ʼill increase in the same proportion as the square of the time f vibration diminishes, or, in other words, it will increase in he same proportion as the square of the number of revolu-

* Handbook of Nat. Phil. First Series, p. 148.

tions per minute. It follows from this, therefore, that the greater is the divergence of the balls of the governor, and the more rapidly they revolve, the greater will be their centrifugal force. Now this centrifugal force, if it were not counterbalanced, would give the balls a constant tendency to recede from the centre; but from the construction of the apparatus, the further they are removed from the centre the greater will be the effect of their gravitation in resisting the centrifugal force.

It is evident that the ball at P will have a greater tendency to fall by gravitation towards O than it would have at *p*, because the acclivity of the arch descending towards O at P is greater than its acclivity at *p*. The gravitation, therefore, or tendency of the ball to fall towards the central axis being greater at P than at *p*, it will be able to resist a greater centrifugal force. This increased centrifugal force, which the ball would have revolving at the distance P above what it would have at the distance *p*, is produced partly by the greater distance of the ball from the central axis, and partly by the greater velocity of its motion. But it will be evident that the time of its revolution may nevertheless be the same, or nearly the same at both distances. If it should appear that the actual velocity of its motion of revolution at P be greater than its velocity at *p*, in the same proportion as the circles in which they revolve, then it is evident that the time of revolution would be as much increased by the greater space which P will have to travel over, as it will have to be diminished by the greater speed with which that space is traversed. The time of revolution, therefore, may be the same, or nearly the same, in both cases.

If this explanation be comprehended, it will not be difficult to apply it to the actual case of the governor. If a sudden increase of the energy of the moving power, or a diminution of the load, should give the machine an increased velocity, then the increased speed of the balls of the governor will give them an increased centrifugal force, which for the moment will be greater than the tendency of their gravitation to make them fall towards the vertical axis. This centrifugal force, therefore, prevailing, the balls will recede from the axis; but, as they recede, their gravitation towards the vertical axis will, as has been already explained, be increased, and will become equal to the centrifugal force produced by the increased velocity, provided that velocity do not exceed a certain limit. When the balls, by diverging, get such increased gravitation as to balance the centrifugal force, then they will continue to revolve at a fixed distance from the vertical axis. When this happens, the time of the revolution must be nearly the same as it was before their increased divergence; in other words, the proportion of the moving power to the load will be so restored by the action of the levers of the governor on the throttle valve that the machine will move at its former velocity, or nearly so.

The principle on which the governor acts, as just explained, necessarily supposes temporary disarrangements of the speed. In fact, the governor, strictly speaking, does not maintain a uniform velocity, but restores it after it has been disturbed. When a sudden change of motion of the engine takes place, the governor being immediately affected will cause a corresponding alteration in the throttle valve; and this will not merely correct the change of motion, but it will, as it were, overdo it, and will cause a derangement of speed of the opposite kind. Thus if the speed be suddenly increased to an undue amount, then the governor being affected will first close the throttle valve too much, so as to reduce the speed below the proper limit. This second error will again affect the governor in the contrary way, and the speed will again be increased rather too much. In this way a succession of alternations of effect will ensue until the governor settles down into that position in which it will maintain the engine at the proper speed.

To prevent the inconvenience which would attend any excess of such variations, the governor is made to act with great delicacy on the throttle valve, so that even a considerable change in the divergence of the balls shall not produce too much alteration in the opening of that valve. The steam in the boiler should have at least two pounds per square inch pressure more than is generally required in the cylinder; this excess being necessary to afford scope for that extent of variation of the power which it is the duty of the throttle valve to regulate.

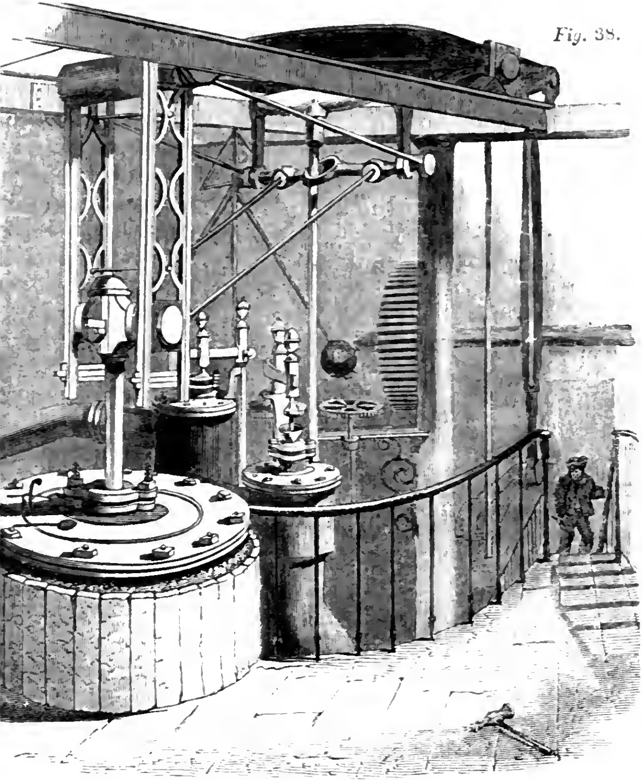
The governor is usually so adjusted as to make thirty-six revolutions per minute, when in uniform motion; but if the motion is increased to the rate of thirty-nine revolutions, the balls will fly to the utmost extent allowed them, being the limitation of the grooves in which their rods move; and if, on the other hand, the speed be diminished to thirty-four revolutions per minute, they will collapse to the lowest extent of their play. The duty of the governor, therefore, is to correct smaller casual derangements of the velocity; but if any permanent change to a considerable extent be made either in the load driven by the machine, or in the moving power supplied to it from the boiler, then a permanent change is necessary to be made in the connection between the governor and the throttle valve, so as to render the governor capable of regulating those smaller changes to which the speed of the machine is liable.

(87.) *Construction and operation of the double-acting engine.* — Having thus explained the principal mechanical contrivances provided by Watt for the maintenance and regulation of the rotatory motion to be produced by his double-acting steam engine, let us now consider the machine as a whole, and investigate the process of its operation. A perspective view of an engine of this kind is represented in *fig.* 38. A section is represented in *fig.* 39.

Steam is supplied from the boiler to the cylinder by the steam pipe S. The throttle valve T in that pipe, near the cylinder, is regulated by a system of levers connected with the governor. The piston P is accurately fitted in the steam cylinder C by packing, as already described in the single-acting engine. This piston, as it moves, divides the cylinder into two compartments, between which there is no communication by which steam or any other elastic fluid can pass. The upper steam box B is divided into three compartments by the two valves. Above the upper steam valve V is a compartment communicating with the steam pipe; below the upper exhausting valve E is another compartment communicating with the eduction pipe which leads to the condenser. By the valves V and E a communication may be opened or closed between the boiler on the one hand, or the condenser on the other, and the top of the cylinder. The continuation

′ of the steam pipe leads to the lower box B′, which, like the pper, is divided into three compartments by two valves V′

Fig. 38.

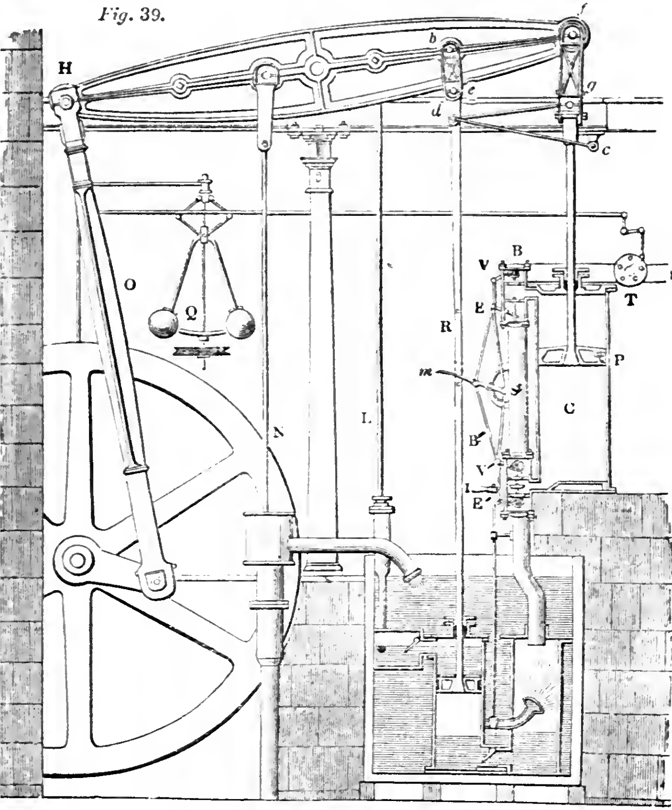


DOUBLE-ACTING ENGINE.—CITY SAW-MILLS.

nd E′. The upper compartment communicates with the team pipe, and thereby with the boiler; and the lower com- artment communicates with the eduction pipe, and thereby vith the condenser. By means of the two valves V′ and E′, communication may be opened or closed between the steam ipe on the one hand, or the exhausting pipe on the other, and the lower part of the cylinder. The four valves V, E, V′, and E′ are connected by a system of levers with a handle or spanner *m*, which, being driven downwards or upwards, is capable of opening or closing the valves in pairs, in the manner already described (§ 75.). The condensers, the air-pump, and the hot-water pump are in all respects similar to those already described in the single-acting engine, except that the condensing jet is governed by a lever I, by which it is allowed to play continually in the condenser, and by which the quantity of water admitted through it is regulated. The cold-water pump N is worked by the engine as already described in the single-acting engine, and supplies the cistern in which the air-pump and condenser are submerged, so as to keep down its temperature to the proper limit. On the air-pump rod R are two pins properly placed, so as to strike the spanner *m*, upwards and downwards, at the proper times, when the piston approaches the termination of the stroke at the top or bottom of the cylinder. The pump L conducts the warm water drawn by the air-pump from the condenser to a proper reservoir for feeding the boiler. The vertical motion of the piston rod in a straight line is rendered compatible with the circular motion of the end of the beam by the parallel motion already described. The point *b*, on the beam, moves upwards and downwards in a circular arc, of which the axis of the beam is the centre. In like manner the point *d* of the rod *d c* moves upwards and downwards, in a similar arc of which the fixed pivot *c* is the centre. The joint or bar *d b*, which joins these two pivots, will be moved so that its middle point *e* will ascend and descend nearly in a straight line, as has been already explained (79.); opposite this point *e* is attached the piston rod of the air-pump, which is accordingly guided upwards and downwards by this means. The jointed parallelogram *b d g f* is attached to the beams by pivots; and, as has been explained, the point *g* will be moved upwards and downwards in a straight line, through twice the space through which the point *e* is moved. To the point *g* the rod of the steam piston is attached. Thus, the rods of the steam piston and air-pump are moved by the same system of jointed bars, and moved through spaces which are in the proportion of two to one.

Although this system of jointed rods forming the parallel motion, appears in the figure to consist only of one parallel-

*Fig.* 39.




ogram *b d g f*, and one rod *c d*, called the *radius rod*, it is, in fact, double, a similar parallelogram and radius rod being attached to corresponding points, and in the same manner on the other side of the beam; but from the view given in the cut, the one set of rods hides the other. The two systems of rods thus attached to opposite sides of the beam at several inches asunder, are connected by cross rods, the ends of which form the pivots or joints, and extend between the parallelograms. The ends of these rods are only visible in the figure. It is to the middle of one of these rods, the end of which is represented at *e*, that the air-pump piston rod is attached; and it is to the middle of another, the end of which is represented at *g*, that the steam piston rod is attached. These two piston rods, therefore, are driven, not immediately by either of the parallelograms forming the parallel motion, but by the bars extending between them.

To the working end of the beam H is attached a rod of cast iron O, called the *connecting rod*, the lower end of which is attached to the crank by a pivot. The weight of the connecting rod is so adjusted, that it shall balance the weight of the piston rods of the air-pump and cylinder on the other side of the beam; and the weight of the piston rod of the cold-water pump N nearly balances the weight of the piston rod of the hot-water pump L. Thus, so far as the weights of the machinery are concerned, the engine is in equilibrium, and the piston would rest in any position indifferently in the cylinder.

The axis of the fly-wheel on which the crank is formed is square in the middle part, where the fly-wheel is attached to it, but has cylindrical necks at each end, which rest in sockets or bearings supported by the framing of the machine, in which sockets the axis revolves freely. On the axle of the crank is placed the fly-wheel, and connected with its axle is the governor Q, which regulates the throttle valve T in the manner already described.

Let us now suppose the engine to be in full operation. The piston being at the top of the cylinder, the spanner *m* will be raised by the lower pin on the air-pump rod, and the upper steam valve V and the lower exhausting valve E′ will be opened, while the upper exhausting valve E and the lower steam valve V′ are closed. Steam will, therefore, be admitted above the piston, and the steam which filled the cylinder below it will be drawn off to the condenser, where it will be converted into water. The piston will, therefore, be urged by the pressure of the steam above it to the bottom of the cylinder. As it approaches that limit, the spanner *m* will be struck downwards by the upper pin on the air-pump rod, and the valves V and E′ will be closed, and at the same time the lower steam valve V′ and the upper exhausting valve E will be opened. Steam will, therefore, be admitted below the piston, while the steam above it will be drawn off into the condenser, and converted into water. The pressure of the steam, therefore, below the piston will urge it upwards, and in the same manner the motion will be continued.

While this process is going on in the cylinder and the condenser, the water formed in the condenser will be gradually drawn off by the operation of the air-pump, in the same manner as explained in the single-acting engine; and at the same time the hot water thrown into the hot well by the air-pump will be carried off by the hot-water pump L.

Such are the chief circumstances attending the continuance of the operation of the double-acting engine. It is only necessary here to recall what has been already explained respecting the operation of the fly-wheel. The commencement of the motion of the piston from the top and bottom of the cylinder is produced, not by the pressure of the steam upon it upwards or downwards, which must, for the reasons already explained, be entirely inefficient; but by the momentum of the fly-wheel, which extricates the crank from those positions in which the moving power cannot affect it.

The manner in which the motion of the crank affects the connecting rod at the dead points produces an effect of great importance in the operation of the engine. When the crank-pin is approaching the lowest point of its play, and therefore the piston approaching the top of the cylinder, the motion of the crank-pin becomes nearly horizontal, and consequently its effect in drawing the connecting rod and the working end of the beam downwards and the piston upwards is extremely small. The consequence of this is, that as the piston approaches the top of the cylinder, its motion becomes very rapidly retarded; and as the motion of the crank-pin at its lowest point is actually horizontal, the piston is brought to a state of rest by this gradually retarded motion at the top of the cylinder. In like manner, when the crank-pin moves from its dead point upwards, its motion at first is very nearly horizontal, and consequently its effect in driving the working end of the beam upwards, and the piston downwards, is at first very small, but gradually accelerated. The effect of this upon the piston is, that it arrives at and departs from the top of the stroke with a very slow motion, being absolutely brought to rest at that point.

The same effect is produced when the piston arrives at the bottom of the cylinder. This retardation and suspension of the motion of the piston at the termination of the stroke affords time for the process of condensation to be effected, so that when the moving power of the steam upon the piston can come into action, the condensation shall be sufficiently complete. As the piston approaches the top of the cylinder, and its motion becomes slow, the working gear is made to open the lower exhausting valve; the steam enclosed in the cylinder below the piston, and which has just driven the piston upwards, presses with an elastic force of 17 lbs. per square inch on every part of the interior of the cylinder, while the uncondensed vapour in the condenser presses with a force of about 2 lbs. per square inch. The steam, therefore, will have a tendency to rush from the cylinder to the condenser through the open exhausting valve, with an excess of pressure amounting to 15 lbs. per square inch, while the piston pauses at the top of the cylinder. This process goes on, and when the piston has descended by the motion of the fly-wheel, a sufficient distance from the top of the cylinder to call the moving force of the steam into action, the exhaustion will be complete, aud the pressure of the uncondensed vapour in the cylinder will become the same as in the condenser.

The pressure of steam in the cylinder, and of uncondensed vapour in the condenser, varies, within certain limits, in different engines, and therefore the amount here assigned to them must be taken merely as an example.

The size of the valves by which the steam is allowed to pass from the cylinder to the condenser should be such as to cause the condensation to take place in a sufficiently short time, to be completed when the steam impelling the piston is called into action.

Watt, in the construction of his engines, made the exhaustion valves with a diameter which was one-fifth of the diameter of the cylinder, and therefore the actual magnitude of the aperture for the escape of the steam was one twenty-fifth of the magnitude of the cylinder; but the spindle of the valve diminished this, so that the available space for the escape of steam did not exceed one twenty-seventh of the magnitude of the cylinder. This was found to produce a sufficiently rapid condensation.

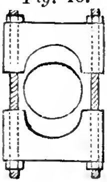
It was usual to make the steam valves of the same magnitude as the exhausting valves, but the flow of steam through the former was resisted by the throttle valve, while no obstruction was opposed to its passage through the latter.

The rapidity with which the cylinder must be exhausted by the condenser will, however, depend upon the velocity with which the piston is moved in it. The magnitude, therefore, of the exhausting valves which would be sufficient for an engine which acts with a slow motion would be too small where a rapid motion is required.

In the single-acting steam engine, where the moving force always acted downwards on the piston, the pressure upon all the joints of the machinery by which the force of the piston was conveyed to the working parts, always took place in the same direction, and consequently, whatever might be the mechanical connection by which the several joints were formed, the pins by which they were connected must always come to a bearing in their respective sockets, however loosely they may have been fitted. For the same reason, however, that the arch head and chain were abandoned as a means of connecting the steam piston with the beam, and the parallel motion substituted, it was also necessary in the double-acting engine, where all joints whatever were driven alternately in opposite directions, to fit the connecting pins with the greatest accuracy in their sockets, and to abandon all connection of the parts by chains. If any sensible looseness was left in the joints, a violent jerk would be produced every time the motion of the piston was reversed. Any looseness either in the pivots or joints of the parallel motion of the working beam, the connecting rod, or crank, would, at every change of stroke, be so accumulated as to produce upon the machinery the effects of percussion, and would consequently be attended with the danger of straining and breaking the moveable parts of the mechanism.

To secure, therefore, the necessary accuracy of the joints, Watt contrived that every joint in the engine should admit of the size of the socket being exactly adapted to the size of the pin, so as always to make a good fitting by closing the socket upon the pin, when any looseness would be produced by wear. With this view, all the joints were fitted with sockets made of brass or gun-metal, capable of adjustment. Each socket was composed of two pieces, accurately fitted into a cell or groove, in which one of the brasses can be moved towards the other by means of a wedge or screw. Each brass has in it a semi-cylindrical cavity, and the two cavities being opposed to each other, form a socket for the joint-pin. One of the two brasses can always be tightened round that pin, so as to enclose it tight between the two semi-cylindrical cavities, and to prevent any looseness taking place. The brasses, and other parts of such a joint, are represented in *fig.* 40. These joints still continue to be used in the engines as now constructed.

*Fig.* 40.



The motion of the working beam, and the pump-rods which it drives, and of the connecting rod, ought, if the whole were constructed with perfect precision, to take place in the same or parallel vertical planes; but this supposes a perfection of execution which could hardly have been expected in the early manufacture of such engines, whatever may have been attained by improvements which have been since made. In the details of construction, Watt saw that there would be a liability to lateral strain, owing to the planes of the different motions not being truly vertical and truly parallel, and that if a provision were not made for such lateral motion, the machinery would be subject to constant strain in its joints and rapid wear. He provided against this by constructing the main joints by which the great working lever was connected with the pistons and connecting rod, so as to form universal joints, giving freedom of motion laterally as well as vertically.

The great lever, or working beam, was so called from being originally made from a beam of oak. It is now, however, universally constructed of cast-iron. The connecting rod is also made of cast-iron, and attached to the beam and to the crank by axles or pivots.

The mechanism by which the four valves are opened and closed, is subject to considerable variation in different engines. They have been described above as being opened and closed simultaneously by a single lever. Sometimes, however, they are opened alternately in pairs by two distinct levers driven by two pins attached to the air-pump rod. One pin strikes the lever, which opens and closes the upper steam valve and lower exhausting valve; the other strikes that which opens and closes the lower steam valve and upper exhausting valve.

Since the date of the earlier double-acting engines, constructed by Boulton and Watt, a great variety of mechanical expedients have been practised for working the valves, by which the steam is admitted to and withdrawn from the cylinder. We shall here describe a few of these methods:—

(88.) *The eccentric.*—The method of working the valves by pins on the air-pump rod driving levers connected with the valves has been, in almost all modern double-acting machines, superseded by an apparatus called an *eccentric*, by which the motion of the axle of the fly-wheel is made to open and close the valves at the proper times.

An eccentric is a metallic circle attached to a revolving axle, so that the centre of the circle shall not coincide with the centre round which the axle revolves. Let us suppose that G (*fig.* 41.) is a square revolving shaft. Let a circular plate of metal B D, having its centre at C, have a square hole cut in it corresponding to the shaft G, and let the shaft G pass through this square aperture, so that the circular plate B D shall be fastened upon the shaft, and capable of revolving with it as the shaft revolves. The centre C of the circular plate B D will be carried round the centre G of the revolving shaft, and will describe round it a circle, the radius of which will be the distance of the centre C of the circular plate from the centre of the shaft. Such circular plate so placed upon a shaft, and revolving with it, is *an eccentric*.

Let E F be a metallic ring, formed of two semicircles of metal screwed together at H, so as to be capable, by the adjustment of the screws, of having the circular aperture formed by the ring enlarged and diminished within certain

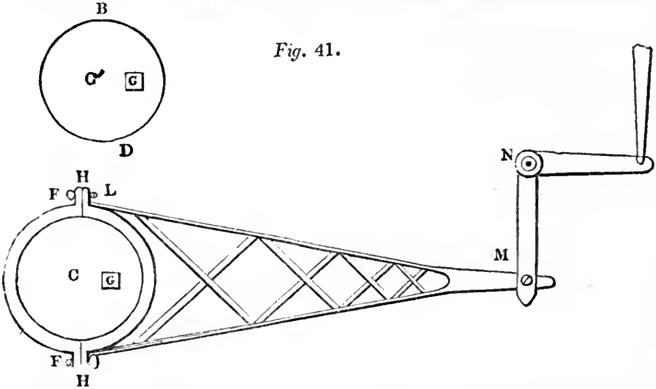



*Fig.* 41.

small limits. Let this circular aperture be supposed to be equal to the magnitude of the eccentric B D. To the circular ring E F let an arm L M be attached. If the ring E F be placed around the eccentric B D, and the screws H be so adjusted as to allow the eccentric B D to revolve within the ring E F, then, while the eccentric revolves, the ring not partaking of its revolution, the arm L M will be alternately driven to the right and to the left, by the motion of the centre C of the eccentric as it revolves round the centre G of the axle. When the centre C of the eccentric is in the same horizontal line with the centre G, and to the left of it, then the position of L M will be that which is represented in *fig.* 41.; but when, after half a revolution of the main axle, the centre C of the eccentric is thrown on the other side of the centre G, then the point M will be transferred to the right, to a distance equal to twice the distance C G. Thus as the eccentric B D revolves within the ring E F, that ring, together with the arm L M, will be alternately driven, right and left, through a space equal to twice the distance between the centre of the eccentric and the centre of the revolving shaft.

If we suppose a notch formed at the extremity of the arm L M, which is capable of embracing a lever N M, movable on a pivot at N, the motion of the eccentric would give to such a lever an alternate motion from right to left, and *vice versa.*

If we suppose another lever N O connected with N M, and at right angles to it, forming what is called a bell-crank, then the alternate motion received by M, from right to left, would give a corresponding motion to the extremity O of the lever N O, upwards and downwards. If this last point O were attached to a vertical arm or shaft, it would impart to such arm or shaft an alternate motion upwards and downwards, the extent of which would be regulated by the length of the levers respectively.

By such a contrivance the revolution of the fly-wheel shaft is made to give an alternate vertical motion of any required extent to a vertical shaft placed near the cylinder, which may be so connected with the valves as to open and close them. Since the upward and downward motion of this vertical shaft is governed by the alternate motion of the centre C to the right and to the left of the centre G, it is evident that by the adjustment of the eccentric upon the fly-wheel shaft, the valves may be opened and closed at any required position of the fly-wheel and crank, and therefore at any required position of the piston in the cylinder.

Such is the contrivance by which the valves, whatever form may be given to them, are now almost universally worked in double-acting steam engines.

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## CHAPTER VI.

### COCKS, VALVES, SLIDES, AND PISTONS.

HAVING described the general structure and operation of the steam engine as improved by Watt, we shall now explain, in a more detailed manner, some parts of its machinery which have been variously constructed, and in which more or less improvements have been made.

(89.) *Of the cocks and valves.*—In the steam engine, as well as in every other machine in which fluids act, it is necessary to open or close, occasionally, the tubes or passages through which these fluids move. The instruments by which this is accomplished are called cocks or valves.

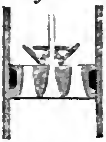
Cocks or valves may be classified by the manner in which they are opened: 1st, they may be opened by a motion similar to the lid of a box upon its hinges; 2d, they may be opened by being raised directly upwards, in the same manner as the lid of a pot or kettle; 3d, they may be opened by a sliding motion, like that of the sash of a window or the lid of a box which slides in grooves; 4th, they may be opened by a motion of revolution, in the same manner as the cock of a beer-barrel is opened or closed. The term *valve* is more properly applied to the first and second of these classes; the third class are usually called *slides*, and the fourth *cocks*.

(90.) *Single clack valves.*—The single clack valve is the most simple example of the first class. It is usually constructed by attaching to a plate of metal larger than the aperture which the valve is intended to stop, a piece of leather, and to the under side of this leather another piece of metal smaller than the aperture. The leather extending on one side beyond the larger metallic plate, and being flexible, forms the hinge on which the valve plays. Such a valve is usually closed by its own weight, and opened by the pressure of the fluid which passes through it. It is also held closed more firmly by the pressure of the fluid whose return it is intended to obstruct. An example of this valve occurs in the steam engine, in the passage between the condenser and the air-pump. The aperture which it stops is there a seat inclined at an angle whose inclination is such as to render the weight of the valve sufficient to close it. In cases where the valve is exposed to heat, as in the example just mentioned, where it is continually in contact with the hot water flowing from the condenser to the air-pump, the use of leather is inadmissible, and in that case the metallic surface of the valve is ground smooth to fit its seat.

The extent to which such a valve should be capable of opening, ought to be such that the aperture produced by it shall be equal to the aperture which it stops. This will be effected if the angle through which it rises be about 30°.

The valve by which the air and water collected in the bottom of the air-pump are admitted to pass through the air-pump piston is a double clack, consisting of two semicircular plates, having the hinges on the diameters of the semicircles, as represented in *fig.* 42.

*Fig.* 42.



(91.) *Conical valves.* — Of the valves which are opened by a motion perpendicular to their seat, the most simple is a flat metallic plate, made larger than the orifice which it is intended to stop, and ground so as to rest in steam-tight contact with the surface surrounding the aperture. Such a valve is usually guided in its perpendicular motion by a spindle passing through its centre, and sliding in holes made in cross bars extending above and below the seat of the valve.

The conical steam-valves, which have been already described (75.), usually called spindle-valves, are the most common of this class. The best angle to be given to the conical seat is found in practice to be 45°. With a less inclination the valve has a tendency to be fastened in its seat, and a greater inclination would cause the top of the valve to occupy unnecessary space in the valve-box. The area, or transverse section of the valve-box, should be rather more than double the magnitude of the upper surface of the valve, in order to allow a sufficiently free passage for the steam, and the play of the valve should be such as to allow it to rise from its seat to a height not less than one fourth of the diameter of its upper surface.

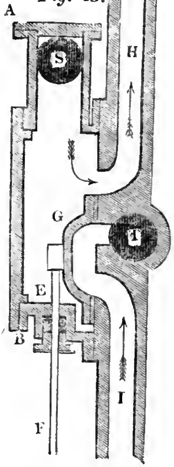
The valves coming under this class are sometimes formed as spheres or hemispheres resting in a conical seat, and in such cases they are generally closed by their own weight, and opened by the pressure of the fluid which passes through them.

(92.) *Slides.* — One of the advantages attending the use of slides, compared with the other form of valves, is the simplicity with which the same slide may be made to govern several passages, so that a single motion with a slide may perform the office of two or more motions imparted to independent valves.

In most modern engines the passage of the steam to and from the cylinder is governed by slides of various forms, some of which we shall now explain.

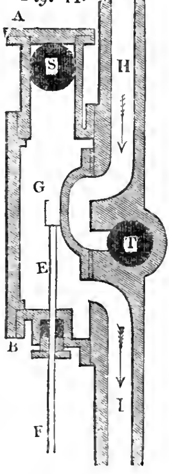
(93.) *Murray's slide-valve.*—In *figs.* 43 and 44. is represented a slide-valve contrived by Mr. Murray of Leeds. A B is a steam-tight case attached to the side of the cylinder; E F is a rod, which receives an alternate motion, upwards and downwards, from the eccentric, or from whatever other part of the engine is intended to move the slide. This rod, passing through a stuffing box, moves the slide G upwards and downwards. S is the mouth of the steam pipe coming from the boiler; T is the mouth of a tube or pipe leading to the condenser; H is a passage leading to the top, and I to the bottom, of the cylinder. In the position of the slide represented in *fig.* 43., the steam coming from the boiler through S passes through the space H to the top of the cylinder, while the steam from the bottom of the cylinder passes through the space I into the tube T, and goes to the condenser.

*Fig.* 43.




When the rod E F is raised to the position represented in *fig.* 44., then the passage H is thrown into communication with the tube T, while the passage I is made to communicate with the tube S. Steam, therefore, passes from the boiler through I below the piston, while the steam which was above the piston, passing through H into T, goes to the condenser. Thus the single slide G performs the office of the four valves described in § 75.

*Fig.* 44.




(94.) *The* D *valve.* — The slide G has always steam of a full pressure behind it, while the steam in front of it escaping to the condenser, exerts but little pressure upon it. It is therefore always forcibly pressed against the surfaces in contact with which it moves, and is thereby maintained steam-tight. Indeed this pressure would rapidly wear the rubbing surfaces, unless they were made sufficiently extensive, and hardened so as to resist the effects of the friction. Where fresh water is used, as in land boilers, the slide may be made of hardened steel; and in the case of marine boilers, it may be constructed of gun-metal. In this and all other contrivances in which the apertures by which the steam is admitted to and withdrawn from the piston are removed to any considerable distance from the top and bottom of the cylinder, there is a waste of steam, for the steam consumed at each stroke of the piston is not only that which would fill the capacity of the cylinder, but also the steam which fills the passage between the slide G and the top or bottom of the cylinder. Any arrangement which would throw the passages H and I on the other side of the slide G, that is, between S and G, instead of being, as they are, between G and the top and bottom of the cylinder, would remove this defect. This is accomplished by a slide, which is usually called the D valve, because, being semi-cylindrical in its form, and hollow, its cross section resembles the letter D. This slide, which is that which at present is in most general use, is represented in *figs.* 45, 46.; is the rod by which the slide is moved, passing through a stuffing box F; G G is the slide represented by a vertical section, *a a* being a passage in it extending from the top to the bottom; S is the mouth of the great steam pipe coming from the boiler; P is the pipe leading to the condenser; T H is a hollow space formed in the slide always in communication with the steam pipe S, and consequently always filled with steam from the boiler. A transverse section of the slide

*Fig.* 45.

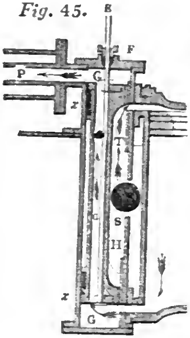
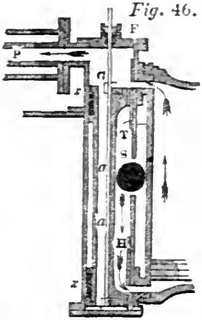
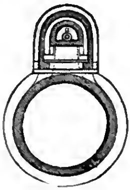



*Fig.* 46.




and cylinder is represented in *fig.* 47., where *a* represents the top of the passage marked *a* in *fig.* 45. In the position of the slide represented in *fig.* 45., the steam filling the space T H has access to the top of the cylinder, but is excluded from the bottom. The steam which was below the piston,

*Fig.* 47.



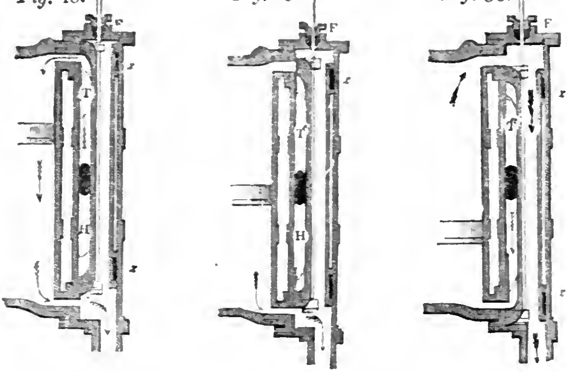
passing up the passage *a*, escapes through the tube P to the condenser. When the piston has descended, the rod E moves the slide downwards, so as to give it the position represented in *fig.* 46. The steam in T H has now access to the bottom of the cylinder, while the steam above the piston passing through P escapes to the condenser. In this way the operation of the piston is continued, and the steam consumed at each stroke only exceeds the capacity of the cylinder by what is necessary to fill the passages between the slide and the cylinder.

In a slide constructed in this manner, the steam filling the space T H has a tendency to press the slide back, so as to break the contact of the rubbing surfaces, and thereby to cause the steam to leak from the space T H to the back of the slide. This is counteracted by the packing *x*, at the back of the slide.

In engines of very long stroke, the extent of the rubbing surfaces of slides of this kind renders it difficult to keep them in steam-tight contact, and to insure their uniform wear. In such cases, therefore, separate slides, upon the same principle, are provided at the top and bottom of the cylinder, moved, however, by a single rod of communication.

(95.) *Adaptation of slide valves to expansion.*—In slides, as we have here described them, the same motion which admits steam to either end of the cylinder, withdraws it from the other end. Such an arrangement is only compatible with the operation of a cylinder which works without expansion; for in such a cylinder the full flow of steam to the piston is only interrupted for a moment during the change of position of the slide. But if the steam act expansively, it would be necessary to move the slide, so as to stop its flow to one end of the cylinder, without at the same time obstructing the escape of steam from the other end to the condenser. It would, therefore, be necessary that the slide should close the passage leading to the cylinder at one end, without at the same time obstructing the communication between the passage from the cylinder to the condenser at the other end. On the arrival of the piston, however, at the bottom of the cylinder, it would be necessary immediately to put the lower passage to the cylinder in communication with the steam pipe, and the upper passage in communication with the condenser. This would necessarily suppose two motions of the slide as well as some modifications in its length. Let the length of the slide be such that when the passage to the top of the cylinder is stopped, the lower part of the slide shall not reach the passage to the lower part of the cylinder; and let such a provision be made in the mechanism by which the rod E governing the slide is driven, that it shall receive two motions during the descent of the piston, the first to be imparted to it at the moment the steam is to be cut off, and the second just before the termination of the stroke. Let the position of the slide at the commencement of the stroke be represented in *fig.* 48., and let it be

*Fig.* 48. *Fig.* 49. *Fig.* 50.




required that the steam shall be cut off at one half of the stroke. When the piston has made half the stroke, the rod governing the slide is moved downwards, so as to throw the slide into the position represented in *fig.* 49. The passage between the steam pipe and the cylinder is now stopped at both ends; but the passage from the bottom of the cylinder to the condenser remains open. During the remainder of the stroke, therefore, the steam in the cylinder works expansively. As the piston approaches the bottom of the cylinder, another motion is imparted to the rod governing the slide, by which the latter is thrown into the position represented in *fig.* 50. Steam now flows below the piston while the steam above it passes to the condenser. In a similar manner, by two motions successively imparted to the slide during the ascent of the piston, the steam may be cut off at half stroke; and it is evident that by regulating the time at which these motions are given to the slide, the steam may be worked expansively to any required extent.

It is easy to conceive various mechanical means by which, in the same engine, the point at which the steam is cut off may be regulated at pleasure.

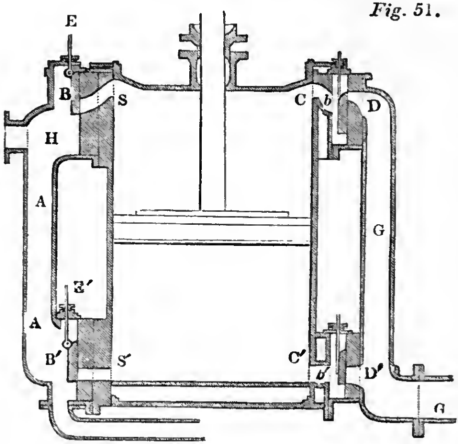
In cases where the motion of the piston is very rapid, as in locomotive engines, it is desirable that the passages to and from the cylinder should be opened very suddenly. This is difficult to be accomplished with any form of slide consisting of a single aperture; but if, instead of admitting the steam to the cylinder by a single aperture, the same magnitude of opening were divided among several apertures, then a proportionally less extent of motion in the slide would clear the passage for the steam, and consequently greater suddenness of opening would be effected.

The great advantages in the economy of fuel resulting from the application of the expansive principle have, of late years, forced themselves on the attention of engineers, and considerable improvements have been made in its application, especially in the case of marine engines used for long voyages, in which the economy of fuel has become an object of the last importance. The mechanism by which expansive slides are moved, is made capable of adjustment, so that the part of the stroke at which the steam is cut off, can be altered at pleasure. The working power of the engine, therefore, instead of being controlled by the throttle valve, is regulated by the greater or less extent to which the expansive principle is applied. Steam of the same pressure is admitted to the cylinder in all cases; but it is cut off at a greater or less portion of the stroke, according to the power which the engine is required to exert.

(96.) *Effect of connecting the governor with the slide.*— The last degree of perfection has been conferred on this principle by connecting the governor with the mechanism by which the slide is moved, so that the governor, instead of acting on the throttle valve, is made to act upon the slide. By this means, when, by reason of any diminution of the resistance, the motion of the engine is accelerated, the balls of the governor diverging shift the cam or lever which governs the slide, so that the steam is cut off after a shorter portion of the stroke, the expansive principle is brought into greater play, and the quantity of steam admitted to the cylinder at each stroke is diminished. If, on the other hand, the resistance to the machine be increased, so as to diminish the velocity of the engine, then the balls collapsing, the levers of the governor shift the cam which moves the slides, so as to increase the portion of the stroke made by the piston before the steam is cut off, and thereby to increase the amount of mechanical power developed in the cylinder at each stroke. The extent to which the expansive principle is capable of being applied, more especially in marine engines, has been hitherto limited by the necessity of using steam of very high pressure, whenever the steam is cut off after the piston has performed only a small part of the stroke.

(97.) *Seaward's slides.* — Mr. Samuel Seaward, of the firm of Messrs. Seawards, engineers, has contrived an improved system of slides, for which he has obtained a patent. A section of Seaward's slides is represented in *fig.* 51. The steam pipe proceeding from the boiler to the cylinder is represented at A A, and it communicates with passages S and S′ leading to the top and bottom of the cylinder. These passages are formed in nozzles of iron or other hard metal cast upon the side of the cylinder. These nozzles present a smooth face outwards, upon which the slides B B′, also formed with smooth faces, play. The slides B B′ are attached by knuckle-joints to rods E E′, which move through stuffing boxes, and the connection of these rods with the slides is such that the slides have play so as to detach their surfaces easily from the smooth surfaces of the nozzles when not pressed against these surfaces. The steam in the steam pipe A A will press against the backs of the slides B B′, and keep their faces in steam-tight contact with the smooth surfaces of the nozzles. These slides may be opened or closed by proper mechanism at any point of the stroke. When steam is to be admitted to the top of the cylinder, the upper

*Fig.* 51.




slide is raised and the passage S opened; and when it is to be admitted to the bottom of the cylinder, the lower slide is raised and the passage S′ opened: and its communication to the top or bottom of the cylinder is stopped by the lowering of these slides respectively. On the other side of the cylinder are provided two passages C C′ leading to a pipe G, which is continued to the condenser. On this pipe are cast nozzles of iron or other metal presenting smooth faces towards the cylinder, and having passages D D′ communicating between the top and bottom of the cylinder respectively and the pipe G G leading to the condenser. Two slides *b b′*, having smooth faces turned from the cylinder, and pressing upon the faces of the nozzles D D′, are governed by rods playing through stuffing boxes, in the same manner as already described. The faces of these slides being turned from the cylinder, the steam in the cylinder having free communication with them, has a tendency to keep them by its pressure in steam-tight contact with the surfaces in which the apertures leading to the condenser are formed. These two slides may be opened or closed whenever it is necessary.

When the piston commences its descent, the upper steam slide is raised, so as to open the passage s, and admit steam above the piston ; and the lower exhausting slide *b′* is also raised, so as to allow the steam below the piston to escape through G to the condenser, the other two passages s′ and C being closed by their respective slides. The slide which governs s is lowered at that part of the stroke at which the steam is intended to be cut off, the other slides remaining unchanged ; and when the piston has reached the bottom of the cylinder, the lower steam slide opens the passage s′, and the upper exhausting slide opens the passage C, and at the same time the lower exhausting slide closes the passage C′. Steam being admitted below the piston through s′, and at the same time the steam above it being drawn away to the condenser through the open passage C and the tube G, the piston ascends. When it has reached that point at which the steam is intended to be cut off, the slide which governs s′ is lowered, the other slides remaining unaltered, and the upward stroke is completed in the same manner as the downward.

These four slides may be governed by a single lever, or they may be moved by separate means. From the small spaces between the several slides and the body of the cylinder, it will be evident that the waste of steam by this contrivance will be very small.

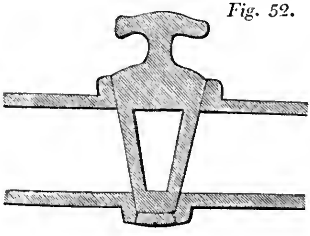
In the slide valves commonly used, the packing of hemp at the back of the slide, by which the pressure necessary to keep the slide in steam-tight contact is obtained, requires constant attention from the engine-man while the engine is at work. Any neglect of this will produce a corresponding loss in the power of the engine ; and accordingly it is found that in many cases where engines work inefficiently, the defect is owing either to ignorance or want of attention on the part of the engine-man in the packing of the slides. In Seaward's slides no hemp packing is used, nor is any attention on the part of the engine-man required after the slides are first adjusted. The slides receive the pressure necessary to keep them in steam-tight contact with the surfaces of the nozzles from the steam itself, which acts behind them.

The eduction and steam slides being independent of each other, they may be adjusted so that the engine shall work expansively in any required degree; and this may be accomplished either by working the slides by separate mechanism, or by a single eccentric.

One of the advantages claimed by the patentees for these slides is, that the engines are secured from the accidents which arise from the accumulation of water within the steam cylinder. If such a circumstance should occur, the action of the piston will press the water against the faces of the steam slides, and the play allowed to them by their connection with the rods which move them permits their faces to be raised from the surfaces of the nozzles, so that the water collected in the cylinder shall be driven into the steam pipe, and sent back from thence to the boiler.

(98.) *Single cocks.* — Of the cocks or valves which are opened and closed by the motion of an axis passing through their centre, the throttle valve, whether worked by hand or by the governor, is an example. But the most common form for cocks is that of a cylindrical or slightly conical plug (*fig.* 52.), inserted in an aperture of corresponding magnitude passing across the pipe or passage which the cock is intended to open or close. One or more holes are pierced transversely in the cock, and when the cock is turned, so that these holes run in the direction of the tube, the passage through the tube is opened; but when the passage through the cock is placed at right angles to the tube, then the sides of the tube stop the ends of the passage in the cock, and the passage through the tube is obstructed. The simple cock is designed to open or close the passage through a single tube. When the cock is turned, as in *fig.* 53., so that the passage through the cock shall be at right angles to the length of the tube, then the passage through the tube is stopped; but when the cock is turned from that position through a quarter of a revolution, as in *fig.* 54., then the passage through the cock takes the direction of the passage through the tube, and the

Fig. 52.



cock is opened, and the passage through the tube unobstructed. In such a cock the passage may be more or less

Fig. 53.

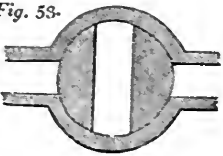
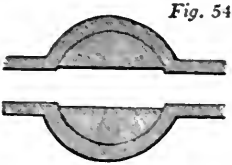


Fig. 54.

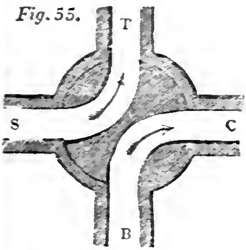


*throttled* by adjusting the position of the cock, so that a part of the opening in it shall be covered by the side of the tube.

It is sometimes required to put one tube or passage alternately in communication with two others. This is accomplished by a *two-way cock.* In this cock the passage is curved, opening usually at points on the surface of the cock, at right angles to each other. Such a cock has already been described, and its use illustrated in the description of the Marquis of Worcester's engine (18.); the two-way cock, as represented at K and R (*fig.* 5.), being the means by which steam and water are alternately supplied to the two forcing vessels.

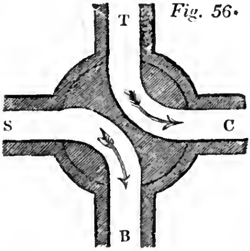
(99.) *Four-way cock.* — When it is required to put four passages alternately in communication by pairs, a *four-way cock* is used. Such a cock has two curved passages (*fig.* 55.), each similar to the curved passage in the two-way cock. Let S C B T be the four tubes which it is required to throw alternately into communication by pairs. When the cock is in the position *fig.* 55., the tube S communicates with T, and the tube C with B. By turning the cock through a quarter of a revolution,

Fig. 55.




as in *fig.* 56., the tube S is made to communicate with B, and the tube C with T; and if the cock continue to be turned at intervals through a quarter of a revolution, these changes of communication will continue to be alternately made. It is evident that this may be accomplished by turning the cock continually in the same direction.

*Fig. 56.*




The four-way cock is sometimes used as a substitute for the valves or slides in a double-acting steam engine to conduct the steam to and from the cylinder. If S represent a pipe conducting steam from the boiler, C that which leads to the condenser, T the tube which leads to the top of the cylinder, and B that which leads to the bottom, then when the cock is in the position (*fig.* 55.), steam would flow from the boiler to the top of the piston, while the steam below it would be drawn off to the condenser: and in the position (*fig.* 56.), steam would flow from the boiler to the bottom of the piston, while the steam above it would be drawn off to the condenser. Thus by turning the cock through a quarter of a revolution towards the termination of each stroke, the operation of the machine would be continued.

One of the disadvantages which is inseparable from the use of a four-way cock for this purpose is the loss of the steam at each stroke, which fills the tubes between the cock and the ends of the cylinder. This disadvantage could only be avoided by the substitution of two two-way cocks instead of a four-way cock. A two-way cock at the top of the cylinder would open an alternate communication between the cylinder and steam pipe, and the cylinder and condenser, while a similar office would be performed by another two-way cock at the other end.

The friction on cocks of this description is more than on other valves; but this is in some degree compensated by the great simplicity of the instrument. When the cock is truly ground into its seat, being slightly conical in its form, the pressure of the steam has a tendency to keep the surfaces in contact; but this pressure also increases the friction, and has a tendency to wear the seat of the cock into an elliptical shape. Consequently, such cocks require to be occasionally ground and refitted.

(100.) *Their adaptation to expansion.* — The four-way cock, as above described, admits the steam to one end of the piston at the same moment that it stops it at the other end. It would therefore be inapplicable where steam is worked expansively. A slight modification, however, analogous to that already described in the slides, will adapt it to expansive action. This will be accomplished by giving to one of the passages through the cock one aperture larger than the other, and working the cock so that this passage shall always be used to conduct steam to the cylinder; also by enlarging both apertures of the other passage, and using it always to conduct steam from the cylinder. The effect of such an arrangement will be readily understood.

Let the position of the cock, when the piston begins to descend, be represented in *fig.* 57. Steam flows from S through T to the top of the cylinder, while it escapes from B through C from the bottom of the cylinder. When the piston has arrived at that point at which the steam is to be cut off, let the cock be shifted to the position represented in *fig.* 58. The passage of steam from the boiler is now stopped, but the escape of steam from the bottom of the cylinder through C continues, and the cock is maintained in this position until the piston approaches the bottom of the cylinder when it is further shifted to the position represented in *fig.* 59. Steam now flows from S through B to the bottom of the cylinder, while the steam from the top of the cylinder escapes through C to the condenser. When the piston has arrived at that point where the steam is to be cut off, the cock is shifted to the position represented in *fig.* 60. The communication between the steam and the bottom of the piston is now stopped, while the communication between the top of the cylinder and

*Fig.* 57.

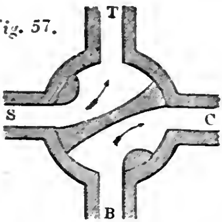
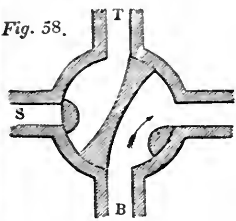



*Fig.* 58.



the condenser is still open. During the next double stroke of the piston the position of the cock is similarly changed, but in the contrary direction, and in the same way the motion

*Fig. 59.*

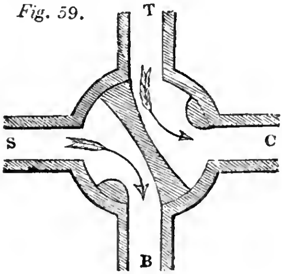
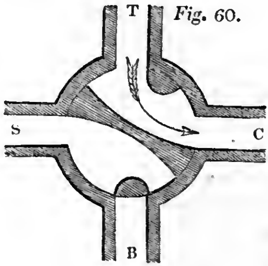



*Fig. 60.*




is continued. Under these circumstances the cock, instead of being moved constantly in the same direction, as in the case of the common four-way cock, will require to be moved alternately in opposite directions.

(101.) *Pistons.* — The office of a piston being to divide a cylinder into two compartments by a movable partition, which shall obstruct the passage of any fluid from one compartment to the other, it is evident that the two conditions which such an instrument ought to fulfil are, *first*, that the contact of its sides with the surface of the cylinder shall be so close and tight throughout its entire play, that no steam or other fluid can pass between them; *secondly*, that it shall be so free from friction, notwithstanding this necessary tightness, that it shall not absorb any injurious quantity of the moving power.

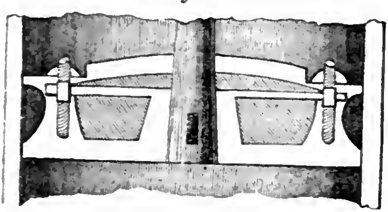
Since, however accurately the surfaces of the piston and cylinder may be constructed, there will always be in practice more or less imperfection of form, it is evident that the contact of the surface of the piston with the cylinder throughout the stroke can only be maintained by giving to the circumference of the piston sufficient elasticity to accommodate itself to such inequalities of form. The substance, whatever it may be, used for this purpose, and by which the piston is surrounded, is called *packing*.

In steam pistons the material used for packing must be such as is capable of resisting the united effects of heat and moisture. Hence leather and other animal substances are inapplicable.

The packing used for steam pistons is therefore of two kinds, *vegetable packing*, usually hemp, or *metallic packing*.

(102.) *Common hemp-packed piston.* — The common hemp-packed piston has been already in part described (50.).

*Fig.* 61.



The bottom of the piston is a circular plate just so much less in diameter than the cylinder as is sufficient to allow its free motion in ascending and descending. A little above its lowest point this plate begins gradually to diminish in thickness until its diameter is reduced to from one to two inches less than that of the cylinder, leaving therefore around it a hollow space, as represented in *fig.* 61. The cover of the piston is a plate similarly formed, being in like manner gradually reduced in thickness downwards, so as to correspond with the lower plate. In the hollow space which thus surrounds the piston, a packing of unspun hemp, or soft rope, called *gasket*, is introduced by winding it round the piston so as to render it an even and compact mass. When the space is thus filled up, the top of the piston is attached to the bottom by screws. The curved form of the space within which the hempen packing is confined is such that when the screws are tightened, that part of the packing which is nearest to the top and bottom of the piston is forced against the cylinder so as to produce upon the two parallel rings as much pressure as is necessary to render it steam-tight. When by use the packing is worn down so as to produce leakage, the cover of the cylinder must be removed, and the screws connecting the top and bottom of the piston tightened: this will force out the packing and render the piston steam-tight. This packing is lubricated by melted tallow let down upon the piston from the funnel inserted in the top of the cylinder, furnished with a stop-cock to prevent the escape of steam. The lower end of the piston rod is formed slightly conical, the thickest part of the cone being downward. It is passed up through the piston, and a nut or wedge between the top and bottom is inserted so as to secure the piston in its position upon the rod.

The process of removing the top of the cylinder for the purpose of tightening the screws in the piston is one of so laborious a nature, that the men entrusted with the superintendence of these machines are tempted to allow the engine to work notwithstanding injurious leakage at the piston, rather than incur the labour of tightening the screws as often as it is necessary to do so.

To avoid this inconvenience, the following method of tightening the packing of the piston without removing the lid of the cylinder was contrived by Woolf. The head of each of the screws was formed into a toothed pinion, and as these screws were placed at equal distances from the centre of the piston, these several pinions were driven by a large toothed wheel, revolving on the piston rod as an axis. By such an arrangement it is evident, that if any one of the screws be turned, a like motion will be imparted to all the others through the medium of the large central wheel. Woolf accordingly formed, on the head of one of the screws, a square end. When the piston was brought to the top of the cylinder, this square end entered an aperture made in the under side of the cover of the cylinder. This aperture was covered by a small circular piece screwed into the top of the cylinder, which was capable of being removed so as to render the square head of the screw accessible. When this was done, a proper key being applied to the square head of the screw, it was turned; and, by being turned, all the other screws were in like manner moved. In this way, instead of having to remove the cover of the cylinder, the packing was tightened by merely unscrewing a piece in the top of the cylinder not much greater in magnitude than the head of one of the screws.

This method was further simplified by causing the great circular wheel already described to move upon the piston rod, not as an axis, but as a screw, the thread being cut upon a part of the piston rod which worked in a corresponding female screw cut upon the central plate. By such means the screw, which turned, whose head was let into the cover of the cylinder, would cause this circular plate to be pressed downwards by the force of the screw constructed on the piston rod. This circular plate thus pressed downwards acted upon pins or plugs which pressed together the top and bottom of the piston in the same manner as they were pressed together by the screws connecting them as already described.

(103.) *Metallic pistons.* — The notion of constructing a piston so as to move steam-tight in the cylinder without the use of packing of vegetable matter was first suggested by the Rev. Mr. Cartwright, a gentleman well known for other mechanical inventions. A patent was granted in 1797 for a new form of steam engine, in which he proposed to use the vapour of alcohol to work the piston instead of the steam of water; and since the principle of the engine excluded the use of lubrication by oil or tallow, he substituted a piston formed of metallic rings pressed against the surface of the cylinder by springs, so as to be maintained in steam-tight contact with it, independently either of packing or lubrication. Although the engine for which this form of piston was intended never came into practical use, yet it is so simple and elegant in its structure, and forms a link so interesting in the history of the steam engine, that some explanation of it ought not to be omitted in this work.

(104.) *Cartwright's engine.* — The steam pipe from the boiler is represented cut off at B (*fig.* 62.); T is a spindle valve, for admitting steam above the piston, and R is a spindle valve in the piston; D is a curved pipe forming a communication between the cylinder and the condenser, which is of very peculiar construction. Cartwright proposed effecting a condensation without a jet, by exposing the steam to contact with a very large quantity of cold surface. For this purpose he formed his condenser by placing two cylinders nearly equal in size, one within the other, allowing the water of the cold cistern in which they were placed to flow through the inner cylinder, and to surround the outer

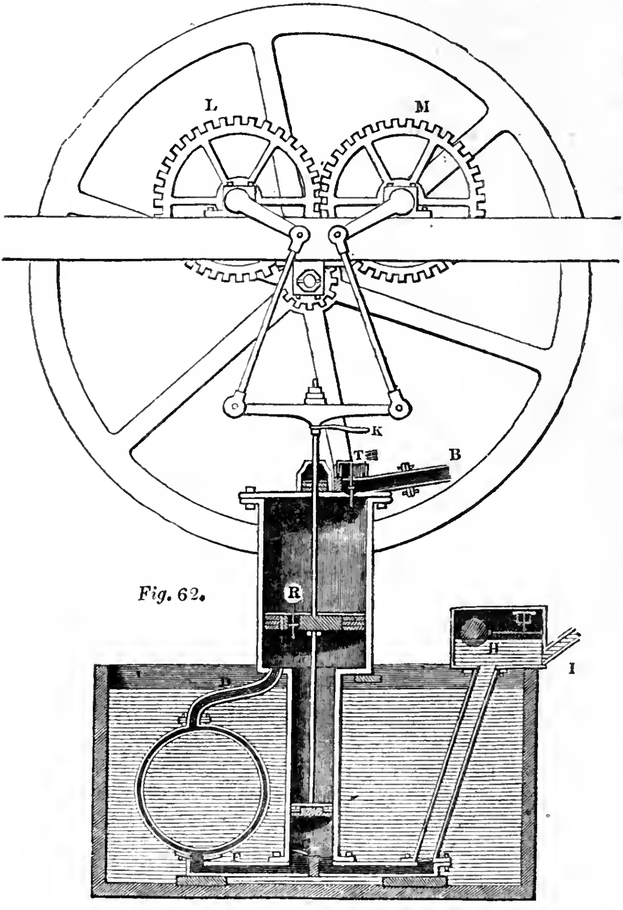



*Fig.* 62.

one. Thus the thin space between the two cylinders formed the condenser.

The air-pump is placed immediately under the cylinder, and the continuation of the piston rod works its piston, which is solid and without a valve. F is the pipe from the condenser to the air-pump, through which the condensed steam is drawn off through the valve G on the ascent of the piston, and on the descent this is forced through a tube into a hot well H, for the purpose of feeding the boiler through the feed-pipe I. In the top of the hot well H is a valve which opens inwards, and is kept closed by a ball floating on the surface of the liquid. The pressure of the condensed air above the surface of the liquid in H forces it through I into the boiler. When the air accumulates in too great a degree in H, the surface of the liquid is pressed so low that the ball falls and opens the valve, and allows it to escape. The air in H is that which is pumped from the condenser with the liquid, and from which it was disengaged.

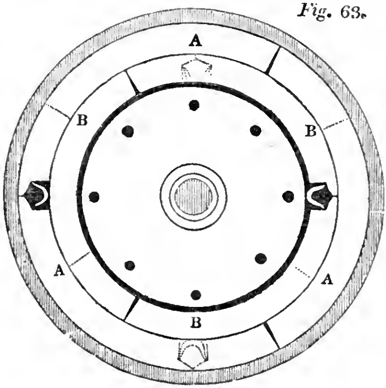
Let us suppose the piston at the top of the cylinder: it strikes the tail of the valve T, and raises it, while the stem of the piston valve R strikes the top of the cylinder, and is pressed into its seat. A free communication is at the same time open between the cylinder, below the piston and the condenser, through the tube D. The pressure of the steam thus admitted above the piston acting against the vacuum below it, will cause its descent. On arriving at the bottom of the cylinder, the tail of the piston valve R will strike the bottom, and it will be lifted from its seat, so that a communication will be opened through it with the condenser. At the same moment, a projecting spring K, attached to the piston rod, strikes the stem of the steam valve T, and presses it into its seat. Thus while the further admission of steam is cut off, the steam above the piston flows into the condenser, and the piston being relieved from all pressure, is drawn up by the momentum of the fly-wheel, which continues the motion it received from the descending force. On the arrival of the piston again at the top of the cylinder, the valve T is opened and R closed, and the piston descends as before, and so the process is continued.

The mechanism by which motion is communicated from the piston to the fly-wheel is peculiarly elegant. On the axis of the fly-wheel is a small wheel with teeth, which work in the teeth of another larger wheel L. This wheel is turned by a crank, which is worked by a cross-piece attached to the end of the piston rod. Another equal-toothed wheel M is turned by a crank, which is worked by the other end of the cross-arm attached to the piston rod.

One of the peculiarities of this engine is, that the liquid which is used for the production of steam in the boiler circulates through the machine without either diminution or admixture with any other fluid, so that the boiler never wants more feeding than what can be supplied from the hot well H. This circumstance forms an important feature in the machine, as it allows of ardent spirits being used in the boiler instead of water, which, since they boil at low heats, promised a saving of fuel. The inventor proposed that the engine should be used as a still, as well as a mechanical power, in which case the whole of the fuel would be saved.

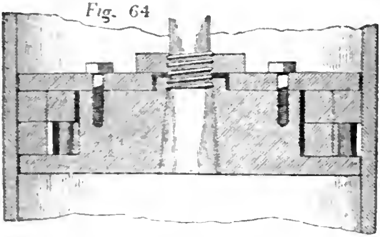
(105.) *His metallic piston.*—That part of Cartwright's piston which in the common piston is occupied by the packing of gasket already explained (102.), was filled by a number of rings, one placed within and above another, and divided into three or four segments. Two rings of brass were made of the full size of the cylinder, and so ground as to fit the cylinder nearly steam-tight. These were cut into several segments A A A (*fig.* 63.), and were placed one above the other, so as to fill the space between the top and bottom plates of the piston. The divisions of the segments of the one ring were made to fit between the divisions of the other. Within these another series of rings, B B B, were placed, similarly constructed, so as to fit within the first series in the same manner as the first series

*Fig.* 63.



were made to fit within the cylinder. The joints of the upper series of each set of rings are exhibited in the plan (*fig.* 63.); the places of the joints of the lower series are shown by dotted lines; the position of the rings of each series one above the other is shown in the section (*fig.* 64.). The joints of the inner series of rings are so placed as to lie between those of the outer series, to prevent the escape of steam which would take place by one continued joint from top to bottom of the packing. The segments into which the rings are divided are pressed outwards by steel springs in the form of the letter V, the springs which act upon the outer series of segments abutting upon the inner series, and those which act on the inner series abutting upon the solid centre of the piston: these springs are represented in *fig.* 63.

*Fig.* 64



(106.) *Barton's metallic piston.* — An improved form was given to the metallic piston by Barton. Barton's piston consists of a solid cylinder of cast iron, represented at A in section in *fig.* 65., and in plan in *fig.* 66. In the centre of this is a conical hole increasing in magnitude downwards, to receive the piston rod, in which the latter is secured by a cross-pin B. A deep groove, square in its section, is formed around the piston, so that while the top and bottom of the piston form circles equal in magnitude to the section of the cylinder, the intermediate part of the body of the piston forms a circle less than the former by the depth of the groove. Let a ring of brass, cast iron, or cast steel, be made to correspond in magnitude and form with this groove, and let it be divided, as represented in

*Fig.* 65.

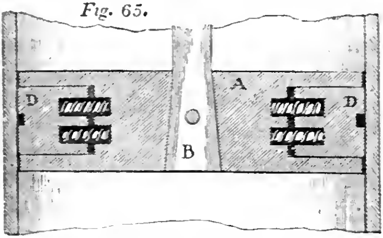
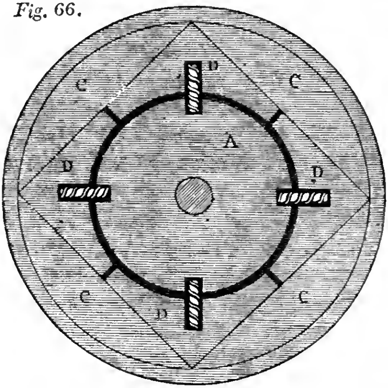


*fig.* 66., into four segments C C C C, and four corresponding angular pieces D D D D. Let the groove which surrounds the piston be filled by the four segments with the four wedge-like angular pieces within them, and let the latter be urged against the former by eight spiral springs, as represented in *fig.* 65 and *fig.* 66. These springs will abut against the solid centre of the piston, and will urge the segments C against the cylinder. The spiral springs which urge the wedges are confined in their action by steel pins which pass through their centre, and by being confined in cylindrical cavities worked into the wedges and into corresponding parts of the solid centre of the piston, as the segments C wear, the springs urge the wedges outwards, and the points of the latter protruding, are gradually worn down so as to fill up the spaces left between the segments, and thus to complete the outer surface of the piston.

*Fig.* 66.




Various other forms of metallic pistons have been proposed, but as they do not differ materially in principle from those we have just described, it will not be necessary here to describe them.

## CHAPTER VII.

### THE BOILER AND ITS APPENDAGES.

(107.) *Importance of the boiler and furnace.* — The machinery which has been explained in the preceding chapters, consisting of the cylinder with its passages and valves, the piston rod, parallel motion, beam, connecting rod and crank, together with the condenser, air-pump, and other appendages, having no source of moving power in themselves, must be regarded as mere instruments by which the mechanical effect developed by the furnace and the boiler is transmitted to the working point, and so modified as to be adapted to the uses to which the machine is applied. The boiler is at once a magazine in which the moving power is stored in sufficient quantity to supply the demands of the engine, and an apparatus in which that power is fabricated. The mechanical effect evolved in the conversion of water into steam by heat, is the means by which the power of the steam engine is produced, and space is provided in the boiler, capacious enough to contain as much steam as is necessary for the engine, besides a sufficient quantity of water to continue that supply undiminished, notwithstanding the constant drafts made upon it by the cylinder: even the water itself, from the evaporation of which the mechanical power is produced, ought to be regarded as an instrument by which the effect of the heat of the combustible is rendered mechanically efficient, inasmuch as the same heat, applied not only to other liquids but even to solids, would likewise be productive of mechanical effects. The boiler and its furnace are therefore parts of the steam engine, the construction and operation of which are entitled to especial attention.

(108.) *Analysis of coal.*—COAL, the combustible almost universally used in steam engines, is a substance, the principal constituents of which are *carbon* and *hydrogen*, occasionally mixed with sulphur in a small proportion, and some incombustible matter. In different sorts of coal the proportions of these constituents vary, but in general about four-fifths of the whole weight of the combustible is carbon.

In the following table is exhibited the composition of the principal varieties of British coal according to the analysis of Mr. H. How. (See Report of Sir H. De la Beche and Dr. L. Playfair on the Coals suited to the Steam Navy, presented to Parliament, 1848.)

| Name or Locality of Coal. | Carbon. | | Hydrogen. | | Ash. | | Sulphur. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| | I. | II. | I. | II. | I. | II. | | |
| Powell's Duffryn - - | 88·4 | 88·12 | 4·54 | 4·81 | 3·18 | 3·34 | 1·77 | 1·45 |
| Mynydd Newydd - - | 84·26 | 85·16 | 5·61 | 5·92 | 3·27 | 3·21 | 1·21 | 1·56 |
| Three-Quarter Rock Vein | 75·45 | 74·85 | 5·02 | 4·85 | 10·71 | 11·21 | 2·85 | 1·07 |
| Park End, Lydney - - | 73·32 | 73·72 | 5·64 | 5·74 | 9·95 | 10·05 | 2·27 | 2·04 |
| Cwm Frood Rock Vein - | 81·72 | 82·78 | 5·75 | 5·93 | 5·95 | 6·05 | 1·22 | 1·11 |
| Cwm Nanty Gros - - | 78·57 | 78·16 | 5·45 | 5·73 | 5·60 | 5·61 | 3·01 | 1·86 |
| Grangemouth - - - | 80·09 | 79·62 | 5·32 | 5·24 | 3·52 | 3·53 | 1·42 | 1·35 |
| Broomhill - - - | 81·40 | 82·00 | 6·22 | 6·12 | 3·13 | 3·02 | 2·85 | 1·84 |
| Wylam's Patent Fuel - | 79·60 | 80·22 | 5·61 | 5·77 | 4·91 | 4·78 | 1·25 | 1·68 |
| Resolven - - - | 79·33 | lost | 4·47 | 5·03 | 9·46 | 9·37 | 5·07 | 1·38 |
| Pontypool - - - | 80·85 | 80·54 | 5·79 | 5·53 | 5·60 | 5·45 | 2·39 | 1·35 |
| Bedwas - - - - | 80·68 | 80·55 | 5·91 | 6·11 | 7·04 | 6·84 | 3·70 | 1·44 |
| Porthmawr Rock Vein - | 74·39 | 75·01 | 4·58 | 5·00 | 14·81 | 14·63 | 0·91 | 1·28 |
| Warlich's Patent Fuel - | 90·26 | 89·78 | 5·24 | 5·88 | 2·92 | 2·90 | 1·63 | trace. |
| Bell's Patent Fuel - - | 87·56 | 88·21 | 5·23 | 5·21 | 4·79 | 5·13 | 0·71 | 0·81 |
| Ebbw Vale - - - | 89·28 | 90·27 | 5·08 | 5·23 | 1·53 | 1·47 | 1·02 | 2·16 |
| Wallsend Elgin - - | 75·88 | 76·30 | 5·33 | 5·11 | 10·63 | 10·78 | 1·53 | 1·41 |
| Maxwell's Coleshill - | 73·95 | 73·74 | 5·14 | lost | 8·78 | 9·06 | 2·34 | 1·47 |
| Fordel Splint - - - | 79·44 | 79·73 | 5·50 | lost | 3·84 | 4·16 | 1·46 | 1·13 |
| Slievardagh - - - | 80·18 | 79·88 | 2·10 | 2·50 | 10·90 | 10·71 | 6·76 | 0·23 |

(109.) *Process of combustion.*—When carbon is heated to a temperature of about 700° in an atmosphere of pure oxygen, it will combine chemically with that gas, and the product will be the gas called *carbonic acid.* The volume of carbonic acid produced by this combination, will be exactly equal to that of the oxygen combined with the carbon, and therefore the weight of a given volume of the gas will be increased by the weight of carbon which enters the combination. It is found that two parts by weight of oxygen combined with three of carbon form carbonic acid. The weight of the carbonic acid, therefore, produced in the combustion, will be greater than the weight of the oxygen, bulk for bulk, in the proportion of five to two, the volume being the same and the gases being compared at the same temperatures and under equal pressures. In this combination heat is evolved in very large quantities. This effect arises from the heat previously latent in the carbon and oxygen being rendered sensible in the process of combustion. The carbonic acid proceeding from the combustion is by such means raised to a very high temperature, and the carbon during the process acquires a heat so intense as to become luminous; no flame, however, is produced.

Hydrogen, heated to a temperature of about 1000°, in contact with oxygen, will combine with the latter, and a great evolution of heat will attend the process; the gases will be rendered luminous, and flame will be produced. The product of this process will be water, which being exposed to the intense heat of combustion, will be immediately converted into steam. Hydrogen combines with eight times its own weight of oxygen, producing nine times its own weight of water.

Hydrogen gas is, however, not usually disengaged from coal in a simple form, but combined chemically with a certain portion of carbon, the combination being called carburetted hydrogen. Pure hydrogen burns with a very faintly luminous blue flame, but carburetted hydrogen gives that bright flame occasionally having an orange or reddish tinge, which is seen to issue from burning coals: this is the gas used for illumination, being expelled from the coal by the process of coking, and conducted to the various burners through proper pipes.

The sulphur, which, as appears from the preceding table, is contained in a very small proportion in coals, is also combustible, and combines in the process of combustion with oxygen, forming sulphurous acid: it is also sometimes evolved in combination with hydrogen, forming sulphuretted hydrogen.

Atmospheric air consists of two gases, azote and oxygen, mixed together in the proportion of four to one; five cubic feet of atmospheric air consisting of four cubic feet of azote and one of oxygen. Any combustible will combine with the oxygen contained in atmospheric air, if raised to a temperature somewhat higher than that which is necessary to cause its combustion in an atmosphere of pure oxygen.

If coals, therefore, or other fuel exposed to atmospheric air be raised to a sufficiently high temperature, their combustible constituents will combine with the oxygen of the atmospheric air, and all the phenomena of combustion will ensue. In order, however, that the combustion should be continued, and should be carried on with quickness and activity, it is necessary that the carbonic acid and other products should be removed from the combustible as they are produced, and fresh portions of atmospheric air brought into contact with it; otherwise the combustible would soon be surrounded by an atmosphere composed chiefly of carbonic acid to the exclusion of atmospheric air, and therefore of uncombined oxygen, and consequently the combustion would cease, and the fuel be extinguished. To maintain the combustion, therefore, a current of atmospheric air must be constantly carried through the fuel: the quantity and force of this current must depend on the quantity and quality of the fuel to be consumed. It must be such that it shall supply sufficient oxygen to the fuel to maintain the combustion, and not more than sufficient, since any excess would be attended with the effect of absorbing the heat of combustion, without contributing to the maintenance of that effect.

(110.) *How heat is imparted to the water.*—Heat is communicated from body to body in two ways, by radiation and by contact.

Rays of heat issue from a heated body, and are dispersed through the surrounding space in a manner, and according to laws, similar to those which govern the radiation of light.* The heat thus radiated meeting other bodies is imparted to them, and penetrates them with more or less facility according to their physical qualities.

A heated body also brought into contact with another body of lower temperature, communicates heat to that other body, and will continue to do so until the temperature of the two bodies in contact shall be equalised. Heat proceeds from fuel in a state of combustion in both these ways: the heated fuel radiates heat in all directions around it, and the heat thus radiated will be imparted to all parts of the furnace which are exposed to the fuel.

The gases, which are the products of the combustion, escape from the fuel at a very high temperature; and consequently, in acquiring that temperature, they absorb a considerable quantity of the heat of combustion. But besides the gases actually formed in the process of combustion, the azote forming four-fifths of the air carried through the fuel to support the combustion, absorbs heat from the combustible, and rises into the upper part of the furnace at a high temperature. These various gases, if conducted directly to the

* Handbook of Natural Philosophy, p. 510.

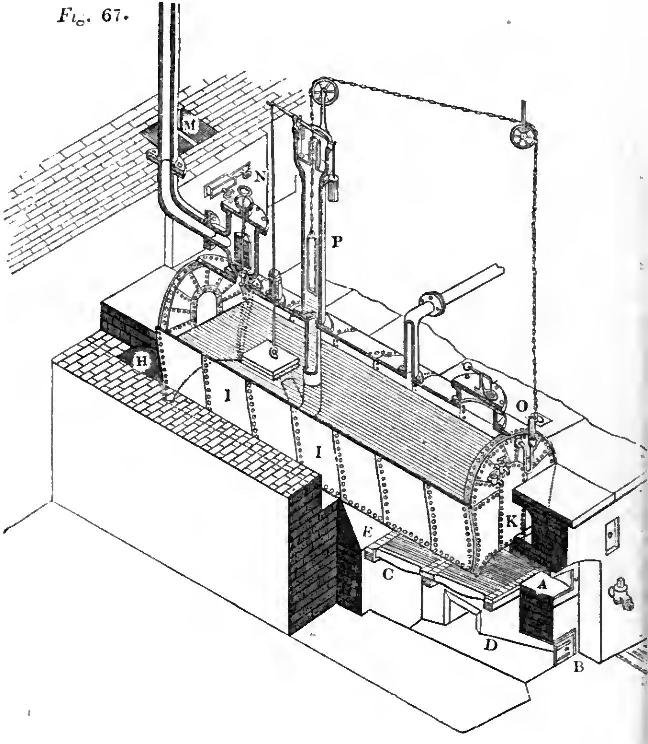
chimney, would carry off with them a considerable quantity of the heat. Provision should therefore be made to keep them in contact with the boiler such a length of time as will enable them to impart such a portion of the heat which they have absorbed from the fuel, as will still leave them at a temperature sufficient, and not more than sufficient, to produce the necessary draft in the chimney.

(111.) *Waggon boiler of Watt.* — The forms of boiler which have been proposed as the most convenient for the attainment of all these requisite purposes have been very various. If strength alone were considered, the spherical form would be the best; and the early boilers were very nearly hemispheres, placed on a slightly concave base. The form adopted by Watt, called the waggon boiler, consists of a semi-cylindrical top, flat perpendicular sides, flat ends, and a slightly concave bottom. The steam intended to be used in boilers of this description did not exceed the pressure of the external atmosphere by more than from 3 to 5lbs. per square inch; and the flat sides and ends, though unfavourable to strength, could be constructed sufficiently strong for this purpose. In a boiler of this sort, the air and smoke passing through the flues that are carried round it, are in contact at one side only with the boiler. The brickwork, or other materials forming the flue, must therefore be non-conductors of heat, that they may not absorb any considerable portion of heat from the air passing in contact with them.

A boiler of this form is represented in *fig.* 67. The grate and a part of the flues are rendered visible by the removal of a portion of the surrounding masonry in which the boiler is set. The interior of the boiler is also shown by cutting off one half of the semi-cylindrical roof. A longitudinal vertical section is shown in *fig.* 68., and a cross section in *fig.* 69. A horizontal section taken above the level of the grate, and below the level of the water in the boiler, showing the course of the flues, is given in *fig.* 70. The corresponding parts in all the figures are marked by the same letters.

(112.) *Method of working the furnace.*—The door by which fuel is introduced upon the grate is represented at A, and the door leading to the ash-pit at B. The fire bars at C slope downwards from the front at an angle of about 25°, giving a tendency to the fuel to move from the front towards

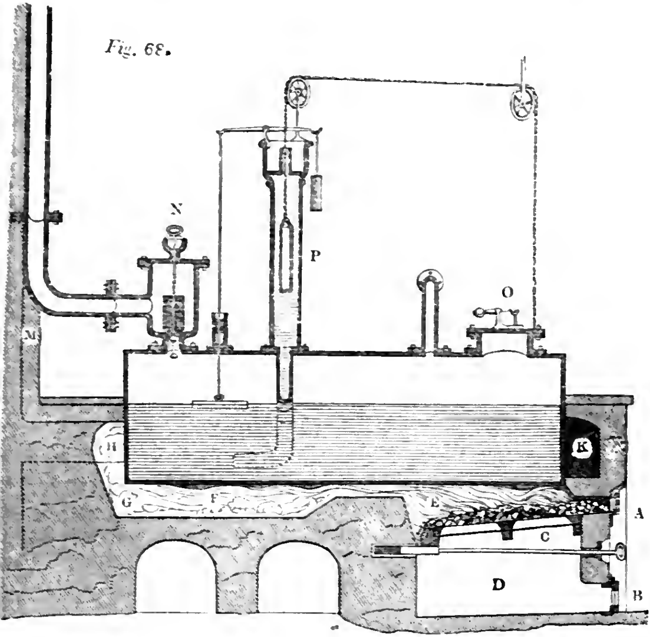
*Fig.* 67.




the back of the grate. The ash-pit D is constructed of such a magnitude, form, and depth, as to admit a current of atmospheric air to the grate-bars, sufficient to sustain the combustion. The form of the ash-pit is usually wide below contracting towards the top.

The fuel when introduced at the fire-door A, should be laid on that part of the grate nearest to the fire-door, called the dead plates: there it is submitted to the process of coking, by which the gases and volatile matter which it contains are expelled, and being carried by a current of air admitted through small apertures in the fire-door over the burning fuel in the hinder part of the grate, they are burnt.

*Fig.* 68.



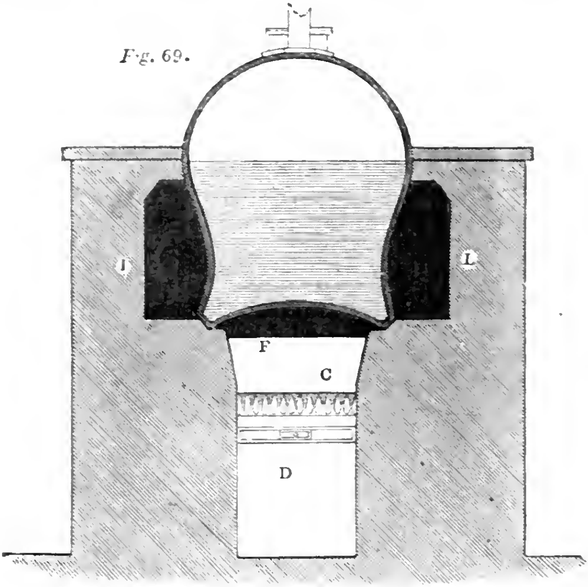

When the fuel in front of the grate has been thus *coked*, it is pushed back, and a fresh feed introduced in front. The coal thus pushed back soon becomes vividly ignited, and by continuing this process, the fuel spread over the grate is maintained in the most active state of combustion at the hinder part of the grate. By such an arrangement, the smoke produced by the combustion of the fuel may be burnt before it enters the flues. The flame and heated air proceeding from the burning fuel arising from the grate, and rushing towards the back of the furnace, passes over the *fire-bridge* E, and is carried through the flue F which passes under the boiler. This flue (the cross section of which is shown in *fig.* 69., by the dark shade put under the boiler) is very nearly equal in width to the bottom of the boiler, the space at the bottom of the boiler, near the corners, being only what is sufficient to give the weight of the boiler support on the masonry forming the sides of the flue. The bottom of the boiler being concave, the flame and heated air as they pass along the flue rise to the upper part by the effects of their high temperature, and *lick* the bottom of the boiler from the fire-bridge at E to the further end G.

At G the flue rises to H, and turning to the side of the boiler at I I, conducts the flame in contact with the side from the back to the front; it then passes through the flue K across the front, and returns to the back by the other side flue L. The side flue is represented, stripped of the masonry, in *fig.* 67., and also appears in the plan in *fig.* 70., and in the cross section in *fig.* 69. The course of the air is represented in *fig.* 70. by the arrows. From the flue L the air is conducted into the chimney at M.

By such an arrangement, the flame and heated air proceeding from the grate are made to circulate round the boiler, and the length and magnitude of the flues through which they are conducted should be such, that when they arrive at the chimney their temperature shall be reduced, as nearly as is consistent with the maintenance of draught in the chimney, to the temperature of the water.

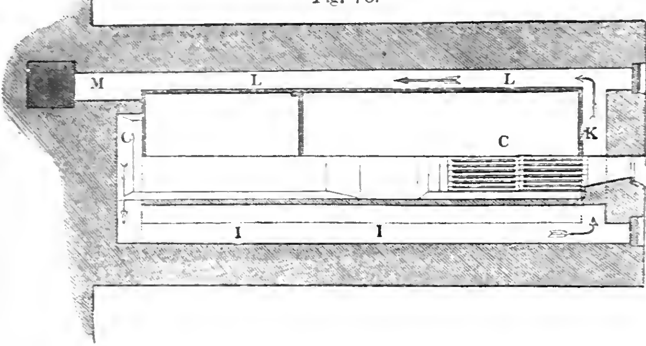
The method of feeding the furnace, which has been described above, is one which, if conducted with skill and care, would produce a much more perfect combustion of the fuel than would attend the common method of filling the grate from the back to the front with fresh fuel, whenever the furnace is fed. This method, however, is rarely observed in the management of the furnace. It requires the constant attention of the stokers (such is the name given to those who feed the furnaces). The fuel must be supplied, not in large quantities, and at distant intervals, but in small quantities and more frequently. On the other hand, the more common practice is to allow the fuel on the grate to be in a great degree burned away, and then to heap on a large quantity of fresh fuel, covering over with it the burning fuel from the back to the front of the grate. When this is done, the heat of the ignited coal acting upon the fresh fuel introduced, expels the gases combined with it, and, mixed with these, a

*Fig.* 69.




quantity of carbon, in a state of minute division, forming an opaque black smoke. This is carried through the flues and

*Fig.* 70.




drawn up the chimney. The consequence is, that not only a quantity of solid fuel is sent out of the chimney unconsumed, but the hydrogen and other gases also escaped unburned, and a proportional waste of the combustible is produced; besides which, the nuisance of an atmosphere filled with smoke ensues. Such effects are visible to all who observe the chimneys of steam vessels, while the engine is in operation. When the furnaces are thus filled with fresh fuel, a large volume of dense black smoke is observed to issue from the chimney. This gradually subsides as the fuel on the grate is ignited, and does not reappear until a fresh feed is introduced.

The former method of feeding, by which the furnace would be made to consume its own smoke, and the combustion of the fuel be rendered complete, is not however free from counteracting effects. In ordinary furnaces the feed can only be introduced by opening the fire-doors, and during the time the fire-doors are opened a volume of cold air rushes in, which passing through the furnace is carried through the flues to the chimney. Such is the effect of this in lowering the temperature of the flues, that in many cases the loss of heat occasioned is greater than any economy of fuel obtained by the complete consumption of smoke. Various methods, however, may be adopted by which fuel may be supplied to the grate without opening the fire-doors, and without disturbing the supply of air to the fire. A hopper built into the front of the furnace, with a moveable bottom or valve, by which coals may be allowed to drop in from time to time upon the front of the grate, would accomplish this.

In order to secure the combustion of the gases evolved from the coals placed in the front of the grate, it is necessary that a supply of atmospheric air should be admitted with them over the burning fuel. This is effected by small apertures or regulators, provided in the fire-doors, governed by sliding plates, by which they may be opened or closed to any required extent.

(113.) *Dimensions and proportions of the boiler.*—Whatever be the form of boiler used, its magnitude and proportions as well as those of the furnaces and their appendages must be determined by the rate at which the steam is required to be produced, and in some degree also by the quality of the fuel. It is much to be regretted, that the proportions of the various parts of steam engines, including their boilers and furnaces, have not been determined by any exact or satisfactory experiments. Those who project and manufacture the engines themselves are not less in ignorance on those points than others. With coals of the common quality a certain average proportion must exist between the magnitude of the grate-surface and the quantity of water to be evaporated in a given time in the boiler. But what that proportion is for any given quality of fuel, is at present unascertained. Each engine maker follows his own rule, and the rule thus followed is in most cases a matter of bare conjecture, unsupported by any experimental evidence. Some engine makers will allow a square foot of grate-surface for every cubic foot of water per hour, which is expected to be evaporated in the boiler; others allow only half a square foot; and practice varies between these limits. Bituminous coals which melt and cake, and which burn with much flame and smoke, must be spread more thinly on the grate than other descriptions of fuel, otherwise a considerable quantity of combustible gases would be dismissed into the flues unburnt. Such coals, therefore, other circumstances being the same, require a larger portion of grate-surface; and the same may be said of coals which produce clinkers in their combustion, and form lumps of vitrified matter on the grate, by which the spaces between the grate bars are speedily closed up. When such fuel is used, the grate bars require to be frequently raked out, otherwise the spaces between them being obstructed, the draught would become insufficient for the due combustion of the fuel.

To facilitate the raking out of the grate, the bars are placed with their ends towards the fire-door: they are usually made of cast-iron, from two to two inches and a half wide on the upper surface, with intervals of nearly half an inch between them. The bars taper downwards, their under-surfaces being much narrower than their upper, the spaces between them thus widening, to facilitate the fall of the ashes between them. The grate-bars slope downwards from the front to the back. The height of the centre of the bottom of the boiler, above the front of the grate, is usually about two feet, and about three feet above the back of it. The concave bottom of the boiler, however, brings its surfaces at the slide closer to the grate.

Between the evaporating power of the boiler and the magnitude of surface it exposes to the action of the furnace, there is a relation which, like that of the grate-surface, has never been ascertained by any certain or satisfactory experimental investigation, much less have the different degrees of efficiency attending different parts of the boiler-surface been determined. That part of the surface of the boiler immediately over and around the grate, is exposed to the immediate radiation of the burning fuel, and is therefore probably the most efficient in the production of steam. The tendency of flame and heated air to rise, would naturally bring them in the flues into closer contact with those parts of the boiler-surface which are horizontal in their position, and which form the tops of the flues, than with those which are lateral or vertical in their position, and which form the sides of the flues. In a boiler constructed like that already described, the flue-surface therefore, which would be most efficient, would be the concave bottom of the boiler extending from the fire-bridge to its remote end. In some boilers, especially those in which steam of high pressure is produced, the form is cylindrical, the middle flue being formed into an elliptical tube, the greater axis of which is horizontal from end to end of the boiler. It seems doubtful, however, whether in such a boiler the heat produces any useful effect on the water below the flue, the water above being always at a higher temperature, and therefore lighter than that below, and consequently no currents being established between the upper and lower strata of the water.

It was considered by Mr. Watt, but we are not aware on what experimental grounds, that from eight to ten square feet of heating surface were sufficient to produce the evaporation of one cubic foot of water per hour. The practice of engine makers since that time has been to increase the allowance of heating surface for the same rate of evaporation. Engine builders have varied very much in this respect, some allowing twelve, fifteen, and even eighteen square feet of surface for the same rate of evaporation. It must, however, still be borne in mind, that whether this increased allowance did or did not produce the actual evaporation imputed to it, has not been, as far as we are informed, ever accurately ascertained. The production of a given rate of evaporation by a moderate heat diffused over a larger surface, rather than by a fiercer temperature confined to a smaller surface, is attended with many practical advantages. The plates of the boiler acted upon by the fire are less exposed to oxidation, and the boiler will be proportionally more durable.

Besides presenting to the action of the fire a sufficient surface to produce steam at the required rate, the capacity of the boiler must be proportioned to the quantity of water to be evaporated. The space within the boiler is appropriated to a twofold purpose: 1st, To contain the water to be evaporated; 2dly, To contain a quantity of ready made steam for the supply of the cylinder.

If the space appropriated to the steam did not bear a considerable proportion to the magnitude of the cylinder, the momentary expansion of the steam passing to the cylinder from the boiler at each stroke would reduce the pressure of the steam in a great proportion, and unless the pressure in the boiler were considerably greater than that which the steam is intended to have in the cylinder, the pressure in the latter would be reduced below the proper amount.

(114.) *Waste of heat produced by priming.* — The water contained in the boiler being maintained in a state of violent ebullition, a spray is thrown up from its surface which is mixed with the steam. If the space provided above the water level for the steam have not sufficient height to allow this spray to subside, it will be drawn with the steam through the steam pipe and through the cylinder, and having none of the mechanical efficacy of steam, will thus produce an expenditure of heat without any corresponding useful effect. This escape of water unevaporated in the form of spray through the pipes and cylinder is called by engineers, PRIMING.

In forms of boilers, such for example as those of locomotive engines, where the necessary height cannot be allowed for the steam space, expedients are contrived for separating the priming from the steam before the latter reaches the steam pipe, as will be explained hereafter.

The water space provided in the boiler should bear such a ratio to its rate of evaporation, that the supply of the feed at a comparatively low temperature shall not unduly chill the water.

(115.) *Average dimensions of boilers in relation to their evaporating power.* — The practice of constructors of steam engines has been so various in the proportions assigned to boilers in relation to their proposed evaporating power, that it is impossible to give an average estimate of them which can pretend to much precision. The following proportions, however, are adopted very extensively among steam engine makers, and, subject to qualification according to the magnitude of the boiler and to the fuel used, may be taken as a fair statement as applied to stationary boilers of the larger class: —

For every cubic foot of water to be evaporated per hour allow

*One square foot* of grate bar,
*Three cubic feet* of furnace space,
*One square yard* of heating surface,
*Ten cubic feet* of water space,
*Ten cubic feet* of steam space,
*Five square feet* of water surface.

(116.) *Position of water surface.* — The surface of the water in the boiler should always be above the range of the flues. When the heated air in the flues acts upon a part of the boiler within which water is contained, the water within receiving an increased temperature becomes, bulk for bulk, lighter than the strata of water above it, and ascends. It is replaced by the descending strata, which, in their turn receiving increased temperature, rise to the surface; or if the action of the heat convert the water into steam, the bubbles of steam rise to the surface, fresh portions of water continually coming into contact with the boiler plates on which the heated air or flame acts. By this process the boiler plates are continually cooled, either by being successively washed by water at a lower temperature, or by the heat taken from them becoming latent in the steam bubbles formed in contact with them. But if the heat act upon a part of the boiler containing steam within it, which steam being a slow recipient of heat, and no currents being established, nor any phenomenon produced in which heat is rendered latent, the heat of the fire communicated to the boiler plates accumulates in them, and raises their temperature to an injurious degree. The plates may by this means be softened, so as to cause the boiler to burst, or the difference between the expansion of the highly heated plates thus exposed to fire in contact with steam and that of the plates which are cooled by contact with water, may cause the joinings of the boiler plates to open, and the boiler to leak. By whatever means, therefore, the boiler be fed, care should be taken that the evaporation should not be allowed to reduce the level of the water in it below the highest flue.

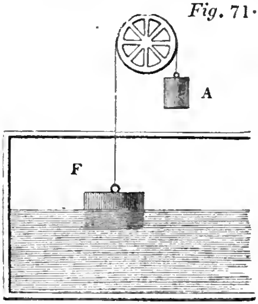
(117.) *Methods of indicating it.* — As the water by which the boiler is fed must always have a much lower temperature than that at which the boiler is maintained, the supply of the feed will have a constant tendency to lower the temperature of the water, and this tendency will be determined by the proportion between the magnitude of the feed and the quantity of water in the boiler.

Since it is requisite that the level of the water in the boiler shall not suffer any considerable change, it is evident that the magnitude of the feed must be equal to the quantity of water evaporated. If it were less, the level of the water would continually fall by reason of the excess of the evaporation over the feed; and if it were greater, the level would rise by the accumulation of water in the boiler. If, therefore, the quantity of water space allowed in the boiler be five times the volume of water evaporated per hour, the quantity introduced by the feed per hour, whether continuously or at intervals, must be of the same amount. Since the process of evaporation is continuous, the variation of level of water in the boiler will be entirely dependent on the intervals between the successive feeds. If the feed be continuous, and always equal to the evaporation, then the level of the water in the boiler will undergo no change; but if while the evaporation is continuous the feed be made at intervals, then the change of level of water in the boiler as well as its change of temperature, will be subject to a variation proportional to the intervals between the successive feeds. It is manifest, therefore, that the feed should either be uninterrupted or be supplied at short intervals, so that the change of level and temperature of the water in the boiler should not be considerable.

(118.) *Water gauges.*—Different methods have been, from time to time, suggested for indicating the level of the water in the boiler. We have already mentioned the two gauge-pipes used in the earlier steam engines (22.), and which are still generally continued. There are, however, some other methods which merit our attention.

A weight F (*fig.* 71.), half immersed in the water in the boiler, is supported by a wire, which, passing steam-tight through a small hole in the top, is connected by a flexible string or chain, passing over a wheel W, with a counterpoise A, which is just sufficient to balance F when half immersed. If F be raised above the water, A being lighter will no longer balance it, and F will descend pulling up A, and turning the wheel W. If, on the other hand, F be plunged deeper in the water, A will more than balance it, and will pull it up, so that the only position in which F and A will balance each other is, when F is half immersed. The wheel W is so adjusted, that when two pins placed on its rim are in the horizontal position, the water is at its proper level. Consequently it follows, that if the water rise above this level, the weight F is lifted and A falls, so that the pins come into another position. If, on the other hand, the level of the water fall, F falls and A rises, so that the pins assume a different position. Thus, in general, the position of the pins becomes an indication of the quantity of water in the boiler.

*Fig.* 71.




Another method is to place a glass tube (*fig.* 72.), with one end T entering the boiler above the proper level, and the other end T′ entering it below the proper level. It must be evident that the water in the tube will always stand at the same level as the water in the boiler, since the lower part has a free communication with that water, while the surface is submitted to the pressure of the same steam as the water in the boiler. This and the last-mentioned gauge have the advantage of addressing the eye of the engineer at once, without any adjustment; whereas the gauge-cocks must be both opened, whenever the depth is to be ascertained.

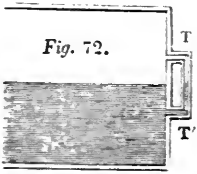


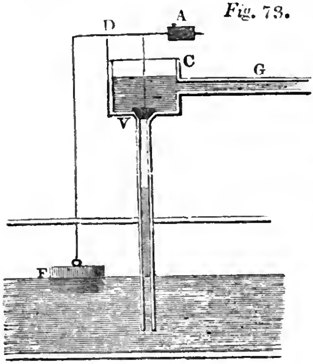
*Fig.* 72.

These gauges, however, require the frequent attention of the engine-man; and it becomes desirable either to find some more effectual means of awakening that attention, or to render the supply of the boiler independent of any attention. In order to enforce the attention of the engine-man to replenish the boiler when partially exhausted by evaporation, a tube was sometimes inserted at the lowest level to which it was intended that the water should be permitted to fall. This tube was conducted from the boiler into the engine-house, where it terminated in a mouth-piece or whistle, so that whenever the water fell below the level at which this tube was inserted in the boiler, the steam would rush through it, and issuing with great velocity at the mouth-piece, would summon the engineer to his duty with a call that would rouse him even from sleep.

(119.) *Self-acting feeders.*— In the most effectual of these methods, the task of replenishing the boiler must still be executed by the engineer; and the utmost that the boiler itself was made to do, was to give due notice of the necessity for the supply of water. The consequence was, among other inconveniencies, that the level of the water was subject to constant variation.

To remedy this a method has been invented, by which the engine is made to feed its own boiler. The pipe G (*fig.* 73.), which leads from the hot water pump, terminates in a small cistern C in which the water is received. In the bottom of this cistern, a valve V is placed, which opens upwards and communicates with a feed pipe, which descends into the boiler below the level of the water in it. The stem of the valve V is connected with a lever turning on the centre D, and loaded with a weight F dipped in the water in the boiler in a manner similar to that described in *fig.* 71., and balanced by a counterpoise A in exactly the same way. When the level of the water in the boiler falls, the float F falls with it, and pulling down the arm of the lever raises the valve V, and lets the water descend into the boiler from the cistern C. When the boiler has thus been replenished, and the level raised to its former place, F will again be raised, and the valve V closed by the weight A. In practice, however, the valve V adjusts itself by means of the effect of the water on the weight F, so as to permit the water from the feeding cistern C to flow in a continued stream, just sufficient in quantity to supply the consumption from evaporation, and to maintain the level of the water in the boiler constantly the same.

*Fig.* 73.




By this arrangement the boiler is made to replenish itself, or, more properly speaking, it is made to receive such a supply, as that it never wants replenishing, an effect which no effort of attention on the part of an engine-man could produce. But this is not the only good effect produced by this contrivance. A part of the steam which originally left the boiler, and having discharged its duty in moving the piston was condensed and reconverted into water, and lodged by the air-pump in the hot well (*fig.* 73.), is here again restored to the source from which it came, bringing back all the unconsumed portion of its heat preparatory to being once more put in circulation through the machine.

The entire quantity of hot water pumped into the cistern C is not always necessary for the boiler. A waste pipe may be provided for carrying off the surplus, which may be turned to any purpose for which it may be required; or it may be discharged into a cistern to cool, preparatory to being restored to the cold cistern, in case water for the supply of that cistern be not sufficiently abundant.

Another method of arranging a self-regulating feeder is shown in *fig.* 74. A is a hollow ball of metal attached to the

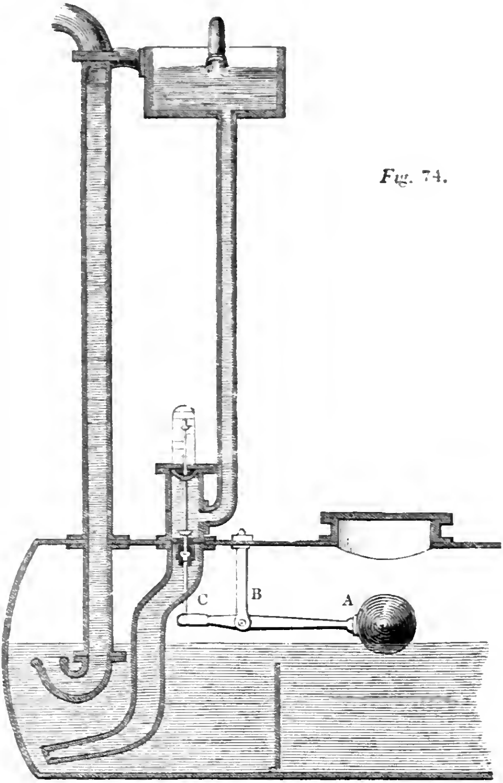
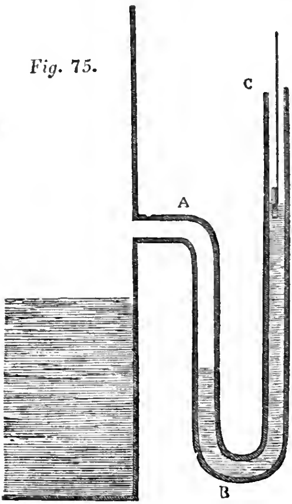



*Fig.* 74.

end of a lever, whose fulcrum is at B. The other arm of the lever C is connected with the stem of a spindle valve, communicating with a tube which receives water from the feeding cistern. Thus, when the level of the water in the boiler subsides, the ball A preponderating over the weight of the opposite arm, the lever falls, the arm C rises and opens the valve, and admits the feeding water. This apparatus will evidently act in the same manner and on the same principles as that already described.

(120.) *Mercurial steam gauge.*—It is necessary to have a ready method of ascertaining at all times the pressure of the steam which is used in working the engine. For this purpose a bent tube containing mercury is inserted into some part of the apparatus, which has free communication with the steam. Let A B C (*fig.* 75.), be such a tube. The pressure of the steam forces the mercury down in the leg A B, and up in the leg B C. If the mercury in both legs be at exactly the same level, the pressure of the steam must be exactly equal to that of the atmosphere; because the steam pressure on the mercury in A B balances the atmospheric pressure on the mercury in B C. If, however, the level of the mercury in B C be above the level of the mercury in B A, the pressure of the steam will exceed that of the atmosphere.

*Fig.* 75.




The excess of its pressure above that of the atmosphere may be found by observing the difference of the level of the mercury in the tubes B C and B A, allowing a pressure of one pound on each square inch for every two inches in the difference of the levels.

If, on the contrary, the level of the mercury in B C should fall below its level in A B, the atmospheric pressure will exceed that of the steam, and the quantity of the excess may be ascertained exactly in the same way.

If the tube be glass, the difference of levels of the mercury would be visible; but it is most commonly made of iron; and, in order to ascertain the level, a thin wooden rod with a float is inserted in the open end of B C, so that the portion of the stick within the tube indicates the distance of the level of the mercury from its mouth. A bulb or cistern of mercury might be substituted for the leg A B, as in the common barometer. This instrument is called the *steam gauge.*

If the steam gauge be used as a measure of the strength of the steam which presses on the piston, it ought to be on the same side of the throttle valve (which is regulated by the governor) as the cylinder; for if it were on the same side of the throttle valve with the boiler, it would not be affected by the changes which the steam may undergo in passing through the throttle valve, when partially closed by the agency of the governor.

For boilers in which steam of very high pressure is used. as in those of locomotive engines, a steam gauge, constructed on the above principle, would have inconvenient or impracticable length. In such boilers the pressure of the steam is equal to four or five times that of the atmosphere, to indicate which the column of mercury in the steam gauge would be four or five feet in height. In such cases a thermometer gauge may be used with advantage. The principle of this gauge is founded on the fact, that between the pressure and temperature of steam produced in contact with water there is a fixed relation, the same temperature always corresponding to the same pressure. If, therefore, a thermometer be immersed in the boiler which shall show the temperature of the steam, a scale may be attached to it, on which shall be engraved the corresponding pressures. Such gauges are now very generally used on locomotive engines.

(121.) *Barometer gauge.* — The force with which the piston is pressed depends on two things, 1st, the actual strength of the steam which presses on it; and, 2ndly, on the actual strength of the vapour which resists it. For although the vacuum produced by the method of separate condensation be much more perfect than what had been produced in the atmospheric engines, yet still some vapour of a small degree of elasticity is found to be raised from the hot water in the bottom of the condenser before it can be extracted by the air-pump. One of these pressures is indicated by the steam-gauge already described; but still, before we can estimate the force with which the piston descends, it is necessary to ascertain the force of the vapour which remains uncondensed, and resists the motion of the piston. Another gauge, called the barometer gauge, is provided for this purpose. A glass tube A B (*fig.* 76.), more than thirty inches long and open at both ends, is placed in an upright or vertical position, having the lower end B immersed in a cistern of mercury C. To the upper end is attached a metal tube, which communicates with the condenser, in which a constant vacuum, or rather high degree of rarefaction, is sustained. The same vacuum must therefore exist in the tube A B, above the level of the mercury, and the atmospheric pressure on the surface of the mercury in the cistern C will force the mercury up in the tube A B, until the column which is suspended in it is equal to the difference between the atmospheric pressure and the pressure of the uncondensed steam. The difference between the column of mercury sustained in this instrument and in the common barometer, will determine the strength of the uncondensed steam, allowing a force proportional to one pound per square inch for every two inches of mercury in the difference of the two columns. In a well-constructed engine which is in good order, there is very little difference between the altitude in the barometer gauge and the common barometer.

*Fig.* 76.


(122.) *Method of computing the effective pressure on the piston.* — To compute the force with which the piston descends, thus becomes a very simple arithmetical process. First, ascertain the difference of the levels of the mercury in the steam gauge; this gives the excess of the steam pressure above the atmospheric pressure. Then find the height of the mercury in the barometer gauge; this gives the excess of the atmospheric pressure above the uncondensed steam. Hence, if these two heights be added together, we shall obtain the excess of the impelling force of the steam from the boiler, on the one side of the piston, above the resistance of the uncondensed steam on the other side; this will give the effective impelling force. Now, if one pound be allowed for every two inches of mercury in the two columns just mentioned we shall have the number of pounds of impelling pressure on every square inch of the piston. Then, if the number of square inches in the section of the piston be found, and multiplied by the number of pounds on each square inch, the force with which it moves will be obtained.

From what we have stated it appears, that, in order to estimate the force with which the piston is urged, it is necessary to refer to both the barometer and the steam gauge. This double computation may be obviated by making one gauge serve both purposes. If the end C of the steam gauge (*fig.* 75.), instead of communicating with the atmosphere, were continued to the condenser, we should have the pressure of the steam acting upon the mercury in the tube B A, and the pressure of the uncondensed vapour which resists the piston acting on the mercury in the tube B C. Hence the difference of the levels of the mercury in the tubes would at once indicate the difference between the force of the steam and that of the uncondensed vapour, which is the effective force with which the piston is urged.

(123.) *Condensation not instantaneous.*—But these methods of determining the effective force by which the piston is urged, can only be regarded as approximations, and not very perfect ones. If the condensation of steam on one side of the piston were instantaneously effected, or the uncondensed vapour were of the same tension during the whole stroke; and if, besides this, the pressure of steam on the piston were of uniform intensity from the beginning to the end of the stroke, then the steam and barometer gauges taken together would become an accurate index of the effective force of steam on the piston: but such is not the case. When the steam is first admitted through the steam valve it acts on the piston with a pressure which is first slightly diminished, and afterwards a little increased, until it arrives at that part of the stroke at which the steam valve is closed, after which the pressure is diminished. The pressure, therefore, urging the piston is subject to variation; but the pressure of the uncondensed vapour on the other side of the piston is subject to still greater change. At the moment the exhausting valve is opened, the piston is relieved from the pressure upon it by the commencement of the condensation; but this process during the descent of the piston is gradual, and the vacuum is rendered more and more perfect, until the piston has nearly attained the limit of its play. These variations both as well of the force urging the piston as of the force resisting it, are such as not to be capable of being accurately measured by a mercurial column, since they would produce oscillations in such a column, which would render any observations of its mean height impracticable.

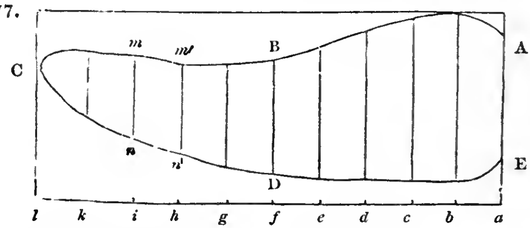
(124.) *Watt's indicator.* — To measure the mean efficient force of the piston, taking into account these circumstances, Mr. Watt invented an instrument, which, like all his mechanical inventions, has answered its purpose perfectly, and is still in general use. This instrument, called an *indicator*, consists of a cylinder of about $1\frac{3}{4}$ inch in diameter, and 8 inches in length. It is bored with great accuracy, and fitted with a solid piston moving steam-tight in it with very little friction. The rod of this piston is guided in the direction of the axis of the cylinder through a collar in the top, so as not to be subject to friction in any part of its play. At the bottom of the cylinder is a pipe governed by a stop-cock and turned in a screw, by which the instrument may be screwed on the top of the steam cylinder of the engine. In this position, if the stop-cock of the indicator be opened, a free communication will be made between the cylinder of the indicator and that of the engine. The piston rod of the indicator is attached to a spiral spring, which is capable of extension and compression, and which by its elasticity is capable of measuring the force which extends or compresses it in the same manner as a spring steel-yard or balance. If a scale be attached to the instrument at any point on the piston rod to which an index might be attached, then the position of that index upon the scale would be governed by the position of the indicator piston in its cylinder. If any force pressed the indicator piston upwards, so as to compress the spring, the index would rise upon the scale; and if, on the other hand, a force pressed the indicator piston downwards, then the spiral spring would be extended, and the index on the piston rod descend upon the scale. In each case the force of the spring, whether compressed or extended, would be equal to the force urging the indicator piston, and the scale might be so divided as to show the amount of this force.

Now let the instrument be supposed to be screwed upon the top of the cylinder of a steam engine, and the stop-cock opened so as to leave a free communication between the cylinder of the indicator below its piston and the cylinder of the steam engine above the steam piston. At the moment the upper steam valve is opened, the steam rushing in upon the steam piston will also pass into the indicator, and press the indicator piston upwards: the index upon its piston rod will point upon the scale to the amount of pressure thus exerted. As the steam piston descends, the indicator piston will vary its position with the varying pressure of the steam in the cylinder, and the index on the piston rod will play upon the scale, so as to show the pressure of the steam at each point during the descent of the piston.

If it were possible to observe and record the varying positions of the index on the piston rod of the indicator, and to refer each of these varying positions to the corresponding point of the descending stroke, we should then be able to declare the actual pressure of the steam at every point of the stroke. But it is evident that such an observation would not be practicable. A method, however, was contrived by Mr. Southern, an assistant of Messrs. Boulton and Watt, by which this is perfectly effected. A square piece of paper, or card, is stretched upon a board, which slides in grooves formed in a frame. This frame is placed in a vertical position near the indicator, so that the paper may be moved in a horizontal direction backwards and forwards, through a space of fourteen or fifteen inches. Instead of an index, a pencil is attached to the indicator of the piston rod: this pencil is lightly pressed by a spring against the paper above mentioned, and as the paper is moved in a horizontal direction, the pencil would trace upon it a line. If the pencil were stationary, this line would be straight and horizontal, but if the pencil were subject to a vertical motion, the line traced on the paper moved under the pencil horizontally would be a curve, the form of which would depend on the vertical motion of the pencil. The board thus supporting the paper is put into connection by a light cord carried over pulleys with some part of the parallel motion, by which it is alternately moved to the right and to the left. As the piston ascends or descends, the whole play of the board in the horizontal direction will therefore represent the length of the stroke, and every fractional part of that play will correspond to a proportional part of the stroke of the steam piston.

The apparatus being thus arranged, let us suppose the steam piston at the top of the cylinder commencing its descent. As it descends, the pencil attached to the indicator piston rod varies its height according to the varying pressure of the steam in the cylinder. At the same time the paper is moved uniformly under the pencil, and a curved line is traced upon it from right to left. When the piston has reached the bottom of the cylinder, the upper exhausting valve is opened, and the steam drawn off to the condenser. The indicator piston being immediately relieved from a part of the pressure acting upon it descends, and with it the pencil also descends; but at the same time the steam piston has begun to ascend, and the paper to return from left to right under the pencil. While the steam piston continues to ascend, the condensation becomes more and more perfect, and the vacuum in the cylinder, and therefore also in the indicator, being gradually increased in power, the atmospheric pressure above the indicator piston presses it downwards and stretches the spring. The pencil meanwhile, with the paper moving under it from right to left, traces a second curve. As the former curve showed the actual pressure of the steam impelling the piston in its descent, this latter will show the pressure of the uncondensed steam resisting the piston in its ascent, and a comparison of the two will exhibit the effective

*Fig.* 77.




force on the piston. *Fig.* 77. represents such a diagram as would be produced by this instrument. A B C is the curve traced by the pencil during the descent of the piston, and C D E that during its ascent. A is the position of the pencil at the moment the piston commences its descent, B is its position at the middle of the stroke, and C at the termination of the stroke. On closing the upper steam valve and closing the exhausting valve, the indicator piston being gradually relieved from the pressure of the steam, the pencil descends, and at the same time the paper moving from left to right, the pencil traces the curve C D E, the gradual descent of this curve showing the progressive increase of the vacuum. As the atmospheric pressure constantly acts above the piston of the indicator, its position will be determined by the difference between the atmospheric pressure and the pressure of the steam below it; and therefore the difference between the heights of the pencil at corresponding points in the ascending and descending stroke, will express the difference between the pressure of the steam impelling the piston in the ascent and resisting it in the descent at these points. Thus, at the middle of the stroke, the line B D will express the extent to which the spring governing the indicator piston would be stretched by the difference between the force of steam impelling the piston at the middle of the descending stroke, and the force of steam resisting it at the middle of the ascending stroke. The force, therefore, measured by the line B D will be the effective force on the piston at that point, and the same may be said of every part of the diagram produced by the indicator.

The whole mechanical effect produced by the stroke of the piston being composed of the aggregate of all its varying effects throughout the stroke, the determination of its amount is a matter of easy calculation by the measurement of the diagram supplied by the indicator. Let the horizontal play of the pencil from A to C be divided into any proposed number of equal parts, say ten: at the middle of the stroke, B D expresses the effective force on the piston; and if this be considered to be uniform through the tenth part of the stroke, as from $f$ to $g$, then the number of pounds expressed by B D multiplied by the tenth part of the stroke expressed in parts of a foot, will be the mechanical effect through that part of the stroke expressed in pounds' weight raised one foot. In like manner $m\,n$ will express the effective force on the piston after three-fourths of the stroke have been performed, and if this be multiplied by a tenth part of the stroke as before, the mechanical effect similarly expressed will be obtained; and the same process being applied to every successive tenth part of the stroke, and the numerical results thus obtained being added together, the whole effect of the stroke will be obtained, expressed in pounds' weight raised one foot.

By means of the indicator, the actual mechanical effect produced by each stroke of the engine can be obtained, and if the actual number of strokes made in any given time be known, the whole effect of the moving power would be determined. An instrument called a *counter* was also contrived by Watt, to be attached either to the working beam, or to any other reciprocating part of the engine. This instrument consisted of a train of wheel-work with governing hands, or indices moved upon divided dials, like the hand of a clock. A record of the strokes was preserved by means precisely similar to those by which the hands of a clock or timepiece indicated and recorded the number of vibrations of the pendulum or balance wheel.

(125.) *Safety valve.* — To secure the boiler from accidents arising from the steam contained in it acquiring an undue pressure, a safety valve is used, similar in principle to those adopted in the early engines. This valve is represented in *fig.* 67. at N. It is a conical valve, kept down by a weight sliding on a rod upon it. When the pressure of the steam overcomes the force of this weight, it raises the valve and escapes, being carried off through the tube.

With a view to the economy of heat, this waste steam tube is sometimes conducted into the feeding cistern, where the steam carried off by it is condensed, and heats the feeding water.

The magnitude of the safety valve should be such that, when open, steam should be capable of passing through it as rapidly as it is generated in the boiler. The superficial magnitude, therefore, of such valves must be proportional to the evaporating power of the boiler. In low pressure boilers the steam is generally limited to five or six pounds' pressure per square inch, and consequently the load over the safety valve in pounds would be found by multiplying the superficial magnitude of its smallest part by these numbers. In boilers in which the steam is maintained at a higher pressure, it would be inconvenient to place upon the safety valve the necessary weight. In such cases a lever is used, the shorter arm of which presses down the valve, and the longer arm is held down by a weight capable of adjustment, so that the pressure on the valve may be regulated at discretion. Two safety valves should be provided on all boilers, one of which should be locked up, so that the persons in care of the engine should have no power to increase the load upon it. In such case, however, it is necessary that a handle connected with the valve should project outside the box containing it, so that it may always be possible for the engineer to ascertain that the valve is not locked in its seat, a circumstance which is liable to happen.

Sometimes also two safety valves are provided, one loaded a little heavier than the other. The escape of steam from the lighter valve in this case gives notice to the engine-man of the growing increase of pressure, and warns him to check the production of steam. The lever by which the safety valve is held down is sometimes acted on by a spiral spring, capable of being so adjusted as to produce any required pressure on the valve. This arrangement is adopted in locomotive engines, where steam of very high pressure is used; and in such cases also there are always provided two such valves, one of which cannot be increased in its pressure.

The pipe by which the boiler is fed with water will necessarily act as a safety valve; for when the pressure of the steam increases in an undue degree, it will press the water in the boiler up through the feed pipe, so as to discharge it into the feed cistern, a circumstance which would immediately give notice of the internal state of the boiler. The steam gauge, already described (*fig.* 75.), would also act as a safety valve; for if the pressure of steam in the boiler should be so augmented as to blow the mercury out of the steam-gauge, the steam would then issue through the gauge, and the pressure of the boiler be reduced, provided that the magnitude of the tube forming the steam gauge were sufficient for this purpose.

(126.) *Fusible plugs.* — In high pressure boilers which are exposed to extreme temperatures and pressures, and which are therefore subject to danger of explosion, a plug of metal is sometimes inserted, which is capable of being fused at a temperature above which the boiler should not be permitted to be raised. If the pressure of steam increase beyond the proper limit, the temperature of the water and steam will undergo a corresponding increase; and if the metal of the plug be capable of being fused at such a temperature, the plug will fall out of the boiler, and the steam and water will issue from it. Various alloys of metal are fusible at temperatures sufficiently low for this purpose. An alloy composed of one part of lead, three of tin, and five of bismuth, will fuse at the common temperature of boiling water; and alloys of the same metals, in various proportions, will fuse at different temperatures from 200° to 400°.

Although fusible plugs may be used, in addition to other means of insuring safety, they ought not to be exclusively relied on at the ordinary working pressure of the boiler. The fusible plug ought to be capable of more than resisting the pressure; but if it be so, its point of fusion would be one at which the steam would have a pressure of at least two atmospheres above its working pressure. The plug would therefore be capable of being fused only as soon as the steam would acquire a pressure of thirty pounds per inch above its regular working pressure.

(127.) *Their inefficiency.* — Practical authorities affirm that plugs of fusible metal inserted in boilers to prevent explosions are inefficient. It is said that the constituents of the compound metal being fusible at different temperatures, the more fusible will be melted first, and will be forced by the pressure of the steam through the interstices of the less fusible, its place being speedily filled by the solid matter which the water holds suspended. The plug thus acquires a composition and properties different from those which it originally had, and ceases to be fusible.*

How far this is mere matter of opinion and theoretical

* Steam Engine, by Artisan Club, p. 83.

conjecture does not appear. The author, however, admits that leaden plugs may with advantage be introduced in the tops of the fire boxes of tubular boilers, not with the idea that they will be melted out by the steam when its pressure becomes too high, but to be melted out and give notice of the danger if the water fall too low.

It must be remembered, however, that this is the proper purpose to which fusible plugs are directed. When the metal in the flues, or elsewhere, being out of contact with water, is unduly heated, the plug melts out, and allowing the steam to escape, at once gives notice of, and removes the danger.

(128.) *Internal safety valve.* — When a boiler ceases to be worked, and the furnace has been extinguished, the space within it appropriated to steam will be left a vacuum by the condensation of the steam with which it was previously filled. The external pressure of the atmosphere acting on the boiler would, under such circumstances, have a tendency to crush it inwards. To prevent this, a safety valve is provided, opening inwards, and balanced by a weight sufficient to keep it closed until it be relieved from the pressure of the steam below.

A large aperture closed by a flange secured with screws, represented at O in *fig.* 67., called the *man-hole*, is provided to admit persons into the boiler for the purpose of cleaning or repairing its interior.

(129.) *Self-regulating damper.* — The manner in which the governor regulates the supply of steam from the boiler to the cylinder, proportioning the quantity to the work to be done, and thereby sustaining a uniform motion, has been already explained (p. 85.). Since then the *consumption* of steam in the engine is subject to variation, owing to the various quantities of work it may have to perform, it is evident that the *production* of steam in the boiler should be subject to a proportional variation. For, otherwise, one of two effects would ensue: the boiler would either fail to supply the engine with steam, or steam would accumulate in the boiler from being produced in too great abundance, and would escape at the safety valve, and thus be wasted.

In order to vary the production of steam in proportion to the demands of the engine, it is necessary to stimulate or mitigate the furnace, as the evaporation is to be augmented or diminished.

The activity of the furnace must depend on the current of air which is drawn through the grate bars, and this will depend on the magnitude of the space afforded for the passage of that current through the flues. A plate called a *damper* is accordingly placed with its plane at right angles to the flue, so that by raising and lowering it in the same manner as the sash of a window is raised or lowered, the space allowed for the passage of air through the flue may be regulated. This plate might be regulated by the hand, so that by raising or lowering it the draught might be increased or diminished, and a corresponding effect produced on the evaporation in the boiler: but the force of the fire is rendered uniformly proportional to the rate of evaporation by the following arrangement, without the intervention of the engineer. The column of water sustained in the feed pipe (*figs.* 67, 68.) represents by its weight the difference between the pressure of steam within the boiler and that of the atmosphere. If the engine consumes steam faster than the boiler produces it, the steam contained in the boiler acquires a diminished pressure, and consequently the column of water in the feed pipe will fall. If, on the other hand, the boiler produce steam faster than the engine consumes it, the accumulation of steam in the boiler will cause an increased pressure on the water it contains, and thereby increase the height of the column of water sustained in the feed pipe. This column, therefore, necessarily rises and falls with every variation in the rate of evaporation in the boiler. A hollow float P is placed upon the surface of the water of this column; a chain connected with this float is carried upwards, and passed over two pulleys, after which it is carried downwards through an aperture leading to the flue which passes beside the boiler: to this chain is attached the damper. By such an arrangement it is evident that the damper will rise when the float P falls, and will fall when the float P rises since the weight of the damper is so adjusted, that it will only balance the float P when the latter rests on the surface of the water.

Whenever the evaporation of the boiler is insufficient, it is evident from what has been stated, that the float P will fall and the damper will rise, and will afford a greater passage for air through the flue. This will stimulate the furnace, will augment its heating power, and will therefore increase the rate of evaporation in the boiler. If, on the other hand, the production of steam in the boiler be more than is requisite for the supply of the engine, the float will be raised and the damper let down, so as to contract the flue, to diminish the draught, to mitigate the fire, and therefore to check the evaporation. In this way the excess, or defect, of evaporation in the boiler is made to act upon the fire, so as to render the heat proceeding from the combustion as nearly as possible proportional to the wants of the engine.

(130.) *Self-regulating furnace.* — The method of feeding the furnace by hand through the fire-door being subject to the double objection of admitting more cold air over the fuel than is necessary for its combustion, and the impracticability of insuring regular attendance on the part of the stokers, directed the attention of engineers to the construction of self-regulating furnaces. The most effectual of these, and that which has come into most general use, was invented by Mr. William Brunton of Birmingham.

The advantages proposed to be attained by him were those expressed in his patent: —

"First, I put the coal upon the grate by small quantities, and at very short intervals, say every two or three seconds. 2dly, I so dispose of the coals upon the grate, that the smoke evolved must pass over that part of the grate upon which the coal is in full combustion, and is thereby consumed. 3dly, As the introduction of coal is uniform in short spaces of time, the introduction of air is also uniform, and requires no attention from the fireman.

"As it respects economy: 1st, The coal is put upon the fire by an apparatus driven by the engine, and so contrived that the quantity of coal is proportioned to the quantity of work which the engine is performing; and the quantity of air admitted to consume the smoke is regulated in the same manner. 2dly, The fire door is never opened, excepting to clean the fire; the boiler, of course, is not exposed to that continual irregularity of temperature which is unavoidable in the common furnace, and which is found exceedingly injurious to boilers. 3dly, The only attention required is to fill the coal receiver every two or three hours, and clean the fire when necessary. 4thly, The coal is more completely consumed than by the common furnace, as all the effect of what is termed stirring up the fire (by which no inconsiderable quantity of coal is passed into the ash-pit), is attained without moving the coal upon the grate."

A circular grate is placed on a vertical revolving shaft; on the lower part of this shaft, under the ash-pit, is placed a toothed wheel driven by a pinion. This pinion is placed on another vertical shaft, which ascends above the boiler; and on the other end of this is placed a bevelled wheel driven by a pinion. This pinion is attached to a shaft, which takes its motion from the axis of the fly-wheel, or any other revolving shaft connected with the engine. A constant motion of revolution is therefore imparted to the circular grate, and its velocity being proportional to that of the engine, will necessarily be also proportional to the quantity of fuel which ought to be consumed. Through that part of the boiler which is over the fire grate, a vertical tube or opening is made directly over that part of the furnace which is most distant from the flues. Over this opening a hopper is placed, which contains the fuel by which the boiler is to be fed; and in the bottom of this hopper is a sliding valve, capable of being opened or closed, so as to regulate the quantity of fuel supplied to the fire grate. The fuel dropping in, in small quantities, through this open valve, falls on the grate, and is carried round by it, so as to leave a fresh portion of the grate to receive succeeding feeds. The coals admitted through the hopper are previously broken to a proper size; and in some forms of this apparatus there are two rollers, at a regulated distance asunder, the surfaces of which are formed into blunt angular points, and which are kept in slow revolution by the engine. Between these rollers the coals must pass before they reach the valve through which the furnace is fed, and they are thus broken and reduced to a regulated size. The valve which regulates the opening through which the feed is admitted, is connected by chains and pulleys with the self-regulating damper already described, so that in proportion as the damper is raised, the valve governing the feed may be opened. Thus, while the quantity of air admitted by the damper is increased according to the demands of the engine, the quantity of fuel admitted for the feed is increased by opening the valve in the bottom of the hopper in the same proportion. Apertures are also provided in the front of the grate, governed by regulators, by which the quantity of air necessary and sufficient to produce the combustion of the gas evolved from the fuel is admitted, these openings being also connected with the self-regulating damper.

(131.) *Non-conducting coating on boiler.*— A considerable portion of the heat imparted to the water in the boiler escapes by radiation from the surface of the boiler, steam pipes, and other parts of the machinery in contact with the steam and hot water. The effects of this are rendered very apparent in marine engines, where a large quantity of water is found to be condensed in the great steam pipes leading from the boiler to the cylinder. In stationary land boilers this loss of heat is usually diminished, and in some cases in a great degree removed, by surrounding the boiler with non-conducting substances. In some cases the boiler is built round in brick work. In Cornwall, where economy is regarded perhaps to a greater extent than elsewhere, the boiler and steam pipes are surrounded with a packing of sawdust, which being almost a non-conductor of heat, is impervious to the heat proceeding from the surfaces with which it is in contact, and consequently confines all the heat within the boiler. In marine boilers it has been the practice recently to clothe the boiler and steam pipes with a coating of felt, which is attended with a similar effect. When these remedies are properly applied, the loss of heat proceeding from the radiation of the boiler is reduced to an extremely small amount. The engine houses of some of the Cornish engines, where the boiler generates steam at a very high temperature, are nevertheless frequently maintained at a lower temperature than the external air, and on entering them they have in a great degree the effect of a cave.

(132.) *Self-regulating and self-registering apparatus proposed by Dr. Lardner.* — About the epoch when the project of navigating the Atlantic by steam was first undertaken, the question of the efficiency of steam engines in relation to their consumption of fuel was much discussed; and the scantiness of reliable data, as well as the difficulty of enforcing such practice among engineers as would supply them, was universally acknowledged.

At this period I brought under the notice of the British Association a self-regulating apparatus, and exhibited its practical performance. A web of paper was rolled upon a small metal drum, and a larger drum, which was kept in revolution by means of clock-work, received the roll of paper as it was discharged from the smaller drum. At proper distances round the larger drum, pencils of different colours were placed, acted upon by floats applied in siphon tubes containing columns of mercury, with which the steam pipe, the condenser, the surface of the water in the boiler and other apparatus of the engine whose changes were required to be registered, were respectively connected. Where any of these varied, the pencil attached to the float of the siphon gauge communicating with the boiler was raised or depressed; and by this motion of the pencil, combined with the motion of the paper on the drum under it, a curve was traced upon the paper, the ordinates of which indicated the varying pressure of the steam, the varying level of the water, or any other change which took place in those parts of the engine which required registration. At convenient intervals the paper was to be taken off, and its indications translated into words.

The difference in the colours of the different pencils prevented the indication made by each from being confused, even though the curves were liable to intersect each other.

This apparatus was never applied in practice. The chief purpose to which it was directed at the time was the registration of the performance of marine engines. It was, however, found impracticable to induce the engineers and others who had the management of steam vessels to adopt it.

# CHAPTER VIII.

## OF THE POWER AND DUTY OF ENGINES.

(133.) *Gross and useful effect of engines.*—All mechanical action is measured by the amount of force exercised, or resistance overcome, and the space through which that force has acted, or through which the resistance has been moved.

The gross amount of mechanical action developed by the moving power of an engine, is expended partly on moving the engine itself, and partly on overcoming the resistance on which the engine is intended to act. That part of the mechanical energy of the moving power which is expended on the resistance or load which the engine moves, exclusively of the power expended on moving the engine itself, is called the *useful effect* of the machine.

The *gross effect*, therefore, exceeds the *useful effect* by the amount of power spent in moving the engine, or which may be wasted or destroyed in any way by the engine.

It is usual to express and estimate all mechanical effect, whatever be the nature of the resistance overcome, by an equivalent weight raised a certain height. Thus, if an engine exerts a certain power in driving a mill, in drawing a carriage on a road, or in propelling a vessel on water, the resistance against which it has to act must be equal to a definite amount of weight. If a carriage be drawn, the traces are stretched by the tractive power, by the same tension that would be given to them if a certain weight were appended to them. If the paddle wheels of a boat are made to revolve, the water opposes to them a resistance equal to that which would be produced, if instead of moving the water the wheel had to raise some certain weight. In any case, therefore, weight becomes the exponent of the energy of the resistance against which the moving power acts.

But the amount of mechanical effect depends conjointly on the amount of resistance, and the space through which that resistance is moved. The quantity of this effect, therefore, will be increased in the same proportion, whether the quantity of resistance, or the space through which that resistance is moved, be augmented. Thus, a resistance of 100 lbs., moved through two feet, is mechanically equivalent to a resistance of 200 lbs. moved through one foot, or of 400 lbs. moved through six inches. To simplify, therefore, the expression of mechanical effect, it is usual to reduce it invariably to a certain weight raised one foot. If the resistance under consideration be equivalent to a certain weight raised through ten feet, it is always expressed by ten times the amount of that weight raised through one foot.

It has also been usual in the expression of mechanical effect, to take the pound as the unit of weight, and the foot as the unit of length, so that all mechanical effect whatsoever is expressed by a certain number of pounds raised one foot.

The gross effect of the moving power in a steam engine, is the whole mechanical force developed by the evaporation of water in the boiler. A part of this effect is lost by the partial condensation of the steam before it acts upon the piston, and by the imperfect condensation of it subsequently: another portion is expended on overcoming the friction of the different moving parts, and in acting against the resistance which the air opposes to the machine. If the motion be subject to sudden shocks, a portion of the power is then lost by the destruction of momentum which such shocks produce. But if those parts of the machine which have a reciprocating motion be, as they ought to be, brought gradually to rest at each change of direction, then no power is absorbed in this way.

(134.) *Power and duty.*—The useful effect of an engine is variously denominated according to the relation under which it is considered. If it be referred to the *time* during which it is produced, it is called POWER.

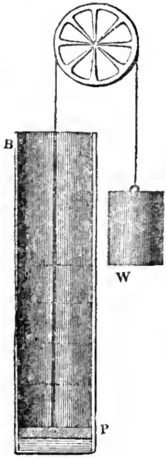
If it be referred to the *fuel*, by the combustion of which the evaporation has been effected, it is called DUTY.

(135.) *Horse-power, origin and import of the term.*—When steam engines were first brought into use, they were commonly applied to work pumps for mills which had been previously worked or driven by horses. In forming their contracts, the first steam engine builders found themselves called upon to supply engines capable of executing the same work as was previously executed by some certain number of horses. It was therefore convenient, and indeed necessary, to be able to express the performance of these machines by comparison with the animal power to which manufacturers, miners, and others, had been so long accustomed. When an engine, therefore, was capable of performing the same work in a given time as any given number of horses of average strength usually performed it, it was said to be an engine of so many horses' power. Steam engines had been in use for a considerable time before this term had acquired any settled or uniform meaning, and the nominal power of engines was accordingly very arbitrary. At length, however, the use of steam engines became more extended, and the confusion and inconvenience arising out of questions respecting the performance of engines, rendered it necessary that some fixed and definite meaning should be assigned to the terms by which the powers of this machine were expressed. To have abandoned the term *horse-power*, which had been so long in use, would have been obviously inconvenient; nor could there be any objection to its continuance, provided all engine makers, and all those who used engines, could be brought to agree upon some standard by which the unit of horse-power might be defined. The performance of a horse of average strength working for eight hours a day was therefore selected as a standard, or unit, of steam engine power. Smeaton estimated that such an animal, so working, was capable of performing a quantity of work equal in its mechanical effect to 22,916 lbs. raised one foot per minute, while Desaguliers estimated the same power at 27,500 lbs. raised through the same height in the same time. The discrepancy between these estimates probably arose from their being made from the performances of different classes of horses. Messrs. Boulton and Watt caused experiments to be made with the strong horses used in the breweries in London, and from the result of these trials they assigned 33,000 lbs. raised one foot per minute, as the value of a horse's power. This is the unit of engine power now universally adopted; and when an engine is said to be of so many horses' power, what is meant is, tha that engine, in good working order and properly managed is capable of moving a resistance equal to so many time 33,000 lbs. through one foot per minute. Thus an engin of ten horse-power is one that would raise 330,000 lbs weight one foot per minute.

Whether this estimate of an average horse's power b correct or not, in reference to the actual work which th animal is capable of executing, is a matter of no presen importance in its application to steam power. The stean engine is no longer used to replace the power of horses, an therefore no contracts are based upon such a comparison The term horse-power, therefore, as applied to steam engines must be understood to have no reference whatever to th actual animal power, but must be taken as a term having n other meaning than the expression of the ability of th engine working under certain prescribed conditions to pro duce a mechanical effect of a certain amount over and abov the force necessary to move itself.

(136.) *Development of mechanical power in evaporation.*— To understand the manner in which mechanical force is deve loped in the evaporation of water, and to estimate the amoun

*Fig.* 78.




of the force developed by the evaporation of a given quantity of water, let it be con ceived that the water is included in a tube or cylinder the base of which is equal to a square inch, and let a piston P (*fig.* 78.) move in it so as to be steam-tight. Let it be sup posed that under this piston there is in the bottom of the cylinder a cubic inch of water between the bottom of the piston and the bottom of the tube. Let the piston be counter balanced by a weight W acting over a pulley which will be just sufficient to counterpois the weight of the piston so as to leave no forc tending to keep the piston down, except th force of the atmosphere acting above i Under the circumstance here supposed, th piston being in contact with the water, an all air being excluded, it will be pressed dow by the weight of the atmosphere which w will suppose to be 15 lbs., the magnitude of the piston being a square inch.

Now let the flame of a lamp be applied at the bottom of the tube; the water under the piston having its temperature thereby gradually raised, and being submitted to no pressure save that of the atmosphere above the piston, it will begin to be converted into steam when it has attained the temperature of 212°. According as it is converted into steam, it will cause the piston to ascend in the tube until all the water has been evaporated. If the tube were constructed of sufficient length, the piston then would be found to have risen to the height of about 1700 inches, or 142 feet; since, as has been already explained, water passing into steam under the ordinary pressure of the atmosphere undergoes an increase of bulk in the proportion of about seventeen hundred to one.

In this process, the air above the piston, which presses on it with a force equal to 15 lbs., has been raised 142 feet. It appears, therefore, that, by the evaporation of a cubic inch of water under a pressure equal to 15 lbs. per square inch, a mechanical force of this amount is developed.

It is evident that 15 lbs. raised 142 feet successively, is equivalent to one hundred and forty-two times 15 lbs. raised one foot. Now, one hundred and forty-two times fifteen is two thousand one hundred and thirty, and therefore the force thus obtained is equal to 2130 lbs. raised one foot high. This being within about 110 lbs. of a ton, it may be stated, in round numbers, that, by the evaporation of a cubic inch of water under these circumstances, a force is obtained equal to that which would raise a ton weight a foot high.

The augmentation of volume which water undergoes in passing into steam under the pressure here supposed, may be easily retained in the memory from the accidental circumstance that a cubic inch of water is converted into a cubic foot of steam, very nearly. A cubic foot contains 1728 cubic inches, which is little different from the proportion which steam bears to water, when raised under the atmospheric pressure.

(137.) *Effect produced by evaporating a given quantity of water.* — It will, therefore, be an advantage to retain in memory the following general facts: —

1. *A cubic inch of water evaporated under the ordinary atmospheric pressure is converted into a cubic foot of steam.*

2. *A cubic inch of water evaporated under the atmospheric pressure gives a mechanical force equal to what would raise about a ton weight a foot high.*

Let us again suppose the piston P (*fig.* 78.) to be restored to its original position, with the liquid water beneath it; and, in addition to the weight of the atmosphere which before pressed it down, let us suppose another weight of fifteen pounds laid upon it, so that the water below shall be pressed by double the weight of the atmosphere. If the lamp were now applied, and at the same time a thermometer were immersed in the water, it would be found that the water would not begin to be converted into steam until it attained the temperature of about 250°. The piston would then begin, as before, to ascend, and the water to be gradually converted into vapour. The water being completely evaporated, it would be found that the piston would be raised to a height little more than half its former height, or seventy-two feet. The mechanical effect, therefore, thus obtained, will be equivalent to double the former weight raised half the former height.

In like manner, if the piston were loaded with thirty pounds in addition to the atmosphere, the whole pressure on the water being then three times the pressure first supposed, the piston would be raised to somewhat more than one third of its first height by the evaporation of the water. This would give a mechanical force equivalent to three times the original weight raised a little more than one third of the original height.

In general, as the pressure on the piston is increased, the height to which the piston would be raised by the evaporation of the water will be diminished in a proportion somewhat less than that in which the pressure on the piston is increased. If the temperature at which the water is converted into steam under these different pressures were the same, then the height to which the piston would be raised by the evaporation of the water would be diminished in precisely the same proportion as the pressure on the piston is increased, and, in that case, the whole mechanical force developed by the evaporation of water would remain exactly the same, whatever might be the pressure under which the water is evaporated.

This would be the case if the temperature of the water did not vary with the pressure. But the increase of pressure being accompanied by an increase of temperature, there is a corresponding increase of volume which renders the density of the steam less than that which would be due to the augmented pressure according to the common law which prevails in the case of air and gases in general.

(138.) *Table showing the temperature and the corresponding pressure of steam and the mechanical effect.* — In the following table are given the temperatures at which water evaporates under different pressures, the volume of vapour produced at these pressures respectively by the unit of volume of water, or, what is the same, the numerical ratio of the volume of vapour to the volume of water which produces it, and in fine the mechanical effect developed in the evaporation expressed in pounds' weight, raised one foot by the evaporation of a cubic inch of water at the temperatures and under the pressures expressed in the table.

| Total Pressure in Pounds per Square Inch. | Corresponding Temperature. | Volume of the Steam compared to the Volume of the Water that has produced it. | Mechanical Effect of a Cubic Inch of Water evaporated, expressed in Pounds raised One Foot. | Total Pressure in Pounds per Square Inch. | Corresponding Temperature. | Volume of the Steam compared to the Volume of the Water that has produced it. | Mechanical Effect of a Cubic Inch of Water evaporated, expressed in Pounds raised One Foot. |
|---|---|---|---|---|---|---|---|
| 1 | 102·9 | 20868 | 1739 | 58 | 292·9 | 484 | 2339 |
| 2 | 126·1 | 10874 | 1812 | 59 | 294·2 | 477 | 2343 |
| 3 | 141·0 | 7437 | 1859 | 60 | 295·6 | 470 | 2347 |
| 4 | 152·3 | 5685 | 1895 | 61 | 296·9 | 463 | 2351 |
| 5 | 161·4 | 4617 | 1924 | 62 | 298·1 | 456 | 2355 |
| 6 | 169·2 | 3897 | 1948 | 63 | 299·2 | 449 | 2359 |
| 7 | 175·9 | 3376 | 1969 | 64 | 300·3 | 443 | 2362 |
| 8 | 182·0 | 2983 | 1989 | 65 | 301·3 | 437 | 2365 |
| 9 | 187·4 | 2674 | 2006 | 66 | 302·4 | 431 | 2369 |
| 10 | 192·4 | 2426 | 2022 | 67 | 303·4 | 425 | 2372 |
| 11 | 197·0 | 2221 | 2036 | 68 | 304·4 | 419 | 2375 |
| 12 | 201·3 | 2050 | 2050 | 69 | 305·4 | 414 | 2378 |
| 13 | 205·3 | 1904 | 2063 | 70 | 306·4 | 408 | 2382 |
| 14 | 209·1 | 1778 | 2074 | 71 | 307·4 | 403 | 2385 |
| 15 | 212·8 | 1669 | 2086 | 72 | 308·4 | 398 | 2388 |
| 16 | 216·3 | 1573 | 2097 | 73 | 309·3 | 393 | 2391 |
| 17 | 219·6 | 1488 | 2107 | 74 | 310·3 | 388 | 2394 |
| 18 | 222·7 | 1411 | 2117 | 75 | 311·2 | 383 | 2397 |
| 19 | 225·6 | 1343 | 2126 | 76 | 312·2 | 379 | 2400 |
| 20 | 228·5 | 1281 | 2135 | 77 | 313·1 | 374 | 2403 |
| 21 | 231·2 | 1225 | 2144 | 78 | 314·0 | 370 | 2405 |
| 22 | 233·8 | 1174 | 2152 | 79 | 314·9 | 366 | 2408 |
| 23 | 236·3 | 1127 | 2160 | 80 | 315·8 | 362 | 2411 |
| 24 | 238·7 | 1084 | 2168 | 81 | 316·7 | 358 | 2414 |
| 25 | 241·0 | 1044 | 2175 | 82 | 317·6 | 354 | 2417 |
| 26 | 243·3 | 1007 | 2182 | 83 | 318·4 | 350 | 2419 |
| 27 | 245·5 | 973 | 2189 | 84 | 319·3 | 346 | 2422 |
| 28 | 247·6 | 941 | 2196 | 85 | 320·1 | 342 | 2425 |
| 29 | 249·6 | 911 | 2202 | 86 | 321·0 | 339 | 2427 |
| 30 | 251·6 | 883 | 2209 | 87 | 321·8 | 335 | 2430 |
| 31 | 253·6 | 857 | 2215 | 88 | 322·6 | 332 | 2432 |
| 32 | 255·5 | 833 | 2221 | 89 | 323·5 | 328 | 2435 |
| 33 | 257·3 | 810 | 2226 | 90 | 324·3 | 325 | 2438 |
| 34 | 259.1 | 788 | 2232 | 91 | 325·1 | 322 | 2440 |
| 35 | 260·9 | 767 | 2238 | 92 | 325·9 | 319 | 2443 |
| 36 | 262·6 | 748 | 2243 | 93 | 326·7 | 316 | 2445 |
| 37 | 264·3 | 729 | 2248 | 94 | 327·5 | 313 | 2448 |
| 38 | 265·9 | 712 | 2253 | 95 | 328·2 | 310 | 2450 |
| 39 | 267·5 | 695 | 2259 | 96 | 329·0 | 307 | 2453 |
| 40 | 269·1 | 679 | 2264 | 97 | 329·8 | 304 | 2455 |
| 41 | 270·6 | 664 | 2268 | 98 | 330·5 | 301 | 2457 |
| 42 | 272·1 | 649 | 2273 | 99 | 331·3 | 298 | 2460 |
| 43 | 273·6 | 635 | 2278 | 100 | 332·0 | 295 | 2462 |
| 44 | 275·0 | 622 | 2282 | 110 | 339·2 | 271 | 2486 |
| 45 | 276·4 | 610 | 2287 | 120 | 345·8 | 251 | 2507 |
| 46 | 277·8 | 598 | 2291 | 130 | 352·1 | 233 | 2527 |
| 47 | 279·2 | 586 | 2296 | 140 | 357·9 | 218 | 2545 |
| 48 | 280·5 | 575 | 2300 | 150 | 363·4 | 205 | 2561 |
| 49 | 281·9 | 564 | 2304 | 160 | 368·7 | 193 | 2577 |
| 50 | 283·2 | 554 | 2308 | 170 | 373·6 | 183 | 2593 |
| 51 | 284·4 | 544 | 2312 | 180 | 378·4 | 174 | 2608 |
| 52 | 285·7 | 534 | 2316 | 190 | 382·9 | 166 | 2622 |
| 53 | 286·9 | 525 | 2320 | 200 | 387·3 | 158 | 2636 |
| 54 | 288·1 | 516 | 2324 | 210 | 391·5 | 151 | 2650 |
| 55 | 289·3 | 508 | 2327 | 220 | 395·5 | 145 | 2663 |
| 56 | 290·5 | 500 | 2331 | 230 | 399·4 | 140 | 2675 |
| 57 | 291·7 | 492 | 2335 | 240 | 403·1 | 134 | 2687 |

By comparing together the numbers in the last column of this table, it will be observed that the mechanical effect developed in the evaporation of water is subject to a very slight augmentation with the increase of the temperature and pressure. Under a pressure of 35 lbs. per square inch, and at the temperature of 261°, the force is exactly equal to a ton weight raised one foot. Under the pressure of 15 lbs., and at the temperature of 213°, it is 2086 lbs., or about seven per cent. less; and under 70 lbs., and at 306°, it is 2382 lbs., or nearly six and half per cent. more than a ton raised a foot.

Although, therefore, the preceding table may be useful for determining the exact mechanical force developed in the evaporation of water under different pressures, it will be sufficient for all practical purposes to assume that each cubic inch evaporated, whatever be the pressure, develops a gross mechanical effect equivalent to a ton weight raised one foot.

(139.) *Mechanical effect of steam used expansively.*— Steam, when used expansively, has two distinct sources of mechanical power, the combination of which is necessary to determine the total mechanical effect. Each cubic inch of water evaporated may be considered as producing a mechanical effect equivalent to a ton weight raised one foot before its communication with the boiler is cut off and its expansion commences. To this is, therefore, to be added the mechanical effect due to the expansion.

When a piston is impelled by steam working expansively, it is urged, as already explained, by a varying pressure; and to determine with precision its mechanical effect, it is necessary to be able, in each case, to assign the mean amount of this pressure. The following tables were computed by Boulton and Watt to simplify and facilitate such calculations.

(140.) *Tables showing this effect for different degrees of expansion.*—The first column of each table contains the full pressure of the steam in pounds per square inch before the expansion begins. The number at the head of each column expresses the fractional part of the stroke through which the steam acts expansively. The number expressing the mean pressure on the piston in pounds per square inch, is found in each case in the same horizontal line with that which expresses the full pressure in the first column, and in the same vertical line with that which expresses the fraction of the stroke through which the steam acts expansively.

## Expanded Steam.

*Mean Pressure at different Densities and Rate of Expansion.*

The columns headed 0 contain the initial pressure in pounds, and the remaining columns contain the mean pressure in pounds, with different grades of expansion.

*Expansion by Eighths.*

| 0 | $\frac{1}{8}$ | $\frac{2}{8}$ | $\frac{3}{8}$ | $\frac{4}{8}$ | $\frac{5}{8}$ | $\frac{6}{8}$ | $\frac{7}{8}$ |
|---|---|---|---|---|---|---|---|
| 3 | 2·96 | 2·89 | 2·75 | 2·53 | 2·22 | 1·789 | 1·154 |
| 4 | 3·95 | 3·85 | 3·67 | 3·38 | 2·96 | 2·386 | 1·539 |
| 5 | 4·948 | 4·818 | 4·593 | 4·232 | 3·708 | 2·982 | 1·924 |
| 6 | 5·937 | 5·782 | 5·512 | 5·079 | 4·450 | 3·579 | 2·309 |
| 7 | 6·927 | 6·746 | 6·431 | 5·925 | 5·241 | 4·175 | 2·694 |
| 8 | 7·917 | 7·710 | 7·350 | 6·772 | 5·934 | 4·772 | 3·079 |
| 9 | 8·906 | 8·673 | 8·268 | 7·618 | 6·675 | 5·368 | 3·463 |
| 10 | 9·896 | 9·637 | 9·187 | 8·465 | 7·417 | 5·965 | 3·848 |
| 11 | 10·885 | 10·601 | 10·106 | 9·311 | 8·159 | 6·561 | 4·233 |
| 12 | 11·875 | 11·565 | 10·925 | 10·158 | 8·901 | 7·158 | 4·618 |
| 13 | 12·865 | 12·528 | 11·943 | 11·004 | 9·642 | 7·754 | 5·003 |
| 14 | 13·854 | 13·492 | 12·862 | 11·851 | 10·384 | 8·531 | 5·388 |
| 15 | 14·844 | 14·456 | 13·781 | 12·697 | 11·126 | 8·947 | 5·773 |
| 16 | 15·834 | 15·420 | 14·700 | 13·544 | 11·868 | 9·544 | 6·158 |
| 17 | 16·823 | 16·383 | 15·618 | 14·390 | 12·609 | 10·140 | 6·542 |
| 18 | 17·813 | 17·347 | 16·537 | 15·237 | 13·351 | 10·737 | 6·927 |
| 19 | 18·702 | 18·311 | 17·448 | 16·803 | 14·093 | 11·333 | 7·312 |
| 20 | 19·792 | 19·275 | 18·375 | 16·930 | 14·835 | 11·930 | 7·697 |
| 25 | 24·740 | 24·093 | 22·968 | 21·162 | 18·543 | 14·912 | 9·621 |
| 30 | 29·688 | 28·912 | 27·562 | 25·395 | 22·252 | 17·895 | 11·546 |
| 35 | 34·636 | 33·731 | 33·156 | 29·627 | 25 961 | 20·877 | 13·470 |
| 40 | 39·585 | 38·550 | 36·750 | 33·860 | 29·670 | 23·860 | 15·395 |
| 45 | 44·533 | 43·368 | 41·343 | 38·092 | 33·378 | 26·842 | 17·319 |
| 50 | 49·481 | 48·187 | 45·937 | 42·325 | 37·067 | 29·825 | 19·243 |

*Expansion by Tenths.*

| 0 | $\frac{1}{10}$ | $\frac{2}{10}$ | $\frac{3}{10}$ | $\frac{4}{10}$ | $\frac{5}{10}$ | $\frac{6}{10}$ | $\frac{7}{10}$ | $\frac{8}{10}$ | $\frac{9}{10}$ |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 2·980 | 2·930 | 2·830 | 2·710 | 2·539 | 2·299 | 1·981 | 1·668 | 0·990 |
| 4 | 3·974 | 3·913 | 3·780 | 3·614 | 3·386 | 3·065 | 2·642 | 2·087 | 1·320 |
| 5 | 4·968 | 4·892 | 4·725 | 4·518 | 4·232 | 3·832 | 3·303 | 2·609 | 1·651 |
| 6 | 5·961 | 5·870 | 5·670 | 5·421 | 5·079 | 4·598 | 3·963 | 3·130 | 1·981 |
| 7 | 6·955 | 6·848 | 6·615 | 6·325 | 5·925 | 5·364 | 4·624 | 3·652 | 2·311 |
| 8 | 7·948 | 7·827 | 7·560 | 7·228 | 6·772 | 6·131 | 5·284 | 4·174 | 6·641 |
| 9 | 8·942 | 8·805 | 8·505 | 8·132 | 7·618 | 6·897 | 5·945 | 4·696 | 2·971 |
| 10 | 9·936 | 9·784 | 9·450 | 9·036 | 8·465 | 7·664 | 6·606 | 5·218 | 3 302 |
| 11 | 10·929 | 10·762 | 10·395 | 9·939 | 9·311 | 8·430 | 7·266 | 5·739 | 3·632 |
| 12 | 11·923 | 11·740 | 11·340 | 10·843 | 10·158 | 9·196 | 7·927 | 6·261 | 3·962 |
| 13 | 12·856 | 12·719 | 12·285 | 11·746 | 10·994 | 9·963 | 8·587 | 6·783 | 4·292 |
| 14 | 13·910 | 13·967 | 13·230 | 12·650 | 11·851 | 10·729 | 9·248 | 7·305 | 4·622 |
| 15 | 14·904 | 14·676 | 14·175 | 13·554 | 12·697 | 11·496 | 9·909 | 7·827 | 4·953 |
| 16 | 15·897 | 15·654 | 15·120 | 14·457 | 13·544 | 12·262 | 10·569 | 8·348 | 5·283 |
| 17 | 16·891 | 16·632 | 16·065 | 15·361 | 14·051 | 13·028 | 11·230 | 8·870 | 5·613 |
| 18 | 17·884 | 17·611 | 17·010 | 16·264 | 15·237 | 13·795 | 11·890 | 9·392 | 5·944 |
| 19 | 18·878 | 18·589 | 17·955 | 17·168 | 16·083 | 14·561 | 12·551 | 9·914 | 6·273 |
| 20 | 19·872 | 19·568 | 18·900 | 18·072 | 16·930 | 15·328 | 13·212 | 10·436 | 6·600 |
| 25 | 24·840 | 24·460 | 23·625 | 22·590 | 21·162 | 19·160 | 16·515 | 13·040 | 8·255 |
| 30 | 29·808 | 29·352 | 28·350 | 27·108 | 25·395 | 22·992 | 19·818 | 15·654 | 9·906 |
| 35 | 34·776 | 34·244 | 33·075 | 31·626 | 29·627 | 26·824 | 23·121 | 18·263 | 11·557 |
| 40 | 39·744 | 39·136 | 37·800 | 36·144 | 33·860 | 30·656 | 26·224 | 20·872 | 13·208 |
| 45 | 44·912 | 44·028 | 42·525 | 40·662 | 38·092 | 34·888 | 29·727 | 23·481 | 14·859 |
| 50 | 49·680 | 48·920 | 47·250 | 45·180 | 42·325 | 38·320 | 33·030 | 26·090 | 16·510 |

The effect gained by expansion will be found by comparing the total effect of the engine with the effect which would be produced without expansion.

If the length of the stroke be taken as the unit, the total effect of a square inch of the piston surface will be expressed by the mean pressure, and the effect which would be produced without expansion will be found by multiplying the fraction which expresses that part of the stroke through which the steam acts, *without expansion*, by the full pressure.

Thus, for example, let it be required to ascertain the effect gained by cutting off the steam when the piston has made three-tenths of the entire stroke.

In this case the steam acts expansively through seven-tenths of the stroke, and if we suppose the full pressure to be thirty pounds, the mean pressure, according to the second table, will be 19·818, which will therefore express the total effect. To find the effect without expansion, we multiply three-tenths, the part of the stroke through which the steam acts with full pressure, by thirty, which gives nine. By this degree of expansion, therefore, the mechanical effect of the steam is increased in the ratio of 90 to 198, being more than double.

The gain of power, with the same amount of expansion, is nearly the same, whatever be the full pressure of the steam; but when the steam is allowed to expand in a large proportion, the initial pressure must always, in practice, be considerable, since otherwise the steam would become too feeble before the stroke would be completed.

(141.) *To determine the rate of evaporation necessary to produce a given power.*—Having thus determined the amount of mechanical force developed in the process of evaporation, it will be easy to ascertain the rate of evaporation necessary to produce any proposed power.

To produce the force expressed by one horse-power, the evaporation per minute must develope a mechanical force equal to 33,000 lbs., or about 15 tons raised one foot. Fifteen cubic inches of water evaporated would accordingly produce this effect, which without expansion would be equivalent to 900 cubic inches per hour. To find, therefore, the *gross power* developed by a boiler, it would be only necessary to divide the number of cubic inches of water evaporated per hour by 900, and the quotient would be the gross horse-power. If, therefore, to 900 cubic inches be added the quantity of water per hour necessary to move the engine itself, independently of its load, we shall obtain the quantity of water per hour which must be supplied by the boiler to the engine for each horse-power, and this will be the same whatever may be the magnitude or proportions of the cylinder.

(142.) *Analysis of the power consumed in moving the engine itself.*—The quantity of power expended in working the engine itself, independently of that required to move its load, will be less in proportion to the degree of perfection which may be attained in the construction of the engine, and to the order in which it is kept while working. Engines vary one from another so much in these respects, that it is scarcely possible to lay down any general rules for the quantity of power to be allowed over and above what is necessary to move the load. The means whereby mechanical power is expended in working the engine may be enumerated as follows: —

*First.* Steam in passing from the boiler to the cylinder is liable to lose its temperature by the radiation of the steam pipes and other passages through which it is conducted. Since the steam produced in the boiler is in contact with water, the least loss of heat will cause a partial condensation. To whatever extent this condensation may be carried, a proportional loss of power, in reference to the heat obtained from the fuel, will be entailed upon the engine.

It has been said that the force necessary to move the steam from the boiler to the cylinder through passages more or less contracted, subject to the friction of the pipes and tubes through which it moves, should be taken into account in estimating the power, and a corresponding deduction made. This, however, is not the case: the steam having passed into the cylinder remains common steam, its pressure being diminished by reason of the force expended in thus moving it from the boiler to the cylinder. But its mechanical efficacy at the reduced pressure is not sensibly different from the efficacy which it had in the boiler. If at the reduced pressure its volume were the same, then a loss of effect would be sustained equivalent to the difference of the pressures; but its volume being augmented in very nearly the same proportion as its pressure is diminished, the mechanical efficacy of a given weight of steam in the cylinder will be sensibly the same as in the boiler.

*Second.* The radiation of heat from the cylinder and its appendages will cause a partial condensation of steam, and thereby produce a diminished mechanical effect.

*Third.* The steam, which at each stroke of the piston fills the passages between the steam valves and the piston at the moment the latter commences the stroke, will be inefficient.

If it were possible for the piston to come into steam-tight contact with each end of the cylinder, and the steam valves to be in immediate contact with the piston, then the whole of the steam which would pass through the steam valve would be efficient; but as some space, however small, must remain between the piston and the ends of the cylinder, and between the side of the cylinder and the steam valve, there will always be a volume of steam bearing a sensible proportion to the magnitude of the cylinder, which at each stroke of the piston will be inefficient. This volume of steam is called the *clearage.*

*Fourth.* Since the piston must move in steam-tight contact with the cylinder, it must have a definite amount of friction with the sides of the cylinder by whatever means it may be packed. This friction will produce a corresponding resistance to the moving power.

*Fifth.* The various joints of the machinery where steam is contained are subject to leakage, and whatever amount of steam shall thus escape must be placed to the account of power lost.

*Sixth.* When the eduction valve is opened to admit the steam to the condenser, a certain force is required to expel the steam from the cylinder. This force reacts upon the piston, and counteracts to a proportional extent the moving power of the steam on the other side. Besides this the water in the condenser cannot be conveniently reduced below the temperature of about 100°, and at this temperature steam has a pressure of about one pound per square inch. This vapour will continue to fill the cylinder, and will resist the moving power which impels the piston.

*Seventh.* Power must be provided for opening and closing the valves or slides, for working the air-pump, hot water pump, and cold water pump, and finally to overcome the friction on the journals and centres of the parts of the parallel motion, the main axle of the beam, the connecting rod, crank, and fly-wheel axle.

It will be apparent how very much these sources of resistance must vary in different engines, and how rough an approximation any general estimate must be of their gross amount.

(143.) *No exact valuation of this has been made.* — There are many circumstances which obstruct the practical application of any standard of engine power: the magnitude of furnace and the extent of heating surface necessary to produce any required rate of evaporation in the boiler are unascertained; each engine maker has his own rule in these matters, and all the rules are equally unsupported by any experimental test entitled to respect. Thus the circumstances that govern the rate of evaporation in the boiler may be regarded as almost wholly unknown. But supposing the rate of evaporation to be ascertained, the amount of power absorbed by the condensation of steam on its passage to the cylinder, the imperfect condensation of the same steam after it has worked the piston, the friction of the various moving parts of the machinery, and, above all, the difference of effect of these losses of power in engines constructed on different scales of magnitude, are absolutely unknown. We are, therefore, not placed in a condition to assign any thing more than a general account of what has been the practice of engine makers in constructing engines which are nominally of a certain power.

(144.) *Practical rules adopted by engine makers.* — In common low-pressure engines of the larger kind, to which class alone we at present refer, it has been usual, with the same fuel and under like circumstances, to allow from ten to eighteen square feet of heating surface in the boiler for every nominal horse-power of the engine. Within these wide limits the practice of engine makers has varied. It is not, however, to be supposed, that the boiler with eighteen square feet of surface per horse-power has the same evaporating power as that which has but ten. This difference, therefore, amounts to nothing more than different manufacturers of steam engines putting into circulation boilers having powers *really* different while they are *nominally* the same.

The magnitude of the cylinder is regulated by the nominal power of the engine, and it is usual so to regulate the evaporating power of the boiler, that the piston shall move at the average rate of 200 feet per minute. This being assumed, it has been customary to allow about twenty-two square inches of piston surface for every nominal horse-power of the engine. If this power were in conformity to the standard already defined, this amount of surface moved at 200 feet per minute would be impelled by a pressure amounting to 7½ lbs. per square inch.

(145.) *Table showing the relation between the dimensions of the cylinder and the power.* — The following table, showing the diameter, stroke, and mean speed of the piston, is in accordance with the practice of Messrs. Boulton and Watt for low-pressure condensing engines: —

| Horse Power. | Diameter of Cylinder. | Length of Stroke in Feet. | Number of Strokes per Minute. | Speed in Feet per Minute. | Effective Pressure per Square Inch in lbs. |
|---|---|---|---|---|---|
| 4 | 12 | 3 | 29 | 174 | 6·8 |
| 6 | 14 | 3½ | 27 | 189 | 6·82 |
| 8 | 16 | 4 | 24 | 192 | 6·84 |
| 10 | 17½ | 4 | 25 | 200 | 6·86 |
| 12 | 19 | 4 | 25 | 200 | 6·88 |
| 14 | 20⅝ | 4 | 25 | 200 | 6·91 |
| 16 | 21¾ | 4½ | 23 | 207 | 6 91 |
| 18 | 23 | 4½ | 23 | 207 | 6·91 |
| 20 | 23¾ | 5 | 21½ | 215 | 6·92 |
| 22 | 25 | 5 | 21½ | 215 | 6·92 |
| 24 | 26 | 5 | 21½ | 215 | 6·92 |
| 26 | 26¾ | 5½ | 20 | 220 | 6·92 |
| 28 | 27⅞ | 5½ | 20 | 220 | 6·92 |
| 30 | 28¼ | 6 | 19 | 228 | 6·92 |
| 36 | 30⅞ | 6 | 19 | 228 | 6·92 |
| 40 | 31½ | 7 | 17½ | 245 | 6·92 |
| 45 | 33⅓ | 7 | 17½ | 245 | 6·92 |
| 50 | 35⅛ | 7 | 17½ | 245 | 6·94 |
| 60 | 38½ | 7 | 17½ | 245 | 6·94 |
| 70 | 40¾ | 8 | 16 | 256 | 6·94 |
| 80 | 43½ | 8 | 16 | 256 | 6·94 |
| 90 | 46⅛ | 8 | 16 | 256 | 6·94 |
| 100 | 48⅝ | 8 | 16 | 256 | 6·94 |

(146.) *Table showing the relation between the dimensions of the boiler and its appendages, and the power.* — The dimensions of the waggon boilers used for the same class of engines, by the same constructors, are as follows: —

*Proportions of Boulton and Watt's Waggon Boilers of various Powers.*

| Horse-power. | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 30 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. |
| Length - - - - | 4 6 | 5 3 | 6 0 | 7 0 | 8 0 | 9 0 | 10 0 | 10 0 | 11 9 | 12 8 | 13 6 | 16 0 | 19 0 |
| Breadth at water-line - | 3 2 | 3 4 | 3 6 | 3 9 | 4 0 | 4 3 | 4 6 | 4 9 | 5 0 | 5 2 | 5 4 | 5 6 | 6 0 |
| Height - - - - | 4 1 | 4 4 | 4 7½ | 5 1½ | 5 6 | 5 9½ | 6 0 | 6 2½ | 6 6 | 6 8 | 6 10 | | |
| Height of water - - | 2 6 | 2 8 | 2 10 | 3 3 | 3 6 | 3 8 | 3 9 | 3 10 | 4 0 | 4 1 | 4 2 | 4 9 | 5 6 |
| Radius of crown - - | 1 7 | 1 8 | 1 9 | 1 10½ | 2 0 | 2 1½ | 2 3 | 2 4½ | 2 6 | 2 7 | 2 8 | 2 9 | 3 0 |
| Heating surface - - | 30 0 | 38 0 | 46 0 | 64 0 | 83 0 | 100 0 | 118 0 | 138 0 | 156 0 | 176 0 | 201 0 | 297 0 | 438 0 |
| Height of flue round boiler | 1 9 | 1 10 | 1 11 | 2 4 | 2 9 | 3 1 | 3 2 | 3 5 | 3 7 | 3 9 | 3 11 | 4 0 | 4 9 |
| Width of flue round boiler | 0 9 | 0 9 | 0 10 | 0 10 | 1 0 | 1 0 | 1 1 | 1 1 | 1 2 | 1 2 | 1 2 | 1 4 | 1 3 |
| Heating surface per horse-power - - - | 15 0 | 13 0 | 11 0 | 10·7 | 10·2 | 10 0 | 9·8 | 9·8 | 9·7 | 9·8 | 10 0 | 9·8 | 9·6 |
| Capacity of steam room in cubic feet - - - | 17½ | 22½ | 23½ | 34½ | 50 | 64 | 72 | 80 | 97 | 106 | 114·7 | 190 | 268 |
| Contents of water in cubic feet - - - - | 37 | 40 | 56 | 76 | 103 | 134 | 162 | 205 | 238 | 270 | 299 | 282 | 342 |

(147.) *General mechanical principles by which the power of engines ought to be estimated.*— Since erroneous notions prevail respecting the circumstances which govern the power of engines, and the relation between the pressures of steam in the cylinder and in the boiler, we shall here briefly explain the general mechanical principles on which such questions must be investigated.

When the engine is in regular and constant work, the motion of the piston must be uniform. Even when working expansively, and when, therefore, the velocity of the piston at different parts of the stroke may be different, the number of strokes per minute, and consequently the mean velocity of the piston, will be invariable. This uniform motion infers an equality between the resistance against which the piston acts, and the pressure of the steam upon it.

If we suppose the total resistance to the motion of the piston, including the resistances arising from the engine itself, to be expressed in pounds by $R$, and if $A$ express the area of the piston in square inches, then $\frac{R}{A}$ will express the resistance opposed by each square inch of the piston to the action of the steam. This resistance being equal to the pressure of the steam in the cylinder, we shall have

$$P = \frac{R}{A},$$

if $P$ be the pressure of the steam in pounds per square inch.

It is necessary to observe, that, whatever may be the pressure of steam in the boiler, its pressure in the cylinder cannot be *permanently* greater or less than $\frac{R}{P}$. If it were greater, the motion of the piston would be indefinitely accelerated; if less, it would be gradually retarded and soon brought to rest.

It is clear, therefore, that the pressure of the steam in the cylinder of an engine in regular work, depends altogether on the resistance opposed to the piston; and the pressure in the boiler, whatever it be, can have no permanent effect upon it.

It may be asked, whether the increased action of the furnace will not in such case augment the pressure of the steam on the piston by stimulating the evaporation? Such increased evaporation will augment the volume of steam supplied per minute to the cylinder, and will proportionally increase the speed of the piston. In certain cases this increase of speed will necessarily be attended with an increased resistance to the motion of the piston, as, for example, in the case of locomotives, where there is an increased resistance from the atmosphere; and in the case of marine engines, where there is an increased resistance both from the water and the air. In these cases, the pressure of steam in the cylinder will be increased, but the cause of this increase is not the increased action of the furnace, but the increased resistance which is a consequence of the increased speed.

In stationary engines, where the increase of speed is not attended with a sensibly increased resistance, the augmented action of the furnace produces no increase of pressure of the steam in the cylinder.

The pressure of steam in the boiler depends jointly on the pressure in the cylinder, and the magnitude, length, and form of the steam passages between the boiler and the cylinder. The pressure in the boiler can only exceed the pressure in the cylinder by that amount of force which is necessary to propel the steam through the passages leading from the boiler to the cylinder with the necessary velocity. When the passages are not very long or contracted, and the velocity of efflux not excessive, the difference of pressures cannot be considerable.

It is evident, therefore, that under no circumstances can the pressure of steam in the boiler be determined by the safety valve. In the regular operation of the engine that valve is inactive, and might as well be soldered up. It comes into action only occasionally, and in emergencies. As, for example, when from any accidental cause the resistance to the motion of the piston is suddenly and unduly increased. In such case the pressure of the steam in the cylinder, and, therefore, in the boiler, will be proportionally increased, and may at length exceed the pressure on the safety valve. The valve, in that case, will be raised, and the steam will escape.

The safety valve, therefore, imposes a major limit to the pressure of steam in the boiler, but does not govern or otherwise regulate that pressure, which, in the normal state of the machine, is always below the limit.

(148.) *Deduction made from the gross power to obtain the effective power.* — The *gross power* with which an engine works is therefore determined by the gross resistance opposed to the piston, and by the speed with which the piston moves. But the *net* or *effective power* can only be obtained when the force expended on moving the machine itself is known. That force being subducted from the gross power, the remainder will be the nett or effective power.

In the larger class of stationary engines it has been the practice of engine builders to allow about forty per cent. of the gross power for this, so that in an engine producing the gross power of a hundred horses, the power of forty horses is allowed for moving the engine, and for waste power.

This has been, and not without justice, regarded as an extravagant estimate of the waste power, and the rule has been the subject of severe censure and much ridicule by the scientific writers of the Continent, who are accustomed to expect more rigour in practical science than English constructors observe.

Thus it is taken as a preposterous assumption, that a machine which develops a gross mechanical force of one thousand, shall require for its own motion a power of 400 horses.

It is, however, well understood among practical men in England, that the *actual* power of the engines is greater than their *nominal* power. Indeed, the *nominal* horse-power of engines is to be understood as nothing more than a mode of indicating the *magnitude* of the machines.

(149.) *Duty of engines.* — The duty of engines varies according to their form and magnitude, the circumstances under which they are worked, and the purposes to which they are applied. In double-acting engines working without expansion, the coal consumed per nominal horse-power per hour varies from seven to twelve pounds. An examination of the steam logs of several government steamers made in 1838 gave, as the average of consumption of fuel at that time of the best class of marine engines, about eight pounds per nominal horse-power per hour. Since, however, no account could be obtained of the actual evaporation of water in the boiler, nor, with the necessary degree of precision, of the quantity and pressure of the steam which passed through the cylinder, this estimate must be regarded as an approximation subject to several causes of error. The question of the duty of boilers and engines applied to the general purposes of manufactures and navigation, is one which has not yet been satisfactorily investigated; and it were much to be desired that the proprietors of such engines should combine to establish a strict analysis of their performance in reference to their consumption of fuel, their evaporation of water, and their useful effects. The results of such an investigation, if properly conducted, would perhaps tend more to the improvement of the steam engine than any discoveries in science, or inventions in mechanical detail likely to be made in the present stage of the progress of that machine.

(150.) *Duty of Cornish engines.* — A strict investigation of this kind has been for many years carried on respecting the performance of the steam engines used for the drainage of the mines in Cornwall; and it has been attended with effects the most beneficial to the interests of those concerned in them. The engines to which this important inquiry has been applied being used for the purpose of pumping, are generally single-acting engines, in which steam is used expansively to a great extent. The steam is produced under a very high pressure in the boiler, and being admitted to the cylinder is cut off after a small portion of the entire stroke has been made, the remainder of the stroke being produced by the expansion of the steam.

About the year 1811, a number of the proprietors of the principal Cornish mines agreed to establish this system of inspection, under the management and direction of Captain Joel Lean, and to publish monthly reports. In these reports were stated the following particulars: — 1. The load per square inch on the piston; 2. The consumption of coal in bushels; 3. The number of strokes made by the engine; 4. The length of the strokes in the pumps; 5. The load in pounds; 6. The duty of the engine, expressed by the number of pounds raised one foot high by the consumption of a bushel of coals; 7. The number of strokes per minute; 8. The diameter and stroke of the cylinder, and a general description of the engine. When these reports were commenced, the number of engines brought under inspection was twenty-one. In the year 1813 it increased to twenty-nine; in 1814 to thirty-two; in 1820 the number reported upon increased to forty; in 1828 the number was fifty-seven; and in 1836 it was sixty-one. This gradual increase in the number of engines brought under this system of inspection, was produced by the good effects which attended it. These beneficial consequences were manifested, not only in the improved performance of the same engines, but in the gradually improved efficiency of those which were afterwards constructed.

(151.) *Table showing the increasing duty of Cornish engines since* 1812.

| Years. | No. of Engines. | Average Duty of the whole. | Average Duty of the best Engine. |
|---|---|---|---|
| 1812 | 21 | 19,300,000 | |
| 1813 | 29 | 19,500,000 | 26,400,000 |
| 1814 | 32 | 20,600,000 | 32,000,000 |
| 1815 | 35 | 20,500,000 | 28,700,000 |
| 1816 | 35 | 23,000,000 | 32,400,000 |
| 1817 | 35 | 26,500,000 | 41,600,000 |
| 1818 | 36 | 25,400,000 | 39,300,000 |
| 1819 | 40 | 26,300,000 | 40,000,000 |
| 1820 | 46 | 28,700,000 | 41,300,000 |
| 1821 | 45 | 28,200,000 | 42,800,000 |
| 1822 | 52 | 28,900,000 | 42,500,000 |
| 1823 | 52 | 28,200,000 | 42,100,000 |
| 1824 | 49 | 28,300,000 | 43,500,000 |
| 1825 | 56 | 32,000,000 | 45,400,000 |
| 1826 | 51 | 30,500,000 | 45,200,000 |
| 1827 | 51 | 32,100,000 | 59,700,000 |
| 1828 | 57 | 37,100,000 | 76,800,000 |
| 1829 | 53 | 41,700,000 | 77,000,000 |
| 1830 | 56 | 43,300,000 | 78,000,000 |
| 1831 | 58 | 43,400,000 | 71,100.000 |
| 1832 | 59 | 45,000,000 | 85,000,000 |
| 1833 | 56 | 46,600,000 | 84,300,000 |
| 1834 | 52 | 47,800,000 | 90,900,000 |
| 1835 | 51 | 47,800,000 | 91,700,000 |
| 1836 | 61 | 46,600,000 | 85,400,000 |
| 1837 | 58 | 47,000,000 | 87,200,000 |
| 1838 | 61 | 48,700,000 | 84,200,000 |

The preceding table, taken from the statement of the duty of Cornish engines by Thomas Lean and brother, lately published by the British Association, will show in a striking manner the improvement of the Cornish engines, from the commencement of this system of inspection to the present time. The duty is expressed by the number of pounds raised one foot high by the consumption of a bushel of coals.

Since 1838, the duty of the Cornish engines has been further augmented, so that in 1843 the average duty amounted to 60,000,000.

As an example of the beneficial effects produced upon the efficiency of an individual engine by the first application of this system of inspection, the case of the Stray Park engine may be mentioned. This engine, constructed by Boulton and Watt, had a sixty inch cylinder, and when first reported in 1811, its duty amounted to 16,000,000 lbs. After having been reported on for three years, its duty was found to have increased to 32,000,000; this estimate being taken from the average result of twelve months' performance. Its duty was doubled in less than three years.

It will appear, by inspection of the duties registered in the preceding table, that the augmentation of the efficiency of the engines has not been the effect of any great or sudden improvement, but has rather resulted from the combination of a great number of small improvements in the details of the operation of these machines. In these improvements more is due to the successful application of practical experience than to any new principles developed by scientific research. Mr. John Taylor, in his "Records of Mining," has traced the successive improvements on which the increased duty of engines depends, and has connected these improvements with their causes in the order of their dates. The following results, abridged from his estimates, may not be uninteresting: —

In 1769, soon after the date of the earliest discoveries of Mr. Watt, but before they had come into practical application, Smeaton computed that the average duty of fifteen atmospheric engines, working at Newcastle-on-Tyne, was

5,590,000. The duty of the best of these engines was 7,440,000, and that of the worst 3,220,000.

In 1772, Smeaton commenced his improvements on the atmospheric engine, and raised the duty to 9,450,000.

In 1776, Watt obtained a duty of 21,600,000.

At this time Smeaton acknowledged that Watt's engines gave a duty amounting to double that of his own.

In 1778-79, Watt reported a duty of 23,400,000.

From 1779 to 1788, Watt introduced the application of expansion, and raised the duty to 26,600,000.

In 1798, an engine by Boulton and Watt, erected at Herland, was reported as giving a duty of 27,000,000.

This engine, which was probably the best which at that time had ever been erected, attracted the particular attention of Mr. Watt, who, on visiting Cornwall, went to see it, and had many experiments tried with it. It was under the care of Mr. Murdock, the agent of Messrs. Boulton and Watt in Cornwall. When Mr. Watt inspected it he pronounced it perfect, and that further improvement could not be expected. How singular an instance this of the impossibility, even of the most sagacious, to foresee the results of mechanical improvement! In twenty years afterwards the average duty of the best engine was nearly 40,000,000, and in forty years it was above 84,000,000.

# PART II.

## STEAM NAVIGATION.

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## CHAPTER I.

### THE MARINE ENGINE.

(152.) *Propulsion by paddle wheels.* — The manner in which the steam engine is applied to the propulsion of vessels must in its general features be so familiar as to require but short explanation. A shaft is carried across the vessel, being continued on either side beyond the timbers: to the extremities of this shaft, on the outside of the vessel, are fixed a pair of wheels, usually constructed like undershot water wheels, having attached to their rims a number of flat boards called *paddle boards.* As the wheels revolve, these paddle boards strike the water, driving it in a direction contrary to that in which it is intended the vessel should be propelled. The moving force imparted to the water thus driven backwards is necessarily accompanied by a re-action upon the vessel through the medium of the paddle shaft, by which the vessel is propelled forwards. On the paddle shaft two cranks are constructed, similar to the crank already described on the axle of the fly-wheel of a stationary engine. These cranks arc placed at right angles to each other, so that when either is in its highest or lowest position the other shall be horizontal. They are driven by two steam engines, which are placed in the hull of the vessel below the paddle shaft. In the earlier steam boats a single steam engine was used, and in that case the unequal action of the engine on the crank was equalised by a fly-wheel. This, however, has been long since abandoned in European vessels, and the use of two engines is now almost universal. By the relative position of the cranks it will be seen, that when either crank is at its dead points the other will be in the positions most favourable to its action, and in all intermediate positions the relative efficiency of the cranks will be such as to render their combined action very nearly uniform.

The steam engines used to impel vessels may be either condensing engines, similar to those of Watt, and such as are used in manufactures generally, or they may be non-condensing and high-pressure engines, similar in principle to those used on railways. Low-pressure condensing engines are, however, universally used for marine purposes in Europe, and to a great extent in the United States. In the latter country, however, high-pressure engines are also used in some of the river steamers.

(153.) *General description of marine engines.* — The arrangement of the parts of a marine engine differs in some respects from that of a land engine. The limitation of space, which is unavoidable in a vessel, renders greater compactness necessary. The paddle shaft on which the cranks to be driven by the engine are constructed being very little below the deck of the vessel, the beam and connecting rod could not be placed in the position in which they usually are in land engines, without carrying the machinery to a considerable elevation above the deck. This is done in the steam boat engines used on the American rivers; but it would be inadmissible in steam boats in general, and more especially in sea-going steamers. The connecting rods, therefore, instead of being presented downwards towards the cranks which they drive, must, in steam vessels, be presented upwards, and the impelling force received from below. If, under these circumstances, the beam were in the usual position above the cylinder and piston rod, it must necessarily be placed between the engine and the paddle shaft. This would require a depth for the machinery which would be incompatible with the magnitude of the vessel. The beam, therefore, of marine engines, instead of being above the cylinder and piston, is placed below them. To the top of the piston rods, cross-pieces are attached, of greater length than the diameter of the cylinders, so that their extremities shall project beyond the cylinders. To the ends of these cross-pieces are attached by joints the rods of a parallel motion: these rods are carried downwards, and are connected with the ends of two beams below the cylinder, and placed on either side of it. The opposite ends of these beams are connected by another cross-piece, to which is attached a connecting rod, which is continued upwards to the crank-pin, to which it is attached, and which it drives. Thus the beam, parallel motion, and connecting rod of a marine engine, are similar to those of a land engine, only that they are turned upside down; and in consequence of the impossibility of placing the beam directly over the piston rod, two beams and two systems of parallel motion are provided, one on each side of the engine, acted upon by, and acting on the piston rod and crank by cross-pieces.

The proportion of the cylinders differs from that usually observed in land engines for like reasons. The length of the cylinder of land engines is generally greater than its diameter, in the proportion of about two to one. The cylinders of marine engines are, however, commonly constructed with a diameter very little less than their length. In proportion, therefore, to their power their stroke is shorter, which infers a corresponding shortness of crank and a greater limitation of play of all the moving parts in the vertical direction. The valves and the gearing by which they are worked, the air-pump, the condenser, and other parts of the marine engines, do not materially differ from those already described in land engines.

These arrangements of a marine engine will be more clearly understood by reference to *fig.* 79., in which is represented a longitudinal section of a marine engine with its boiler as placed in a steam vessel. The sleepers of oak, supporting the engine, are represented at X, the base of the engine being secured to these by bolts passing through them and the bottom timbers of the vessel; S is the steam pipe leading from the steam chest in the boiler to the slides *c*, by which it is admitted to the top and bottom of the cylinder. The condenser is represented at B, and the air-pump at E.

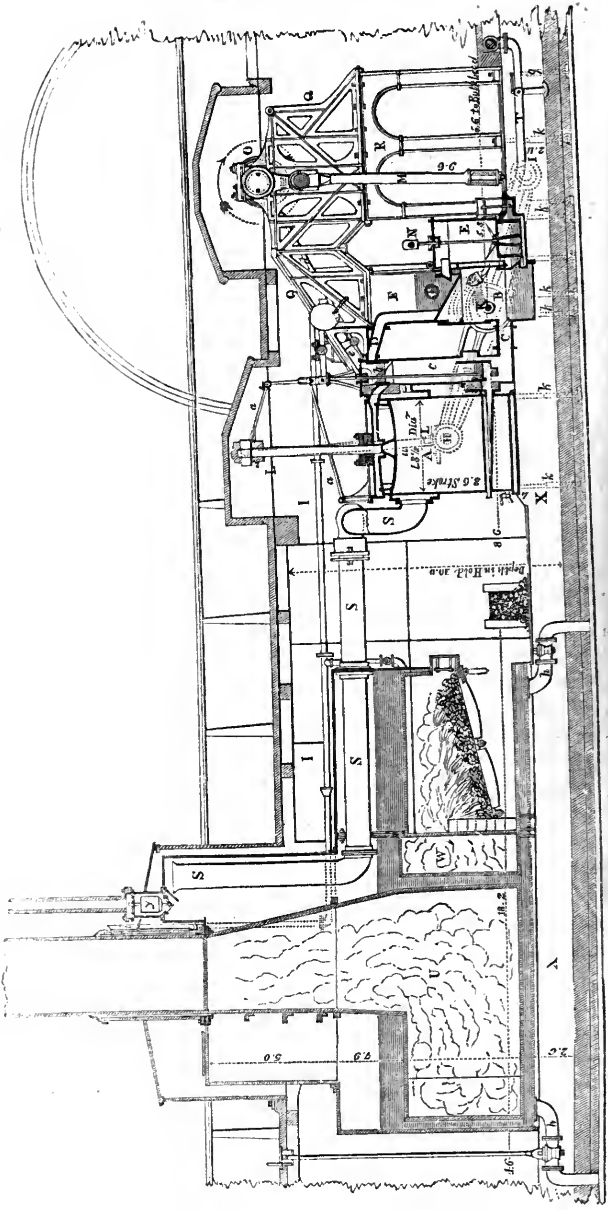
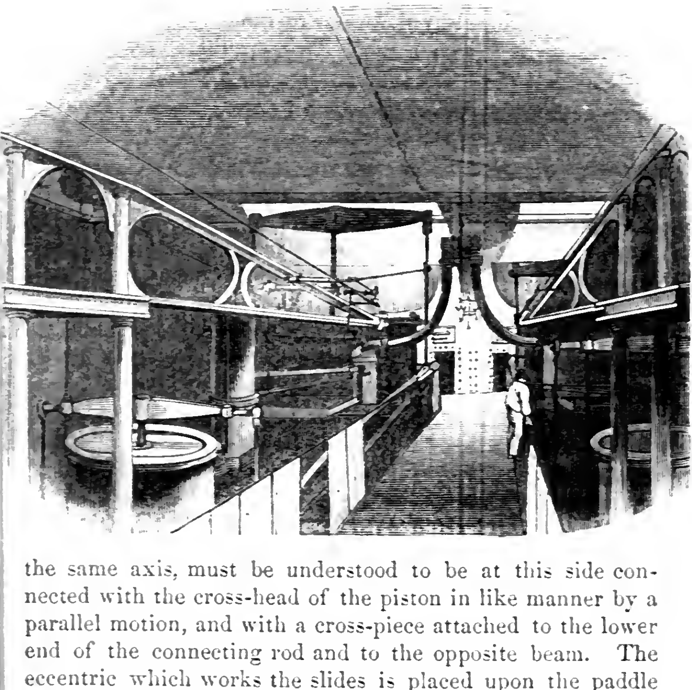


Fig 79.

The hot well is seen at F, from which the feed is taken for the boiler; L is the piston rod connected by the parallel motion *a* with the beam H, working on a centre K, near the base of the engine. The other end of the beam I drives the connecting rod M, which extends upwards to the crank, which it works upon the paddle shaft O. Q R is the framing by which the engine is supported. The beam here exhibited is shown on dotted lines as being on the further side of the engine. A similar beam similarly placed, and moving on

*Fig.* 80.



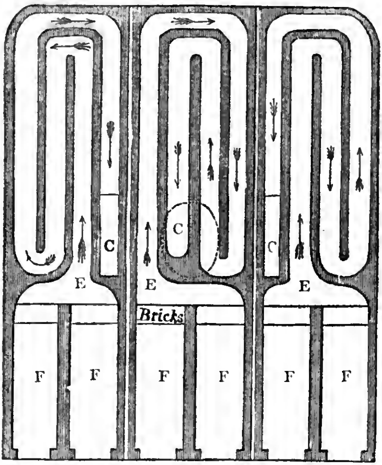
the same axis, must be understood to be at this side connected with the cross-head of the piston in like manner by a parallel motion, and with a cross-piece attached to the lower end of the connecting rod and to the opposite beam. The eccentric which works the slides is placed upon the paddle shaft O, and the connecting arm which drives the slides may be easily detached when the engine requires to be stopped. The section of the boiler, grate, and flues is represented at W U. The safety valve *y* is enclosed beneath a pipe carried up beside the chimney, and is inaccessible to the engine man; *h* are the cocks for blowing the salted water from the boiler, and I I the feed pipe.

The general arrangement of the engine room of a steam vessel is represented in *fig.* 80.

The nature of the effect required to be produced by marine engines does not render either necessary or possible that great regularity of action which is indispensable in a steam engine applied to the purposes of manufacture. The agitation of the surface of the sea will cause the immersion of the paddle wheels to be subject to great variation, and the resistance produced by the water to the engine will undergo a corresponding change. The governor, therefore, and other parts of the apparatus, contrived for giving to the engine that great regularity required in manufactures, are omitted in nautical engines, and nothing is introduced save what is necessary to maintain the machine in its full working efficiency.

(154.) *Description of marine boilers and furnaces.* — To save space, marine boilers are constructed so as to produce the necessary quantity of steam within the smallest possible dimensions. With this view a more extensive surface in proportion to the capacity of the boiler is exposed to the action of the fire. The flues, by which the flame and heated air are conducted to the chimney, are generally so constructed that the heat may act upon the water on every side in thin oblong shells or plates. This is accomplished by flues so formed as to tra-

*Fig* 81.



verse the boiler backwards and forwards several times before they terminate in the chimney. Such an arrangement renders the expense of the boilers greater, but their steam-producing power is proportionally augmented; and experiments made by Mr. Watt, at Birmingham, have proved that such boilers with the same consumption of fuel will produce, as compared with common land boilers, an increased evaporation in the proportion of about three to two.

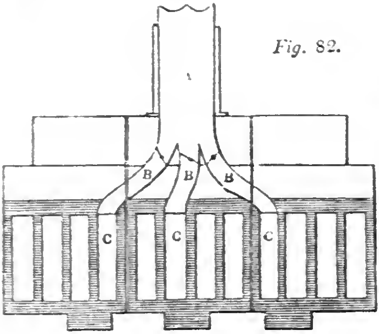
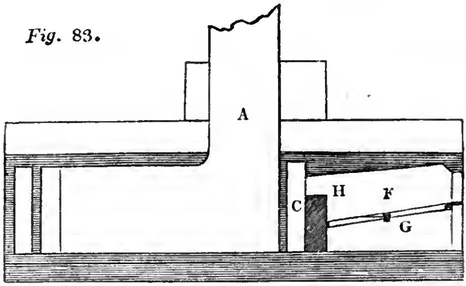


*Fig.* 82.

The form and arrangement of the water-spaces and flues in marine boilers are infinitely various. The sections of the boilers used in some of the government steamers are exhibited in *figs.* 81, 82, 83. A section made by a horizontal plane passing through the flues is exhibited in *fig.* 81. The furnaces F communicate in pairs with the flues E, the air following the course through the flues represented by the arrows. The flue E passes to the back of the boiler, then returns to the front, then to the back again, and is finally carried back to the front, where it communicates at C with the curved flue B, represented in the transverse vertical section, *fig.* 82. This curved flue B finally terminates in the chimney A. There are, in this case, three independent boilers, each worked by two furnaces communicating with the same system of flues; and in the curved flues B, *fig.* 82., by which the air is finally conducted through the chimney, are placed three independent dampers, by means of which the furnace of each boiler can be regulated independently of the other, and by which each boiler may be separately detached from communication with the chimney.

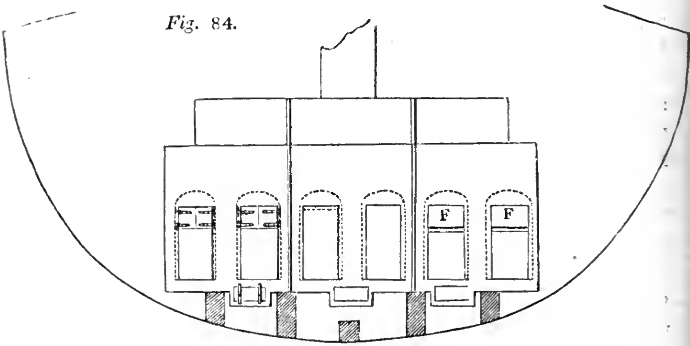
A longitudinal section of the boiler made by a vertical plane extending from the front to the back is given in *fig.* 83., where F, as before, is the furnace, G the grate bars sloping downwards from the front to the back, H the fire bridge, C the commencement of the flues, and A the chimney.

*Fig.* 83.




An elevation of the front of the boiler is represented in *fig.* 84., showing two of the fire doors closed, and the other two removed, displaying the position of the grate bars in

*Fig.* 84.




front. Small openings are also provided, closed by proper doors, by which access can be had to the under-side of the flues, between the foundation timbers of the engine, for the purpose of cleaning them.

Each of these boilers can be worked independently of the others. By this means, when at sea, the engine may be worked by any two of the three boilers, while the third is being cleaned and put in order. In all sea-going steamers, multiple boilers are at present provided for this purpose.

In the boilers here represented the flues are all upon the same level, winding backwards and forwards without passing one above the other. In other boilers, however, the flues, after passing backwards and forwards near the bottom of the boiler, turn upwards and pass backwards and forwards through a level of the water nearer its surface, finally terminating in the chimney. More heating surface is thus obtained with the same capacity of boiler.

(155.) *Want of general principles in the construction of marine boilers and their appendages.*—There cannot be a more striking proof of the ignorance of general principles which prevails respecting this branch of steam engineering, than the endless variety of forms and proportions which are adopted in the boilers and furnaces, which are constructed, not only by different engineers but by the same engineer, for steamers of like power and capacity, and even for the same steamer at different times. Thus the original boilers of the *Great Western*, built for the New York and Bristol or Liverpool voyage, was of the common flue sort. They were subsequently taken out and replaced by tubular boilers. The dimensions and relative proportions of these two sets of boilers, thus supplied to the same vessel for the same voyage, were as follows:—

| | Original Boilers. | Second Boilers. |
|---|---|---|
| Flue surface - - | 2950 sq. ft. | 5900 sq. ft. |
| Fire surface - - | 890 „ | 420 „ |
| Smoke box surface - - | — „ | 830 „ |
| Total heating surface - | 3840 „ | 7150 „ |
| Area of grate - - | 202 „ | 145 „ |
| Steam space in boiler - | 1150 cub. ft. | 1320 cub. ft. |
| Weight of boiler - - | 202 tons. | 56 tons. |
| Weight of water - - | 80 „ | 52 „ |
| Average consumption of fuel per voyage, out and home | 1000 „ | 696 „ |
| Average time of voyage - | $27\frac{1}{2}$ days. | 29 days. |
| Nominal horse-power - | 400 „ | 400 „ |

| | Original Boilers. | Second Boilers. |
|---|---|---|
| Heating surface, per H. P. - | 9·6 sq. ft. | 17·875 sq. ft. |
| Fire grate, ditto - | 0·5 „ | 0·3625 „ |
| Steam space, ditto - | 2·875 cub. ft. | 3·300 cub. ft. |
| Coal per hour, ditto - | 8·333 lbs. | 5·600 lbs. |

The speed of the vessel was less with the second set of boilers. Her consumption of fuel per voyage was, as might be expected, also diminished, but in a much greater ratio than her speed.

On contemplating engineering proceedings, such as are exhibited in the preceding table, it is impossible to deny that practical men in such cases are groping in the dark, without the slightest benefit from the light which they ought to derive from the present advanced state of physical science.

(156.) *Tubular marine boilers.* — Tubular flues have been in many recently built steamers adopted in preference to the flat and longer flues already described. In the second set of boilers of the *Great Western* above-mentioned, the tubes were 8 feet in length and 3 inches inside diameter. In the boilers of the steamer *Ocean*, which are also tubular, the following are the principal dimensions: —

| | |
|---|---|
| Boilers : | |
| Number - - - - | 3 |
| Length - - - - | 14 feet. |
| Breadth - - - - | $19\frac{1}{2}$ feet. |
| Furnaces : | |
| Number - - - - | 7 |
| Length - - - - | 7 feet. |
| Breadth - - - - | $2\frac{1}{12}$ feet |
| Tubes : | |
| Material - - - - | Iron |
| Number - - - - | 378 |
| Length - - - - | 9 feet. |
| Diameter - - - - | $3\frac{1}{4}$ inches. |
| Cylinders : | |
| Number - - - - | 2 |
| Diameter - - - - | 56 inches. |
| Stroke - - - - | $5\frac{1}{2}$ feet. |
| Pressure of steam above atmosphere - - | $4\frac{1}{2}$ lbs. per in. |
| Consumption of coal per hour - - - | 18 cwt. |

(157.) *Inconvenience arising from the use of sea water in the boiler.* — A formidable difficulty which has been encountered in the application of the steam engine to sea voyages has arisen from the necessity of supplying the boiler with sea water instead of pure fresh water. The sea water is injected into the condenser for the purpose of condensing the steam, and it is thence mixed with the condensed steam, conducted as feeding water into the boiler.

Sea water holds, as is well known, certain alkaline substances in solution, the principal of which is muriate of soda, or common salt. Ten thousand grains of pure sea water contain two hundred and twenty grains of common salt, the remaining ingredients being thirty-three grains of sulphate of soda, forty-two grains of muriate of magnesia, and eight grains of muriate of lime. The heat which converts pure water into steam does not at the same time evaporate those salts which the water holds in solution. As a consequence it follows, that as the evaporation in the boiler is continued, the salt, which was held in solution by the water which has been evaporated, remains in the boiler, and enters into solution with the water remaining in it. The quantity of salt contained in sea water being considerably less than that which water is capable of holding in solution, the process of evaporation for some time is attended with no other effect than to render the water in the boiler a stronger solution of salt. If, however, this process be continued, the quantity of salt retained in the boiler having constantly an increasing proportion to the quantity of water, it must at length render the water in the boiler a saturated solution; that is, a solution containing as much salt as at the actual temperature it is capable of holding in solution. If, therefore, the evaporation be continued beyond this point, the salt disengaged from the water evaporated instead of entering into solution with the water remaining in the boiler will be precipitated in the form of sediment; and if the process be continued in the same manner, the boiler would at length become a mere salt-pan.

But besides the deposition of salt sediment in a loose form, some of the constituents of sea water having an attraction for the iron of the boiler, collect upon it in a scale or crust in the same manner as earthy matters held in solution by spring water are observed to form and become incrusted on the inner surface of land-boilers and of common culinary vessels.

The coating of the inner surface of a boiler by incrustation and the collection of salt sediment in its lower parts, are attended with effects highly injurious to the materials of the boiler. The crust and sediment thus formed within the boiler are non-conductors of heat, and placed, as they are, between the water contained in the boiler and the metallic plates which form it, they obstruct the passage of heat from the outer surface of the plates in contact with the fire to the water. The heat, therefore, accumulating in the boiler plates so as to give them a much higher temperature than the water within the boiler, has the effect of softening them, and by the unequal temperature which will thus be imparted to the lower plates which are incrusted, compared with the higher parts which may not be so, an unequal expansion is produced, by which the joints and seams of the boiler are loosened and opened, and leaks produced.

(158.) *Remedies proposed for these inconveniences.*—These injurious effects can only be prevented by either of two methods; first, by so regulating the feed of the boiler that the water it contains shall not be suffered to reach the point of saturation, but shall be so limited in its degree of saltness that no injurious incrustation or deposit shall be formed; and secondly, by the adoption of some method by which the boiler may be worked with fresh water. This end can only be attained by condensing the steam by a jet of fresh water, and working the boiler continually by the same water, since a supply of fresh water sufficient for a boiler worked in the ordinary way could never be commanded at sea.

(159.) *Method by blowing out the over-salted water.*—The method by which the saltness of the water in the boiler is most commonly prevented from exceeding a certain limit has been to discharge from the boiler into the sea a certain quantity of over-salted water, and to supply its place by sea-water introduced into the condenser through the injection-cock for the purpose of condensing the steam, this water being mixed with the steam so condensed, and being, therefore, a weaker solution of salt than common sea water. To effect this, cocks, called *blow-off cocks*, are usually placed in the lower parts of the boiler, where the over-salted, and therefore heavier, parts of the water collect. The pressure of the steam and incumbent weight of the water in the boiler force the lower strata of water out through these cocks; and this process, called *blowing out*, is, or ought to be, practised at such intervals as will prevent the water from becoming over-salted. When the salted water has been blown out in this manner, the level of the water in the boiler is restored by a feed of corresponding quantity.

This process of blowing out, on the due and regular observance of which the preservation and efficiency of the boiler mainly depend, is too often left at the discretion of the engineer, who is, in most cases, not even supplied with the proper means of ascertaining the extent to which the process should be carried. It is commonly required that the engineer should blow out a certain portion of the water in the boiler every two hours, restoring the level by a feed of equivalent amount; but it is evident that the sufficiency of the process founded on such a rule must mainly depend on the supposition that the evaporation proceeds always at the same rate, which is far from being the case with marine boilers.

(160.) *Advantage of an indicator which would show the saltness.*— An indicator, by which the saltness of the water in the boiler would always be exhibited, ought to be provided, and the process of blowing out should be regulated by the indications of that instrument. To blow out more frequently than is necessary is attended with a waste of fuel; for hot water is thus discharged into the sea while cold water is introduced in its place, and consequently all the heat necessary to produce the difference of the temperatures of the water blown out and the feed introduced is lost. If, on the other hand, the process of blowing out be observed less frequently than is necessary, then more or less incrustation and deposit may be produced, and the injurious effects already described ensue.

(161.) *The hydrometer might be used.* — As the specific gravity of water holding salt in solution is increased with every increase of the strength of the solution, any form of hydrometer capable of exhibiting a visible indication of the specific gravity of the water contained in the boiler would serve the purpose of an indicator, to show when the process of blowing out is necessary, and when it has been carried to a sufficient extent. The application of such instruments, however, would be attended with some practical difficulties in the case of sea boilers.

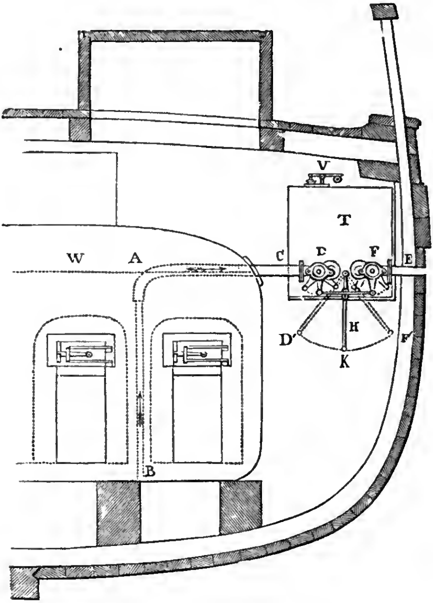
(162.) *Indication by the thermometer or by the pressure.*— The temperature at which a solution of salt boils under a given pressure varies considerably with the strength of the solution; the more concentrated the solution is, the higher will be its boiling temperature under the same pressure. A comparison, therefore, of a steam gauge attached to the boiler, and a thermometer immersed in it, showing the pressure and the temperature, would always indicate the saltness of the water; and it would not be difficult so to graduate these instruments as to make them at once show the degree of saltness.

If the application of the thermometer be considered to be attended with practical difficulty, the difference of pressures under which the salt water of the boiler and fresh water of the same temperature boil, might be taken as an indication of the saltness of the water in the boiler, and it would not be difficult to construct upon this principle a self-registering instrument, which would not only indicate but record from hour to hour the degree of saltness of the water. A small vessel of distilled water being immersed in the water of the boiler would always have the temperature of that water, and the steam produced from it communicating with a steam-gauge, the pressure of such steam would be indicated by that gauge, while the pressure of the steam in the boiler under which pressure the salted water boils might be indicated by another gauge. The difference of the pressures indicated by the two gauges would thus become a test by which the saltness of the water in the boiler would be measured. The two pressures might be made to act on opposite ends of the same column of mercury contained in a siphon tube, and the difference of the levels of the two surfaces of the mercury would thus become a measure of the saltness of the water in the boiler. A self-registering instrument founded on this principle formed part of the self-registering steam-log which I proposed to introduce into steam-vessels some time since.

(163.) *Indicator proposed by Messrs. Seaward.*—The Messrs. Seaward of Limehouse adopted, in some of their engines, a method of indicating the saltness of the water, and of measuring the quantity of salted water or brine discharged, by blowing out. A glass-gauge, similar in form to that already described in land engines (118.), is provided to indicate the position of the surface of the water in the boiler. In this gauge two hydrometer balls are provided, the weight of which in proportion to their magnitude is such that they would both sink to the bottom in a solution of salt of the same strength as common sea-water. When the quantity of salt exceeds $\frac{5}{32}$ parts of the whole weight of the water, the lighter of the two balls will float to the top; and when the strength is further increased until the proportion of salt exceeds $\frac{6}{32}$ parts of the whole, then the heavier ball will float to the top. The actual quantity of salt held in solution by sea water in its ordinary state is $\frac{1}{32}$ part of its whole weight; and when by evaporation the proportion of salt in solution has become $\frac{9}{32}$ parts of the whole, then a deposition of salt commences. With an indicator such as that above described, the ascent of the lighter hydrometer ball gives notice of the necessity for blowing out, and the ascent of the heavier may be considered as indicating the approach of an injurious state of saltness in the boiler.

The ordinary method of blowing out the salted water from a boiler is by a pipe having a cock in it leading from the boiler through the bottom of the ship, or at a point low down at its side. Whenever the engineer considers that the water in the boiler has become so salted that the process of blowing out should commence, he opens the cock communicating by this pipe with the sea, and suffers an indefinite and uncertain quantity of water to escape. In this way he discharges, according to the magnitude of the boiler, from two to six tons of water, and repeats this at intervals of from two to four hours, as he may consider to be sufficient. If, by observing this process, he prevents the boiler from getting incrusted during the voyage, he considers his duty to be effectually discharged, forgetting that he may have blown out many times more water than is necessary for the preservation of the boiler, and thereby produced a corresponding and unnecessary waste of fuel. In order to limit the quantity of water discharged, Messrs. Seaward adopted the following method. In *fig.* 85. is represented a transverse section of

*Fig.* 85.




a part of a steam vessel; W is the water-line of the boiler, B is the mouth of a blow-off pipe, placed near the bottom of the boiler. This pipe rises to A, and turning in the horizontal direction, A C, is conducted to a tank T, which contains exactly a ton of water. This pipe communicates with the tank by a cock D, governed by a lever H. When this lever is moved to D′, the cock D is open, and when it is moved to K, the cock D is closed. From the same tank there proceeds another pipe E, which issues from the side of the vessel into the sea, governed by a cock F, which is likewise put in connection with the lever H, so that it shall be opened when the

the lever H is drawn to the position F′, the cock D′ being closed in all positions of the lever between K and F′. Thus, whenever the cock F communicating with the sea is open, the cock D communicating with the boiler is closed, and *vice versâ*, both cocks being closed when the lever is in the intermediate position K. By this arrangement the boiler cannot, by any neglect in blowing off, be left in communication with the sea, nor can more than a ton of water be discharged except by the immediate act of the engineer. The injurious consequences are thus prevented which sometimes ensue when the blow-off cocks are left open by any neglect on the part of the engineer. When it is necessary to blow off, the engineer moves the lever H to the position D′. The pressure of the steam in the boiler on the surface of the water W forces the salted water or brine up the pipe B A, and through the open cock C into the tank, and this continues until the tank is filled: when that takes place, the lever is moved from the position D′ to the position F′, by which the cock D is closed, and the cock F opened. The water in the tank flows through the pipe E into the sea, air being admitted through the valve V, placed at the top of the tank, opening inwards. A second ton of brine is discharged by moving the lever back to the position D′, and subsequently returning it to the position F′; and in this way the brine is discharged ton by ton, until the supply of water from the feed which replaces it has caused both the balls in the indicator to sink to the bottom.

(164.) *Field's brine pumps.* — A different method of preserving the requisite freshness of the water in the boiler was adopted by Messrs. Maudslay and Field. Pumps called *brine pumps* are put into communication with the lower part of the boiler, and so constructed as to draw the brine therefrom, and drive it into the sea. These brine pumps are worked by the engine, and their operation is constant. The feed pumps are likewise worked by the engine, and they bear such a proportion to the brine pumps that the quantity of salt discharged in a given time in the brine is equal to the quantity of salt introduced in solution by the water of the feed pumps. By this means the same actual quantity of salt is constantly maintained in the boiler, and consequently the strength of the solution remains invariable. If the brine discharged by the brine pumps contains $\frac{5}{32}$ parts of salt, while the water introduced by the feed pumps contains only $\frac{1}{32}$ part, then it is evident that five cubic feet of the feeding water will contain no more salt than is contained in one cubic foot of brine. Under such circumstances the brine pumps would be so constructed as to discharge $\frac{1}{5}$ of the water introduced by the feed pumps, so that $\frac{4}{5}$ of all the water introduced into the boiler would be evaporated, and rendered available for working the engine.

To save the heat of the brine, a method has been adopted in the marine engines constructed by Messrs. Maudslay and Field similar to one which has been long practised in steam-boilers, and in various apparatus for the warming of buildings. The current of heated brine is conducted from the boiler through a tube which is contained in another, through which the feed is introduced. The warm current of brine, therefore, as it passes out, imparts a considerable portion of its heat to the cold feed which comes in; and it is found that by this expedient the brine discharged into the sea may be reduced to a temperature of about 100°.

This expedient is so effectual, that when the apparatus is properly constructed, and kept in a state of efficiency, it may be regarded as nearly a perfect preventive against the incrustation, and the deposition of salt in the boilers, and is not attended with any considerable waste of fuel.

(165.) *Precautions necessary in the use of brine pumps.*— It is maintained by many practical men, that the economy of heat effected by brine pumps, such as have been just described, is more than counterbalanced by the risk which attends them, if not accompanied by proper precautions. The pipes through which the salted water is discharged are, it is said, apt to get choked, in which case the pumps will necessarily cease to act, though they appear to the engineer to do so; and thus the water in the boiler may become salted to any extent without the knowledge of the engineer. When the process of *blowing out* is executed in the ordinary way, without brine pumps, the engineer looks at his water gauge and keeps the blow-off cock open until the water level has fallen to the required point. Under these circumstances there is a certainty of having discharged from the boiler a certain quantity of salted water, a certainty which does not exist in the case of a continuous discharge of water by brine pumps.

Such expedients, therefore, it is contended, should always be accompanied by some indicator, which shall show the degree of saltness of the water in the boiler, such as we shall presently explain.

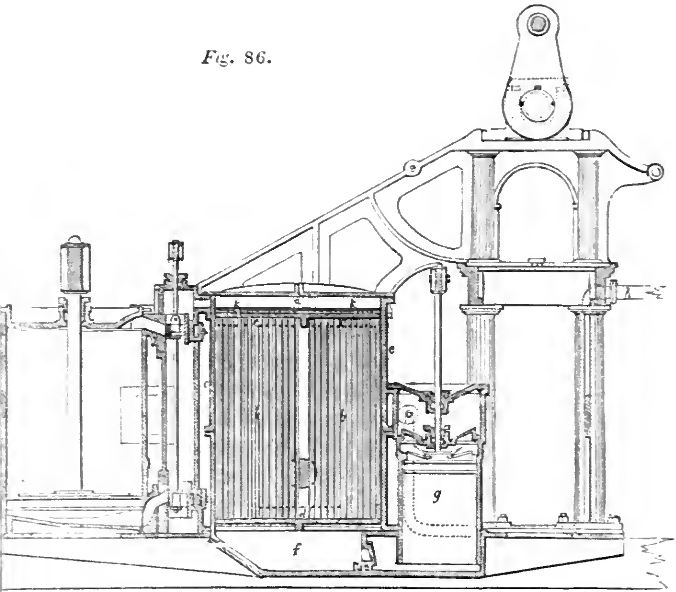
(166.) *Methods of working with fresh water.* — *Tubular condensers.* — About the year 1776, Mr. Watt invented a tubular condenser, with a view to condense the steam drawn off from the cylinder without the process of injection. This apparatus consisted of a number of small tubes connecting the top and bottom of the condenser, arranged in a manner not very different from that of the tubes which traverse the boiler of a locomotive engine. These tubes were continually surrounded by cold water, and the steam, as it escaped from the cylinder passing through them, was condensed by their cold surfaces, and collected in the form of water in a reservoir below, from whence it was drawn off by a pump in the same manner as in engines which condensed by injection. One of the advantages proposed by this expedient was, that no atmospheric air would be introduced into the condenser, as is always the case when condensation by injection is practised. Cold water, which is injected, has always combined with it more or less common air. When this water is mixed with the condensed steam, the elevation of its temperature disengages the air combined with it, and this air circulating to the cylinder, vitiates the vacuum. One of the purposes for which the air-pump in condensing steam engines was provided, and from which it took its name, was to draw off this air. If, however, a tubular condenser could be made to act with the necessary efficiency, no injection water would be introduced for condensation, and the pump would have no other duty except to remove the small quantity of water produced by the condensed steam. That water being subsequently carried back to the boiler by the feed pumps, a constant system of circulation would be maintained, and the boiler would never require any fresh supply of water, except what might be necessary to make good the waste by leakage and other causes.

(167.) *Hall's condenser.* — This contrivance was revived by Mr. Samuel Hall, of Basford, near Nottingham, with a view to supersede in marine engines the necessity of using sea water in the boilers. Mr. Hall proposed to make marine boilers with fresh water to condense the steam without injection, by a tubulated condenser, and to provide by the distillation of sea water the small quantity of fresh water which would be necessary to make good the waste. These condensers were introduced into several steam vessels, but their use has not been continued. Mr. Watt abandoned these condensers from finding that the condensation of the steam was not sufficiently sudden, and that consequently, at the commencement of the stroke, the piston was subject to a resistance which injuriously diminished the amount of the moving power, whereas condensation by jet was almost instantaneous, and the efficiency of the piston throughout the entire stroke was more uniform.

Mr. Watt also found that a fur collected around the tubes of the condenser, so as to obstruct the free passage of heat from the steam to the water of the cold cistern; and that, consequently, the efficiency of the condenser was gradually impaired, and could only be restored by frequent cleansing.

A tubular condenser of the form proposed by Mr. Hall is represented in *fig.* 86.; *a* is the upper part of the condenser to which steam is admitted from the slide after having worked the piston; *k* is the section of a thin plate, forming the top of the condenser, perforated with small holes, in which the tubes are inserted so as to be steam-tight and water-tight. Water is admitted to flow around these tubes between the top *k* and the bottom *d* of the condenser, so as to keep them constantly at a low temperature. The steam passes from *a* through the tubes to the lower chamber *f* of the condenser, where it is reduced to water by the cold to which it has been exposed. A supply of cold water is constantly pumped through the condenser, so as to keep the tubes at a low temperature. The air-pump *g* is of the usual construction, having valves in the piston opening upwards, and similar valves in the cover of the pump also opening upwards. The water formed by the condensed steam in *f* is drawn through the foot valve, and after passing through the piston valves, is discharged by the up-stroke of the piston into the hot well.

*Fig.* 86.



Any air, or other permanent gas, which may be admitted by leakage through the tubes of the condenser, or by any other means, is likewise drawn out by this pump, and when drawn into the hot well is carried from thence to the feeding apparatus of the boiler, to which it is transferred by the feed pump.

A provision is likewise made by which the steam escaping at the safety valve is condensed and carried away to the feeding cistern.

(168.) *Ericsson's condenser.*—Another form of tubular condenser has more recently been invented and constructed in the United States by Captain John Ericsson. This apparatus consists of a cylindrical vessel resembling in form the boiler of a locomotive, which is traversed from end to end by a great number of small tubes. The steam is conducted from the boiler to a reservoir or hot cistern through these tubes. The sea water is driven in to the vessel containing the tubes by a force pump, so that a continual current of this water is kept flowing through the vessel and round the tubes, a pipe of escape being provided, by which, after passing through, it is discharged into the sea.

(169.) *Copper boilers.*—One of the remedies proposed for the evil consequences arising from incrustation is the substitution of copper for iron boilers. The attraction which produces the adhesion of the calcareous matter held in solution by salt water to the surface of iron has no existence in copper, and all the saline and other alkaline matter precipitated in the boiling water in copper boilers is suspended in a loose form, and carried off by the process of blowing out.

Besides the injury arising from the deposition of salt and the incrustation on the inner surface of boilers, an evil of a formidable kind attends the accumulation of soot mixed with salt in the flues, which proceeds from the leaks. In the seams of the boiler there are numerous apertures, of dimensions so small as to be incapable of being rendered stanch by any practicable means, through which the water within the boiler filters, and the salt which it carries with it mixes with the soot, forming a compound which rapidly corrodes the boilers. This process of corrosion in the flues takes place not less in copper than in iron boilers. In cleansing the flues of a copper boiler, the salt and soot which was thrown out upon the iron plates which formed the flooring of the engine-room, having remained there for some time, left behind it a permanent appearance of copper on the iron flooring, arising from the precipitation of the copper which had combined with the soot and salt in the flues. In this case the leaks from whence the salt proceeded were found, on careful examination, so unimportant, that the usual means to stanch them could not be resorted to without the risk of increasing the evil.

(170.) *Efficiency of blowing out renders such expedients of less value.*—In practice, however, if a marine boiler be regularly attended to, and the salted water be discharged either by the common method of blowing-off cocks or by brine pumps, or any other expedient which shall impose the necessary limit on the degree of concentration of the water in the boiler, the evil arising from incrustation will be quite inconsiderable.

A scale will in all cases be formed on the inner surface of the boilers, which must be removed from time to time when the vessel is in port. The best method of effecting this is by lighting some shavings, or other light and flaming combustible, in the furnaces when the boilers are empty and the safety valves open. The expansion of the metal by the heat thus produced being greater than that of the matter composing the scale, the latter will be detached and will fall in pieces to the bottom of the boiler, from which it can be withdrawn with the water at the man-holes.

In some cases, however, it will be preferable to detach the scale by the hammer or chisel.

(171.) *Corrosion of boilers.*—It is a great error to suppose that incrustation is either the sole or principal cause of the rapid destruction of marine boilers. If it were so, it would necessarily happen that marine boilers in which expedients are adopted by which fresh water is used, or even those in which the process of blowing out has been regularly observed, and in which the scale is detached before it is allowed to thicken to an injurious extent, would last as long or nearly as long as land boilers. It is found, however, that the boilers in which these expedients are adopted with the greatest effect and regularity are, nevertheless, less durable in a very large proportion than land boilers. Thus, while a land boiler will last for twenty years, a marine boiler similarly constructed will, even with the greatest care, be worn out in four or five years.

The cause of this rapid destruction of the boiler is corrosion, but how this corrosion is produced is a question which has not hitherto been satisfactorily answered. It is contended that this is not to be ascribed to any chemical action of the sea-water on the iron, inasmuch as the flues of marine boilers rarely show any deterioration from this cause, and even in worn-out marine boilers the hammer marks on the flues are as conspicuous as when they are fresh from the boiler maker. The thin film of scale which covers the interior surface would rather protect the iron from the action of the water. In fine, the seat of the corrosion is almost never those parts of the boiler which are in contact with the water. It is that part of the metal which includes the steam space that exhibits corrosion; but even there the effect is so irregular that no data can be obtained by which the cause can be satisfactorily traced. The part which is most rapidly corroded in one boiler is not at all affected in another; and in some cases we find one side of the steam chest attacked, the other side being untouched. Sometimes the iron exfoliates in flakes, while in others it appears as though it were eaten away by an acid.

(172.) *Importance of economising fuel.*—In the application of the steam engine to the propulsion of vessels in voyages of great extent, the economy of fuel acquires an importance greater than that which appertains to it in land engines, even in localities the most removed from coal mines, and where its expense is greatest. The practical limit to steam voyages being determined by the greatest quantity of coals which a steam vessel can carry, every expedient by which the efficiency of the fuel can be increased becomes a means, not merely of a saving of expense, but of an increased extension of steam power to navigation. Much attention has been bestowed on the augmentation of the duty of engines in the mining districts of Cornwall, where the question of their efficiency is merely a question of economy; but far greater care should be given to this subject when the practicability of maintaining intercourse by steam between distant points of the globe will perhaps depend on the effect produced by a given quantity of fuel. So long as steam navigation was confined to river and channel transport and to coasting voyages, the speed of the vessel was a paramount consideration, at whatever expenditure of fuel it might be obtained; but since steam navigation has been extended to ocean voyages, where coals must be transported sufficient to keep the engine in operation for a long period of time without a fresh relay, greater attention has been bestowed upon the means of economising it.

Much of the efficiency of fuel must depend on the management of the fires, and therefore on the skill and care of the stokers. Formerly the efficiency of firemen was determined by the abundant production of steam, and so long as the steam was evolved in superabundance, however it might have blown off to waste, the duty of the stoker was considered as well performed. The regulation of the fires according to the demands of the engine were not thought of, and whether much or little steam was wanted, the duty of the stoker was to urge the fires to their extreme limit.

Since the resistance opposed by the action of the paddle wheels of a steam vessel varies with the state of the weather, the consumption of steam in the cylinders must undergo a corresponding variation; and if the production of steam in the boilers be not proportioned to this, the engines will either work with less efficiency than they might do under the actual circumstances of the weather, or more steam will be produced in the boilers than the cylinders can consume, and the surplus will be discharged to waste through the safety valves. The stokers of a marine engine, therefore, to perform their duty with efficiency, and obtain from the fuel the greatest possible effect, must discharge the functions of a self-regulating furnace, such as has been already described: they must regulate the force of the fires by the amount of steam which the cylinders are capable of consuming, and they must take care that no unconsumed fuel is allowed to be carried away from the ash-pit.

(173.) *Coating boiler with non-conducting substances.*— Formerly the heat radiated from every part of the surface of the boiler was allowed to go to waste, and to produce injurious effects on those parts of the vessel to which it was transmitted. This evil, however, has been removed by coating the boilers, steam pipes, &c. of steam vessels with felt, by which the escape of heat from the surface of the boiler is very nearly, if not altogether, prevented. This felt is attached to the boiler surface by a thick covering of white and red lead. This expedient was first applied in the year 1818 to a private steam vessel of Mr. Watt's, called the *Caledonia;* and it was subsequently adopted in another vessel, the machinery of which was constructed at Soho, called the *James Watt.*

(174.) *Management of the furnaces.*—The economy of fuel depends in a considerable degree on the arrangement of the furnaces, and the method of feeding them. In general, each boiler is worked by two or more furnaces communicating with the same system of flues. While the furnace is fed, the door being open, a stream of cold air rushes in, passing over the burning fuel and lowering the temperature of the flues: this is an evil to be avoided. But, on the other hand, if the furnaces be fed at distant intervals, then each furnace will be unduly heaped with fuel, a great quantity of smoke will be evolved, and the combustion of the fuel will be proportionally imperfect. The process of coking in front of the grate, which would insure a complete combustion of the fuel, has been already described (112.). A frequent supply of coals, however, laid carefully on the front part of the grate, and gradually pushed backwards as each fresh feed is introduced, would require the fire door to be frequently opened, and cold air to be admitted. It would also require greater vigilance on the part of the stokers than can generally be obtained in the circumstances in which they work. In steam vessels the furnaces are therefore fed less frequently, fuel is introduced in greater quantities, and a less perfect combustion produced.

When several furnaces are constructed under the same boiler, communicating with the same system of flues, the process of feeding, and consequently opening one of them, obstructs the due operation of the others, for the current of cold air which is thus admitted into the flues checks the draft, and diminishes the efficiency of the furnaces in operation. It was formerly the practice in vessels exceeding one hundred horse-power, to place four furnaces under each boiler, communicating with the same system of flues. Such an arrangement was found to be attended with a bad draft in the furnaces, and therefore to require a greater quantity of heating surface to produce the necessary evaporation. This entailed upon the machinery the occupation of more space in the vessel in proportion to its power; it has therefore been more recently the practice to give a separate system of flues to each pair of furnaces, or, at most, to every three furnaces. When three furnaces communicate with a common flue, two will always be in operation, while the third is being cleared out; but if the same quantity of fire were divided among two furnaces, then the clearing out of one would throw out of operation half the entire quantity of fire, and during the process the evaporation would be injuriously diminished.

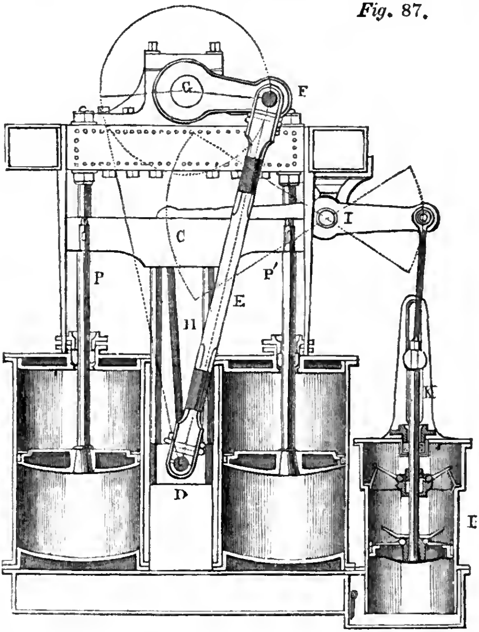
It is found by experience, that the side plates of furnaces are liable to more rapid destruction than their roofs, owing, probably, to a greater liability to deposit. Furnaces, therefore, should not be made narrower than a certain limit. Great depth from front to back is also attended with practical inconvenience, as it renders firing tools of considerable length, and a corresponding extent of stoking room necessary. It is recommended by those who have had much practical experience in steam vessels, that furnaces six feet in depth from front to back should not be less than three feet in width to afford means of firing with as little injury to the side plates as possible, and of keeping the fires in the condition necessary for the production of the greatest effect. The tops of the furnaces almost never decay, and seldom are subject to an alteration of figure, unless the level of the water be allowed to fall below them.

(175.) *Advantage of more extended application of expansion.*—The method by which the greatest quantity of practical effect can be obtained from a given quantity of fuel must, however, mainly depend on the extended application of the expansive principle. This has been the means by which an extraordinary amount of duty has been obtained from the Cornish engines. The difficulty of the application of this principle in marine engines has arisen from the objections entertained in Europe to the use of steam of high-pressure under the circumstances in which the engine must be worked at sea. To apply the expansive principle, it is necessary that the moving power at the commencement of the stroke shall considerably exceed the resistance, its force being gradually attenuated till the completion of the stroke, when it will at length become less than the resistance. This condition may, however, be attained with steam of limited pressure, if the engine be constructed with a sufficient quantity of piston surface.

(176.) *Maudslay and Field's Siamese engine.*—This method of rendering the expansive principle available at sea, and compatible with low-pressure steam, was projected and executed by Messrs. Maudslay and Field. Their improvement consists in adapting two steam cylinders in one engine, in such a manner that the steam shall act simultaneously on both pistons, causing them to ascend and descend together. The piston rods are both attached to the same horizontal cross-head, whereby their combined action is applied to one crank by means of a connecting rod placed between the pistons.

A section of such an engine (which has been called the Siamese engine), made by a plane passing through the two

*Fig.* 87.




piston rods P P′ and cylinders, is represented in *fig.* 87. The piston rods are attached to a cross-head C, which ascends and descends with them. This cross-head drives upwards and downwards an axle D, to which the lower end of the connecting rod E is attached. The other end of the connecting rod drives the crank pin F, and imparts revolution to the paddle shaft G. A rod H conveys motion by means of a beam I to the rod K of the air-pump E.

Engines constructed on this principle have been applied in several steamers, and amongst others in Her Majesty's steam frigate "*Retribution*."

It is objected by some authorities that, in this system, there is a greater liability to leakage and increased friction.

If either piston should leak, or either stuffing-box leak air, a twist must be given to all parts of the engine, arising from the unequal effective action of the two pistons.

It is also objected that the plan involves the necessity of a low condenser, which the air-pump cannot thoroughly drain out; and the pitching of the vessel, by causing the water to run from one end of the condenser to the other, will occasionally render the working of the air-pump ineffectual, while at other times it is choked with water, which it can only with difficulty deliver, and that fractures are liable to occur in consequence.*

(177.) *Maudslay and Field's improved framing.* — Connected with this, and in the same patent, another improvement was included, consisting of the application of a hollow wrought-iron framing carried across the vessel above the machinery, to support the whole of the bearings of the crank shaft. A plan of this, including the cylinders and paddle wheel, is represented in *fig.* 88. The advantages proposed by these improvements are simplicity of construction, more direct action on the crank, economy of space and weight of material, combined with increased area of the piston, whereby a given evaporating power of the boiler is rendered productive, by extended application of the expansive principle, of a greater moving power than in former arrangements. Consequently, under like circumstances, greater power and economy of fuel is obtained, with the further advantage at sea, that when the engine is reduced in its speed, either by the vessel being deeply laden with coal, as is the case at the commencement of a long sea voyage, or by head winds, more steam may be given to the cylinders, and consequently more speed imparted to the vessel, all the steam produced in the boiler being usefully employed.

(178.) *Their double piston-rod.* — Another improvement, having the same objects, and analogous to the preceding, has been likewise patented by Messrs. Maudslay and Field. This consists in the adoption of a cylinder of greater

* Steam Engine, Artisan Club, p. 180.

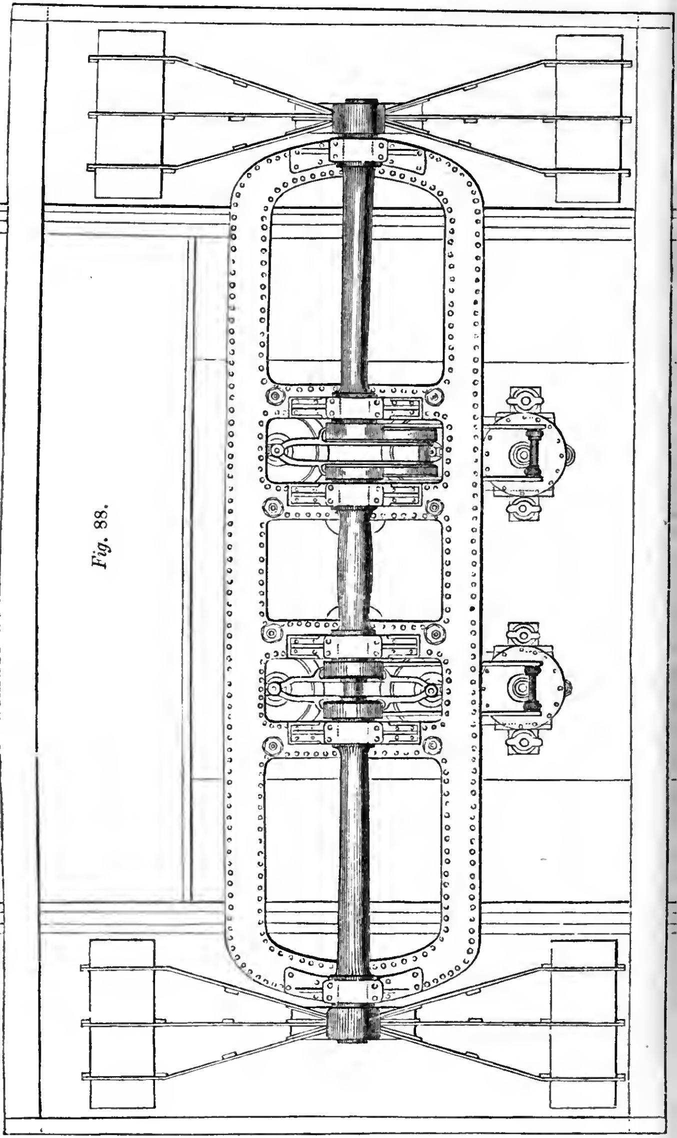
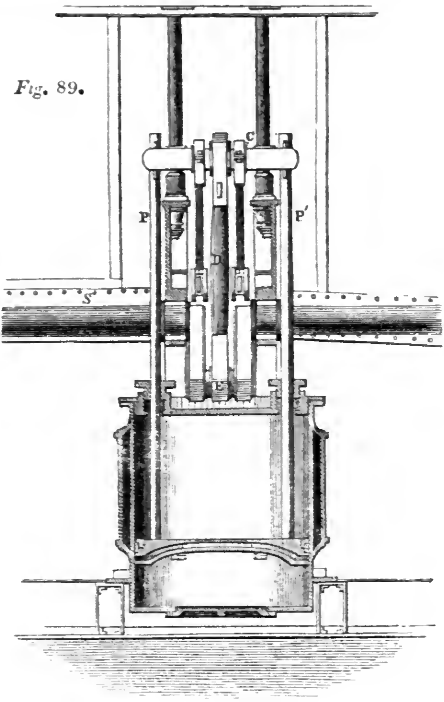


Fig. 88.

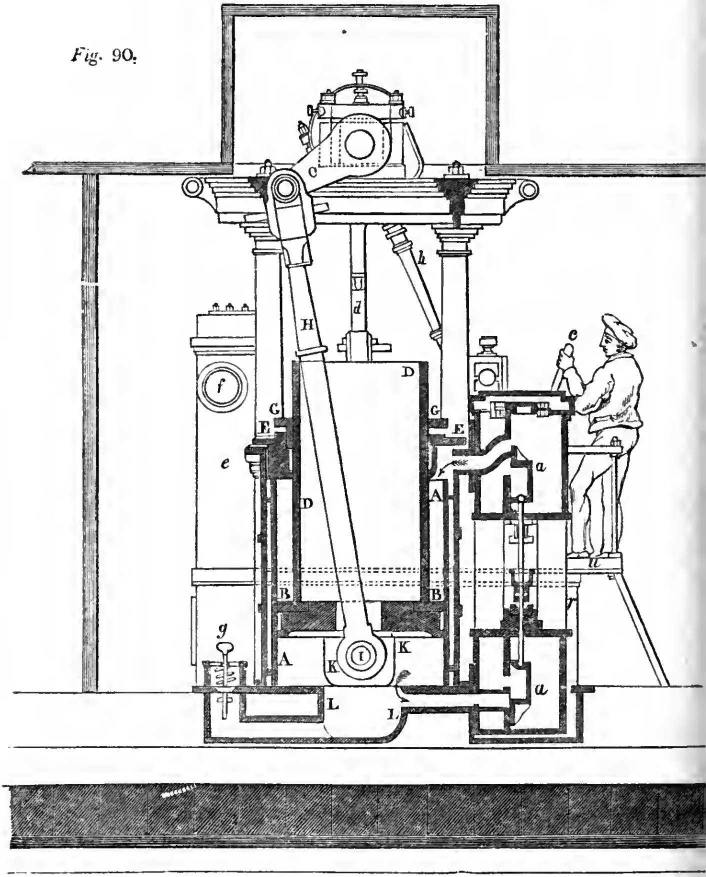
diameter, having two piston rods P P′, as represented in *fig.* 89., of considerable length, connected at the top by a cross-head C. From this cross-head is carried downwards the connecting rod D, which drives the crank pin E, and thereby works the paddle shaft S. In this case the paddle

*Fig.* 89.




shaft is extended immediately above the piston, and the double piston rod has sufficient length to be above the paddle shaft when the piston is at the bottom of its stroke. This improvement is intended to be applied more particularly for engines for river navigation, the advantages resulting from it being that a paddle shaft placed at a given height from the bottom of the vessel will be enabled to receive a longer stroke of piston than by any other arrangement now in use. A more compact and firm connection of the cylinder with the crank shaft bearings is effected by it, and a cylinder of much greater diameter may be applied, by which the expansive action of steam may be more fully brought into play; and a more direct action of the steam power on the crank with a less weight of materials and a greater economy of

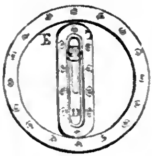
*Fig.* 90.




space may be obtained than by any of the arrangements of marine engines hitherto used.

(179.) *Mr. F. Humphrys' engine.*—Mr. Francis Humphrys has obtained a patent for a form of marine engine, by which some simplification of the machinery is attained, and the same power comprised within more limited dimensions. In this engine there is attached to the piston of the cylinder, instead of a piston rod, a hollow casing D D (*fig.* 90.), which moves through a stuffing box G, constructed in a manner similar to the stuffing box of a piston rod. In the figure, this casing is presented in section, but its form is that of a long narrow slit, or opening, rounded at either end, as exhibited in the plan (*fig.* 91.) of the cylinder cover. The crank C is driven by the other end of the connecting rod H, the crank shaft being immediately above the centre of the piston, and the connecting rod passing through the oblong opening D, and descending into the hollow piston rod, is attached to an axis I at the bottom of the piston. A box or cover K K encloses the cross-piece or axis I with its bearings, and is attached so as to be steam-tight to the bottom of the piston. A hollow space L L is cast in the bottom of the cylinder for the reception of the box K K, when the piston is at the bottom of the cylinder.

*Fig.* 91.




By this arrangement the force by which the piston is driven in its ascent and descent is communicated to the connecting rod, not, as usual, through the intervention of a piston rod, but directly from the piston itself by the cross-pin I, and from thence to the crank C, which it drives without the intervention of beams, cross-heads, or any similar appendage.

The slide valves regulating the admission and eduction of steam are represented at *a*; the rod of the air-pump is shown at *d*, being worked by a crank placed on the centre of the great crank shaft.

(180.) *Engines which act by connecting rods without beams.* — To simplify the machinery of the marine engine, and, at the same time, to diminish its bulk, and thus augment the profitable tonnage of the vessel, the form of beam engine described in (153.) has been, to a considerable extent, superseded by various other models of marine engines, in which the piston acts directly on the paddle shaft, without the intervention of any machinery except the connecting rod. The Siamese engines of Maudslay and Field and the engine of Humphrys are examples of this.

The piston rod is, in such engines, maintained in its direction by guides, and its force is transmitted to the crank, directly by the connecting rod. There are, usually, two cranks, placed at right angles, as already described in the case of the ordinary beam engine, which are driven by the connecting rods of the two cylinders.

(181.) *Engines which act by connecting rods on the same crank.*— In some cases, however, the two connecting rods act upon the same crank, the cylinders being placed with their axes at right angles, so that when the connecting rod of one is at the dead point, that of the other is at right angles with the crank.

(182.) *Engines which act on a single crank without either beam or connecting rods.* — *Rocking engines.*— A still greater simplification is effected in some smaller steamers, more especially in river boats, in which the connecting rods themselves are dispensed with, and the ends of the piston rods are directly jointed to the crank. In these cases the cylinders are supported on an axis at right angles to their length, on which they are capable of moving with a vibratory or rocking motion. By this motion the piston rods are enabled to follow the revolution of the crank, and at the same time the valves are worked. The two pistons usually act upon the same crank, being suspended with their axes at right angles to each other, and at 45° with the vertical line.

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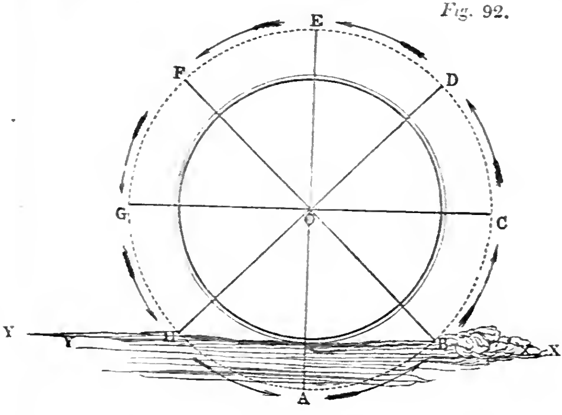
## CHAPTER II.

### PROPELLERS.

(183.) *Common paddle wheel.* — To obtain from the moving power its full amount of mechanical effect in propelling the vessel, it would be necessary that it should constantly act against the water in a horizontal direction, and with a motion contrary to the course of the vessel. No system of propellers has, however, yet been contrived capable of perfectly accomplishing this. Patents have been granted for many ingenious mechanical combinations to impart to the propelling surfaces such angles as appeared to the respective contrivers most advantageous. In most of these the mechanical complexity has formed a fatal objection. No part of the machinery of a steam vessel is so liable to become deranged at sea as the propellers; and, therefore, that simplicity of construction which is compatible with those repairs which are possible on such emergencies is quite essential for safe practical use.

The ordinary paddle wheel, as has been already stated, is a wheel revolving upon a shaft driven by the engine, and carrying upon its circumference a number of flat boards, called paddle boards, which are secured by nuts and braces in a fixed position; and that position is such that the planes of the paddle boards diverge from the centre of the shaft on which the wheel turns. The consequence of this arrangement is that each paddle board can only act in that direction which is most advantageous for the propulsion of the vessel

*Fig.* 92.




when it arrives at the lowest point of the wheel. In *fig.* 92. let O be the shaft on which the common paddle wheel revolves; the position of the paddle boards are represented at A, B, C, &c.; X Y represents the water line, the course of the vessel being supposed to be from X to Y; the arrows represent the direction in which the paddle wheel revolves. The wheel is immersed to the depth of the lowest paddle board, since a less degree of immersion would render a portion of the surface of each paddle board mechanically useless. In the position A, the whole force of the paddle board is efficient for propelling the vessel; but as the paddle enters the water in the position H, its action upon the water not being horizontal, is only partially effective for propulsion: a part of the force which drives the paddle is expended in depressing the water, and the remainder in driving it contrary to the course of the vessel, and, therefore, by its re-action producing a certain propelling effect. The tendency, however, of the paddle entering the water at H is to form a hollow or trough, which the water, by its ordinary property, has a continual tendency to fill up. After passing the lowest point A, as the paddle approaches the position B, where it emerges from the water, its action again becomes oblique, a part only having a propelling effect, and the remainder having a tendency to raise the water, and throw up a wave and spray behind the paddle wheel. It is evident that the more deeply the paddle wheel becomes immersed, the greater will be the proportion of the propelling power thus wasted in elevating and depressing the water; and if the wheel were immersed to its axis, the whole force of the paddle boards, on entering and leaving the water, would be lost, no part of it having a tendency to propel. If a still deeper immersion take place, the paddle boards above the axis would have a tendency to retard the course of the vessel. When the vessel is, therefore, in proper trim, the immersion should not exceed nor fall short of the depth of the lowest paddle; but for various reasons it is impossible in practice to maintain this fixed immersion: the agitation of the surface of the sea causing the vessel to roll, will necessarily produce a great variation in the immersion of the paddle wheels, one becoming frequently immersed to its axle, while the other is raised altogether out of the water. Also the draught of water of the vessel is liable to change, by the variation in the cargo; this will necessarily happen in steamers which take long voyages. At starting they are heavily laden with fuel, which as they proceed is gradually consumed, whereby the vessel is lightened.

(184.) *Feathering paddles.*— To remove this defect, and economise as much as possible the propelling effect of the paddle boards, it would be necessary so to construct them that they may enter and leave the water edgeways, or as nearly so as possible; such an arrangement would be, in effect, equivalent to the process called feathering, as applied to oars. Any mechanism which would perfectly accomplish this would cause the paddles to work in almost perfect silence, and would very nearly remove the inconvenient and injurious vibration which is produced by the action of the common paddles. But the construction of feathering paddles is attended with great difficulty, under the peculiar circumstances in which such wheels work. Any mechanism so complex that it could not be easily repaired when deranged, with such engineering implements and skill as can be obtained at sea, would be attended with great objections.

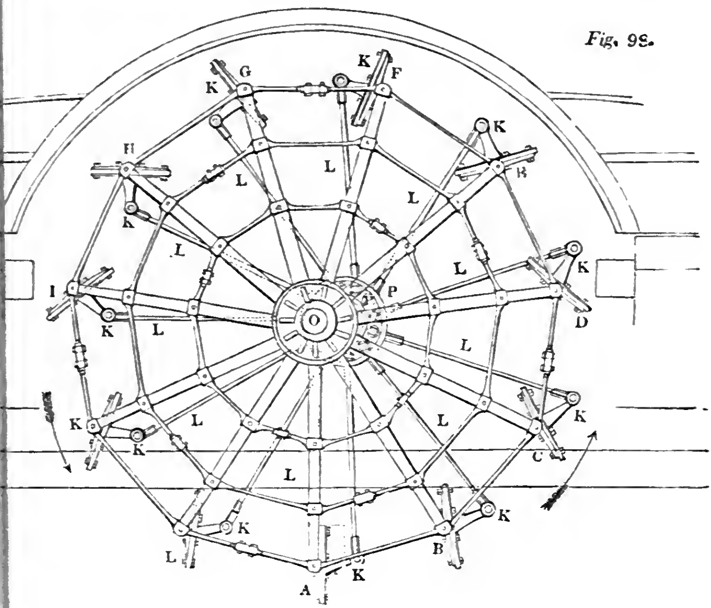
Feathering paddle boards must necessarily have a motion independently of the motion of the wheel, since any fixed position which could be given to them, though it might be most favourable to their action in one position would not be so in their whole course through the water. Thus the paddle board when at the lowest point should be in a vertical position, or so placed that its plane, if continued upwards, would pass through the axis of the wheel. In other positions, however, as it passes through the water, it should present its upper edge, not towards the axle of the wheel, but towards a point above the highest point of the wheel. The precise point to which the edge of the paddle board should be directed is capable of mathematical determination. But it will vary according to circumstances, which depend on the motion of the vessel. The progressive motion of the vessel, independently of the wind or current, must obviously be slower than the motion of the paddle boards round the axle of the wheel; since it is by the difference of these velocities that the re-action of the water is produced by which the vessel is propelled. The proportion, however, between the progressive speed of the vessel and the rotative speed of the paddle boards is not fixed; it will vary with the shape and structure of the vessel, and with its depth of immersion; nevertheless it is upon this proportion that the manner in which the paddle boards should shift their position must be determined. If the progressive speed of the vessel were nearly equal to the rotative speed of the paddle boards, the latter should so shift their position that their upper edges should be presented to a point very little above the highest point of the wheel. This is a state of things which could only take place in the case of a steamer of a small draught of water, shallop-shaped, and so constructed as to suffer little resistance from the fluid. On the other hand, the greater the depth of immersion, and the less fine the lines of the vessel, the greater will be the resistance in passing through the water, and the greater will be the proportion which the rotative speed of the paddle boards will bear to the progressive speed of the vessel. In this latter case the independent motion of the paddle boards should be such that their edges, while in the water, shall be presented towards a point considerably above the highest point of the paddle wheel.

A vast number of ingenious mechanical contrivances have been invented and patented for accomplishing the objects just explained. Some of these have failed from the circumstance of their inventors not clearly understanding what precise motion it was necessary to impart to the paddle boards; others have failed from the complexity of the mechanism by which the desired effect was produced.

(185.) *Morgan's paddle wheel.*—In the year 1829, a patent was granted to Elijah Galloway for a paddle wheel with moveable paddles, which patent was purchased by Mr. William Morgan, who made various alterations in the mechanism, not very materially departing from the principle of the invention.

This paddle wheel is represented in *fig.* 93. The contrivance may be shortly stated to consist in causing the wheel which bears the paddles to revolve on one centre, and the radial arms which move the paddles to revolve on another centre. Let A B C D E F G H I K L be the polygonal circumference of the paddle wheel, formed of straight bars, securely connected together at the extremities of the spokes or radii of the wheel which turns on the shaft which is worked by the engine; the centre of this wheel being at O. So far this wheel is similar to the common paddle wheel; but the paddle boards are not, as in the common wheel, fixed at A B C, &c., so as to be always directed to the centre O, but are so placed that they are capable of turning on axles which are always horizontal, so that they can take any angle with respect to the water which may be given to them. From the centres, or the line joining the pivots on which these paddle boards turn, there proceed short arms K, firmly fixed to the paddle boards at an angle of about 120°. On a motion given to this

Fig. 98.

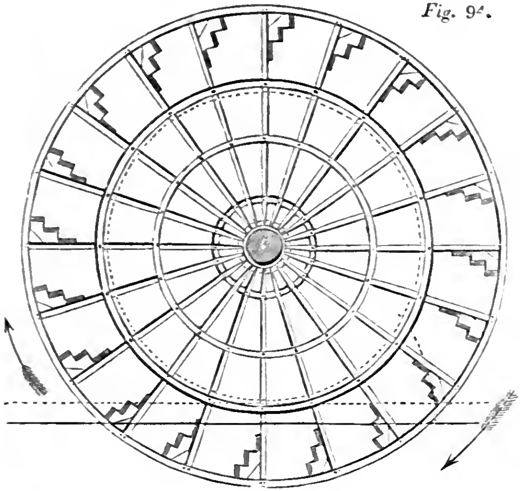



arm K, it will therefore give a corresponding angular motion to the paddle board, so as to make it turn on its pivots. At the extremities of the several arms marked K is a pin or pivot, to which the extremities of the radial arms L are severally attached, so that the angle between each radial arm L and the short paddle arm K is capable of being changed by any motion imparted to L; the radial arms are connected at the other end with a centre, round which they are capable of revolving.

Now, since the points A B C, &c., which are the pivots on which the paddle boards turn, are moved in the circumference of a circle, of which the centre is O, they are always at the same distance from that point; consequently they will continually vary their distance from the other centre P. Thus, when a paddle board arrives at that point of its revolution at which the centre round which it revolves lies precisely between it and the centre O, its distance from the former centre is less than in any other position. As it departs from that point, its distance from that centre gradually increases until it arrives at the opposite point of its revolution, where the centre O is exactly between it and the former centre; then the distance of the paddle board from the former centre is greatest. This constant change of distance between each paddle board and the centre P is accommodated by the variation of the angle between the radial arm L and the short paddle board arm K: as the paddle board approaches the centre P, this gradually diminishes; and as the distance of the paddle board increases, the angle is likewise augmented. This change in the magnitude of the angle, which thus accommodates the varying position of the paddle board with respect to the centre P, will be observed in the figure. The paddle board D is nearest to P; and it will be observed that the angle contained between L and K is there very acute; at E the angle between L and K increases, but is still acute; at G it increases to a right angle; at H it becomes obtuse; and at K, where it is most distant from the centre P, it becomes most obtuse. It again diminishes at K, and becomes a right angle between A and B. Now this continual shifting of the direction of the short arm K is necessarily accompanied by an equivalent change of position in the paddle board to which it is attached; and the position of the second centre P is, or may be, so adjusted that this paddle board, as it enters the water and emerges from it, shall be such as shall be most advantageous for propelling the vessel, and therefore attended with less of that vibration which arises chiefly from the alternate depression and elevation of the water, owing to the oblique action of the paddle boards.

(186.) *Field's split paddles.*—In the year 1833, Mr. Field, of the firm of Maudslay and Field, constructed a paddle wheel with fixed paddle boards, but each board being divided into several narrow slips arranged one a little behind the other, as represented in *fig.* 94. These divided boards he proposed to arrange in such cycloidal curves that they must all enter the water at the same place in immediate succession, avoiding the shock produced by the entrance of the common board. These split paddle boards are as efficient in propelling when at the lowest point as the common paddle boards, and, when they emerge, the water escapes simultaneously from each narrow board, and is not thrown up, as is the ease with common paddle boards.

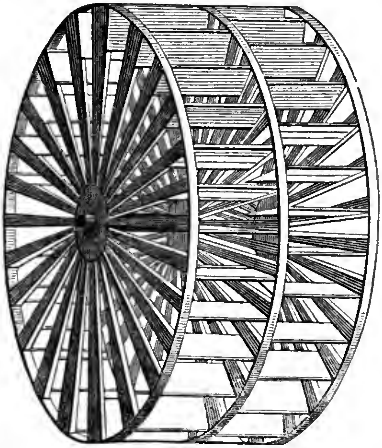
*Fig.* 94.



The number of bars, or separate parts into which each paddle board is divided, has been very various. When first introduced, each board was divided into six or seven parts: this was subsequently reduced; and in the wheels of this form constructed for the government vessels, the paddle boards consist only of two parts, coming as near to the common wheel as is possible, without altogether abandoning the principle of the split paddle.

(187.) *American paddle wheel.*—The paddle wheels generally used in American steam-boats are formed, as if by the combination of two or more common paddle wheels, placed one outside the other, on the same axle, but so that the paddle boards of each may have an intermediate position between those of the adjacent one, as represented in *fig.* 95.

*Fig.* 95.



The spokes, which are bolted to cast-iron flanges, are of wood. These flanges, to which they are so bolted, are keyed upon the paddle shaft. The outer extremities of the spokes are attached to circular bands or hoops of iron, surrounding the wheel; and the paddle boards, which are formed of hard wood, are bolted to the spokes. The wheels, thus constructed, sometimes consist of three, and not unfrequently four, independent circles of paddle boards, placed one beside the other, and so adjusted in their position, that the boards of no two divisions shall correspond.

The great magnitude of the paddle wheels, and the circumstance of the navigation being carried on, for the most part, in smooth water, have rendered unnecessary, in America, the adoption of any of those expedients for neutralising the effects of the oblique action of the paddles, which have been tried, but hitherto with so little success, in Europe.*

(188.) *Ericsson's propeller.* — A great variety of forms of submerged propellers have been projected, both in this country and in the United States, but none have survived a short practical trial except that invented by Capt. Ericsson and the screw propeller.

* For a notice of the inland steam navigation of the United States, see Railway Economy, chap. xvi.

Ericsson's propeller consists of a single wheel applied at the stern of a vessel, having its axis horizontal and parallel to the keel, so that the face of the wheel is presented sternwards, and its plane is vertical when the ship floats in calm water. A hoop of metal is connected by twisted arms with the axis of the wheel, and turns with it. To the external surface of this hoop a number of spiral blades are attached, the effect of which is, that when the wheel revolves the water is driven backwards, and the consequent re-action propels the vessel.

The twisted arms by which the hoop is attached to the axle are so shaped as to offer the smallest resistance to the water as they revolve. The spiral plates attached to the external surface of the hoop act upon the water in such a manner as to drive it sternwards on a principle nearly similar to that by which the sails of a windmill are affected by the wind, only that in the latter case air is the agent and the sails the object acted upon, whereas, in this case, the propeller is the agent, and the fluid the object acted upon. Suppose the atmosphere quiescent, and the arms of the windmill made to revolve by a steam engine within the building, a current of air would then be produced by the action of the sails contrary in direction to that current which would have imparted to these sails the motion which they are here supposed to receive from some internal power. Imagine, then, the fluid thus acted on to be water instead of air, and the revolving sails to be augmented in number, diminished in breadth, and increased in speed, and we have an apt illustration of the principle of this propeller.

(189.) *Machinery of the U. S. frigate Princeton.*—The engines which give rotation to the shaft of the propeller, constructed on board the United States' frigate *Princeton*, according to the plans of Capt. Ericsson, consisted of two semi-cylinders placed with their axes horizontal and parallel to the shaft, and their convex surfaces downwards.

On the axis of the semi-cylinder is placed a solid parallelogram, equal in length to the cylinder, and in breadth to its radius. This parallelogram being suspended on the axis of the semi-cylinder would hang in the vertical position when not acted on by the steam, and being moveable in each direction is capable of being raised on either side to the height of the flat top of the semi-cylinder. Thus this parallelogram is susceptible of a pendulous motion from side to side, through an angle of 90°. It is this parallelogram which discharges the functions of the piston. Steam is admitted and discharged by proper valves on each side of it, and it is thus driven from side to side, alternately, with a corresponding force. The discharged steam passes to a condenser, where, in the usual way, it is converted into water, and the piston is suddenly relieved from its re-action.

These semi-cylinders are placed symmetrically on each side of the shaft, parallel to the keel, and in the bottom of the vessel. The action of the vibrating pistons is transmitted to the shaft of the propeller by short connecting rods attached to vibrating crank levers on the axis of the vibrating pistons, so as to convert the reciprocating pendulous motion into one of continuous rotation. This mechanical arrangement, which we could not hope to render intelligible without a model, presents a singularly happy combination of elegance and simplicity.

In the *Princeton* the entire machinery, as well as the propeller, is below the water line. The draft of the furnaces being produced by small separate engines acting the part of blowers, a funnel is not needed; a short one, with the telescope tube motion, is used in the present case, which may be raised or lowered at pleasure.

The fuel used is hard coal, of the species commonly called anthracite, which having an inconsiderable proportion of bitumen, is consumed without flame or smoke. The inventor claims that these engines occupy only one-eighth of the tonnage necessary for British marine engines of the common kind of equal power, and are only half the weight.

(190.) *Extensive use of Ericsson's propellers in the United States.* — Propellers on this principle have been for several years in extensive operation in the inland steam navigation of the United States. In the line of navigation between Chicago and Quebec alone, there were fifty vessels thus propelled in 1849, and about as many more in other parts of the Union.

It will be apparent that this, as well as every other submerged propeller, has the advantage of producing the same propelling effect, whatever position may be given to it in the water. However the ship may pitch or roll, or however unequal the surface of the sea may be, such a propeller will always produce the same backward current without any variation of effect.

The circumstances which prevent the co-operation of the power of steam with that of the sails in steam vessels propelled by the common paddle wheels, will not operate with submerged propellers, inasmuch as their effect is altogether independent of the careening of the ship.

(191.) *Propeller adapted to auxiliary steam power.*— But though this defect is remedied, the submerged propellers in general are still subject to objections to which even the common paddle wheel is not obnoxious. Being permanently submerged and liable to accident, fracture, and derangement from various causes, they are inaccessible, and cannot be repaired at sea. But, besides this, when the object in view is to take full advantage of the power of the sails at times when it is expedient to suspend the action of the machinery, the submerged propeller becomes an obstruction, more or less considerable, to the progress of the vessel. An expedient was some years since invented and patented by Captain Ericsson, and applied on board several vessels in the United States for the removal of this inconvenience. By this contrivance, the commander was enabled at any time, within the space of ten minutes, to raise the propeller out of the water, or, being so raised, to submerge it so as to convert, for all intents and purposes, a steamer into a sailing vessel, or a sailing vessel into a steamer, as he may see fit.

The shaft on which the propelling wheel is fixed is provided with a simple mechanism within the vessel, by which it may be easily at any time drawn out of the nave of the wheel. The wheel itself is sustained by a powerful vertical arm, the upper end of which is attached to a strong axis, which enters the vessel parallel to the main axis, and above the summit of the wheel. To this axis, within the vessel, is attached a piece of mechanism, by which it may be turned through half a revolution by the power of two men, with such force that the propeller will be made to perform half a revolution round the upper end of the vertical arm which supports it, by which that arm will be presented upward instead of downward. The wheel, therefore, instead of being submerged, will be supported at the stern of the vessel, at the place where a boat is usually suspended.

The vessel will thus be free from all obstruction in passing through the water, and will acquire all the efficiency which any mere sailing vessel can have; besides which the propeller is placed in such a situation that it may be repaired if necessary.

The main shaft which drives the propeller when submerged, is at a depth of seven or eight feet under the lower deck. The cylinders, by which it is impelled, are supported in a standing position on the timbers of the vessel, their piston rods being presented towards the crank on the shaft which they drive in the usual manner by connecting rods. The boilers and the fuel occupy the space immediately before the cylinders. The entire machinery, including the boilers with the fuel, are below the second deck of the vessel.

(192.) *The screw propeller.*—This instrument is similar in form and mechanical principle to the hydraulic machine known as the screw of Archimedes. A cylinder placed at the bottom of the vessel, and in the direction of the keel, is surrounded by a spiral blade similar, precisely, to the thread of a common screw, but projecting from it instead of being cut into its surface. If such a screw were turned in a solid, it would move forward through a space equal to the distance between two contiguous threads in each revolution; but the water not being solid yields more or less to the re-action of the screw, and consequently the screw moves forward through a space in each revolution less than the distance between two contiguous threads.

The distance between two contiguous threads is technically called the *pitch* of the screw; a term, however, which is sometimes also used to express the angle formed by the blade of the screw with its axis, such angle supplying the means of calculating the distance between such contiguous threads. We shall here, however, use the term pitch in the former sense. The difference between the pitch of the screw and the space through which the screw actually progresses in the water in one revolution is called the *slip*.

In the first vessels to which screw propellers were applied, the screw consisted of a single spiral blade, which made one convolution only round the cylinder. This arrangement was subsequently modified, and a half convolution of a double threaded screw was used instead of a complete convolution of a single threaded screw. More recently a smaller portion of a convolution has been adopted, about a sixth of a convolution being at present the most approved proportion.

In English steamers screws of two blades, or two arms, are most commonly employed; but in France, and in America, these propellers are constructed with from four to six arms. In light vessels, few blades give the best results; but for heavy cargo vessels, propellers with more arms are preferred, especially where there is a limited draft of water.

Propellers with two arms are usually made as large in diameter as the draft of water will admit, and the pitch is made about equal to the diameter.

The slip of the screw is observed to vary in different vessels from an indefinitely small amount to fifty per cent. of the motion which the screw would have if working in a solid nut.

(193.) *Paradoxical effect imputed to the screw.*—I find a curious paradoxical statement respecting the action of the screw advanced by a writer in "The Steam Engine, by the Artisan Club." He says that "in some cases the vessel is propelled at a faster rate than if the screw worked in a solid." Now, if this be true as a matter of fact, it would appear that the vessel in such case must be under the influence of some propelling power independent of the screw, for, according to the common principles which govern the action of the screw, a progressive motion faster than one determined by the pitch of the screw would cause the screw to act against the water in the direction of the vessel's course, and consequently to retard the vessel. However, I give this as the statement of a practical authority, and it will be proper also to give the solution proposed for it by the same authority. The writer goes on to say, "One cause of this anomaly probably is, that the water in closing in upon the wake of the vessel having a motion given to it, the screw impinges not upon still, but upon moving water, whereby an increased reaction is obtained."

I am assured by the same practical authority, that "in some of the earlier trials of the Archimedes, this negative slip, as it has been called, was remarked, but its reality was at that time disbelieved, and the apparent effect was imputed to some unobserved source of error. Experiments made with the war steamer *Arrogant* have given a negative slip of 1·02 per cent., and like experiments with the *Plumper* have given a negative slip varying from 5·33 to 18·43 per cent."

In other words, it is inferred that the screw propeller moves faster in that proportion through the water than it would if it worked in a solid nut.

Not being in possession of experimental data sufficiently varied and extensive to enable me to submit this question to rigorous investigation, I leave the statements, advanced by the highly respectable practical authority already named, as they stand. It is probable, however, that more numerous data will soon be published, which no doubt will elucidate the point.

(194.) *Expedient for giving the necessary velocity to screw propellers.* — The adoption of the screw propeller involves a condition which renders necessary an important modification of the engine. To produce a given propelling effect, the velocity of rotation imparted to the screw must be much greater, while the resistance it opposes to the engine is much less than in the case of any form of paddle wheel, or, indeed, than any other form of propeller whatever. Smaller cylinders developing the same power by a greater velocity of the piston, or the common magnitude of piston, acting on the propeller through the intervention of any mechanism which would increase the velocity, and consequently diminish the force, would attain this end.

But various circumstances render a very rapid reciprocating motion of the piston in condensing engines of the usual construction disadvantageous, the principal of which is, the impossibility of driving the air pump at a high speed without causing the valves to strike so hard as to knock themselves to pieces.

Various expedients have been proposed to surmount this difficulty.

1. A non-condensing engine acting on the propeller in the same manner as the pistons of a locomotive engine act on the driving wheels.

Against this method, which is recommended by its great simplicity, is objected the necessity of using high-pressure steam and the inferior duty obtained from the fuel.

2. The interposition of cog wheels, or endless bands or chains acting over cylinders or drums so as to give the propeller a greater velocity in any required proportion than that of the piston.

To this is objected the complexity of the mechanism intervening between the piston and the propeller, and its liability to fracture, accidental derangement, and rapid wear.

3. The substitution of slides for the foot and delivery valves of the air pump.

This expedient has been proposed by Mr. John Bourne, the editor and principal author of the excellent practical work on the Steam Engine, which bears the sanction of the Artisan Club.*

4. The interposition of any mechanism between the piston and the air pump, by which the velocity of the air pump bucket would be diminished, would also supply an expedient for surmounting the difficulty.

This method of surmounting the difficulty has been practically introduced by Messrs. Stothart, Slaughter and Co. of Bristol.

5. The use of a separate engine for working the air pump.

This plan has been introduced in France in a vessel called the *John Ericsson.*

6. The substitution of a number of small discs of Indian rubber, bound down at the centre, for the metal air pump valves heretofore employed.

This is the plan which has come into the most general adoption.

* Steam Engine, by Artisan Club, p. 178.

## CHAPTER III.

### PROGRESS OF STEAM NAVIGATION.

(195.) *Inventors of steam navigation uneducated.*—If the spirits of Watt, Trevithick, and Fulton can look down on the things of this nether world, and behold the grand results their discoveries and inventions have produced, what triumph must be theirs! For half a century the steam engine had remained a barren fact in the archives of science, when the self-taught genius of the Glasgow mechanic breathed into it the spirit of vitality, and conferred upon it energies by which it revived the drooping commerce of his country, and, when the auspicious epoch of general peace arrived, diffused its beneficial influence to the very skirts of civilization. Scarcely had the fruit of the labour of Watt ripened, and this great mover been adopted as the principal power in the arts and manufactures, than its uses received that prodigious extension which resulted from its acquiring the LOCOMOTIVE character. As it had previously displaced animal power in the MILL, and usurped its nomenclature, so it now menaced its displacement on the ROAD. A few years more witnessed perhaps the greatest and most important of all the manifold agencies of steam — that by which it has given wings to the ship, and bade it laugh to scorn the opposing elements, transporting it in triumph over the expanse of the trackless ocean, regardless of wind or current, and conferring upon locomotion over the deep a regularity, certainty, and precision, surpassed by nothing save the movement of chronometers or the course of the heavenly bodies. Such are the vast results which have sprung from the intelligence of men, none of whom shared those privileges of mental culture enjoyed by the favoured sons of wealth; none of whom grew up within the walls of schools or colleges, drawing inspiration from the fountains of ancient learning; none of whom were spurred on by those irresistible incentives to genius arising from the competition of ardent and youthful minds, and from the prospect of scholastic honours and professional advancement. Sustained by that innate consciousness of power, stimulated by that irrepressible force of will, so eminently haracteristic of and inseparable from minds of the first rder, they, in their humble and obscure positions, persevered gainst adverse and embarrassing circumstances, impelled by he faith that was in them, against the doubts, the opposition, nd, not unfrequently, the ridicule of an incredulous world, ntil at length, by time and patience, truth was triumphant, nd mankind now gathers the rich harvest sown by these llustrious labourers.

(196.) *First steamers on the Hudson and the Clyde.*—It vas about the eighth year of the present century that Fulton aunched the first steamboat on the Hudson. After the apse of four years the first European steamboat was esta- lished on the Clyde. From that time the art of steam navi- ation, in the two great maritime and commercial nations, dvanced with a steady and rapid progress. But it took ifferent directions, governed by the peculiar geographical nd commercial circumstances attending these countries. The genius and enterprise of the United States saw before nd around it a vast territory, intersected by navigable rivers f unequalled length, forming lines of water communication n a colossal scale between its extensive interior and the sea- oard. The Mississippi and its tributaries, with their sources, ost in distant tracts as yet untrodden by civilized man, and avigable by large vessels for many thousands of miles,— he Hudson, all but touching upon those magnificent inland eas that stretch along the northern boundary, and are almost onnected with the Mississippi by the noble stream of the llinois,—the Delaware, the vast Potomac, and, in fine, a coast housands of miles in extent, fringed by innumerable bays nd harbours, and land-locked basins having all the attributes f lakes,— these addressed themselves to the eye of the en- ineer and the capitalist, and determined the direction of nterprise. The application of steam power to inland navi- ation — the construction of vessels suited to traverse with peed, safety, and economy, rivers and lakes, harbours, bays, nd extensive inlets — this was the task and the vocation of he American engineer, and this the interest of the capitalist nd the merchant.*

* For a more developed notice of American steam navigation, see ailway Economy, chap. xvi.

(197.) *Sea-going steamers due to British engineers.*— The problem of steam navigation, however, presented itse to the British engineer under other conditions. In a grou of islands intersected by no considerable navigable rivers and neither requiring nor admitting any inland navigatio save that of artificial canals,—separated, however, fro each other and from the adjacent continent of Europe b straits, channels, gulfs, and other arms of the sea,—it wa apparent that if steam power should become available at al it must be adapted to the navigation of these seas an channels—it must be adapted to accelerate and cheape the intercourse between the British islands, between po and port upon their coasts, between them and the variou ports on the adjacent coast of Europe, and finally to establis a communication with the Mediterranean and the coasts c Africa, Asia, and Europe, which are washed by it. Whil the American, therefore, was called on to contrive a steam vessel adapted to inland and smooth-water navigation, th British engineer had the more difficult task to construct on which should be capable of meeting and surmounting all th obstructions arising from the vicissitudes of the deep.

The result of the labour and enterprise of the Englis nation directed to this inquiry has been the present sea-goin steam ship.

(198.) *Progress of steam navigation from* 1812 *to* 1837.— In the quarter of a century which elapsed between 1812 an 1837 steam navigation made a steady and continuous, but not sudden progress. The first lines of steamers were establishe naturally between the ports of England and the nearest sea ports of Ireland on the one side, and France on the othe The length of each unbroken passage was then regarded a the great difficulty of the project. Thus steamers were es tablished between Holyhead and Dublin, and between Dove and Calais, long before projectors ventured to try them be tween Dublin and Liverpool, or between London and th Low Countries.

After some years' experience, however, and the consequen improvement of the marine engine, passages of greater lengt were attempted with success. Lines of steamers were es tablished first between more distant parts of the Unite

Kingdom; as, for example, between London and Edinburgh, and between Dublin, Liverpool, and Glasgow. At a later period still longer trips became practicable, and lines of steamers were established between the United Kingdom and the Mediterranean; touching, however, for fuel at the peninsular ports, such as Corunna, Lisbon, and Gibraltar.

During this period, also, a fleet of steamers was constructed by Government for post-office purposes, and a steam navy was gradually created, among which were found ships of large tonnage and considerable power.

(199.) *Atlantic steamers projected.* — At length, in the year 1836, a project, then considered as a startling one, was first announced to supersede the far-famed New York and Liverpool packet-ships, by a magnificent establishment of STEAM SHIPS.

These vessels were to sustain a constant, regular, and rapid communication between the New and Old World. They were to be the great channel for commerce, intelligence, and social intercourse, between the metropolis of the West and the vast marts of the United Kingdom; they were, in a word, to fulfil, not only all the functions which for half a century had been so admirably discharged by the packet-ships, but to do so with expedition increased in a threefold proportion at the least. Such an announcement could not fail to captivate the public. The results to be anticipated were so obvious, so grand, and must be attended with effects so widely spread, that all persons of every civilized nation at once felt and acknowledged their importance. The announcement of the project was accordingly hailed with one general shout of acclamation.

Some, who, being conversant with the actual condition of the art of steam-engineering as applied to navigation, and aware of various commercial conditions which must affect the problem, and were enabled to estimate calmly and dispassionately the difficulties and drawbacks, as well as the advantages, of the undertaking, entertained doubts which clouded the brightness of their hopes, and warned the commercial world against the indulgence of too sanguine anticipations of the immediate and unqualified realisation of the project. They counselled caution and reserve against an improvident investment of extensive capital in schemes which could still be only regarded as experimental, and which might prove its grave. But the voice of remonstrance was drowned amid the enthusiasm excited by the promise of an immediate practical realisation of a scheme so grand. The keel of the Great Western was laid; an assurance was given that the seasons would not twice run through their changes before she would be followed by a splendid line of vessels, which should consign the packet-ships to the care of the historian as "things that were."

(200.) *Abstract possibility of the voyage could not be doubted.* — It cannot be seriously imagined that any one who had been conversant with the past history of steam navigation could entertain the least doubt of the abstract practicability of a steam vessel making the voyage between Bristol and New York.

A vessel having as her cargo a couple of hundred tons of coals would, *cæteris paribus*, be as capable of crossing the Atlantic as a vessel transporting the same weight of any other cargo. A steam vessel of the usual form and construction would, it is true, labour under comparative disadvantages, owing to obstructions presented by her paddle wheels and paddle boxes; but still it would have been preposterous to suppose that these impediments could have rendered her passage to New York impracticable.

(201.) *The voyage had been already accomplished by two steamers.* — But, independently of these considerations, it was a well-known fact, that, long antecedent to the epoch now adverted to, the Atlantic had actually been crossed by the steamers *Savannah* and *Curacoa.* Nevertheless a statement was not only widely circulated, but generally credited, that I had publicly asserted that a steam voyage across the Atlantic was "*a physical impossibility!*"

Although this erroneous statement has been again and again publicly contradicted through various organs of the press, it continues nevertheless to be repeated. I shall therefore take this opportunity once more to put on record what I really did state on the occasion on which I am reported to have affirmed that the Atlantic steam voyage was a physical impossibility.

(202.) *Projects advanced in* 1836.—Projects had been started in the year 1836 by two different and opposing interests, one advocating the establishment of a line of steamers to ply between the west coast of Ireland and Boston, touching at Halifax; and the other a direct line, making an uninterrupted trip between Bristol and New York. In the year 1836, on the occasion of the meeting of the British Association in Dublin, I had advocated the former of these projects.

(203.) *Discussion at Bristol in* 1837. — On the occasion of the next meeting in 1837 at Bristol, I again urged its advantages, and by comparison discouraged the project of a direct line between Bristol and New York. When I say that I advocated one of these projects, it is needless to add that the popular rumour that I had pronounced the Atlantic voyage impracticable is utterly destitute of foundation. But I am enabled to offer more conclusive proofs than this, that, so far from asserting that the Atlantic voyage by steam was impossible, *I distinctly affirmed the contrary.*

The "Times" newspaper sent a special reporter to attend the meeting at Bristol, and more particularly to transmit a report of the expected discussion on the Atlantic steam voyage, which at the moment excited much interest.

(204.) *Report of Dr. Lardner's speech from "Times" of 27th August — showing the falsehood of the report that he pronounced the project impracticable.* — The meeting took place on the 25th, and the report appeared in the "Times" of the 27th of August. From that report I extract the following: —

"Dr. Lardner said he would beg of any one, and more especially of those who had a direct interest in the inquiry, to dismiss from their minds all previously-formed judgments about it, *and more especially upon this question, to be guarded against the conclusions of mere theory*, for if ever there was one point in practice of a commercial nature which, more than another, required to be founded on experience, it was this one of extending steam navigation to voyages of extraordinary length. He was aware that since the question had arisen, it had been stated that his own opinion was averse to it. *This statement was totally wrong*, but he did feel that great caution should be used in the adoption of the means of carrying the project into effect. Almost all depended on the first attempt, for a failure would much retard the ultimate consummation of the project.

"Mr. Scott Russel said that he had listened with great delight to the lucid and logical observations they had just heard. He would add one word. Let them try this experiment, with a view only to the enterprise itself, but on no account try any new boiler or other experiment, but to have a combination of the most approved plans that had yet been adopted.

"After some observations from Messrs. Brunel and Field, Dr. Lardner, in reply, said, that *he considered the voyage practicable*, but he wished to point out that which would *remove the possibility of a doubt*, because if the first attempt failed it would cast a damp upon the enterprise, and prevent a repetition of the attempt."

Such was the report of the "Times" of the speech in which I was afterwards, and have ever since been represented as having declared a steam voyage across the Atlantic a *mechanical impossibility!*

(205.) *Similar report from the Edinburgh Review.* — But the "Times" report, though conclusive, is not the only proof I can produce that my statements were directly the reverse of those imputed to me. In the number of the "Edinburgh Review" which appeared soon after the Bristol meeting, there was an article on this question, in which the speech delivered by me at Bristol was adverted to and quoted. The following is an extract from that article: —

"The statement laid before that section by Dr. Lardner obtained such publicity, at the time, through the press, that it would be superfluous to recapitulate its arguments. The conclusions, however, to which he arrived, were briefly these: — That *in the present state* of the steam engine, as applied to nautical purposes, he regarded a *permanent* and *profitable* communication between Great Britain and New York by steam vessels making the voyage IN ONE TRIP, as in a high degree improbable; that since the length of the voyage exceeds the present limits of steam power, it would be desirable to resolve it into the shortest practicable stages, and, therefore, that the most eligible point of departure would be the most western shores of the British Isles, and the first point of arrival the most eastern available port of the western continent; and that under such circumstances the length of the trip, though it would come fully up to the present limit of this application of steam power, would not exceed it, and that we might reasonably look for such a degree of improvement in the efficiency of marine engines, as would render such an enterprise permanent and profitable."

(206.) *Similar report from the Monthly Chronicle.* — In the "Monthly Chronicle," also, a periodical edited by me at this time, appeared an article published immediately after the Bristol meeting, from which the following is extracted: —

"In fact, no doubt has been entertained or expressed as to the practicability of establishing a communication between these countries and New York by a line of steam vessels; but a difference of opinion has been entertained as to what mode of accomplishing the object may best ensure certainty, safety, regularity and profit, without which last element it is presumed the other objects could hardly be secured."

(207.) *Atlantic steam voyage advocated by Dr. Lardner in* 1836–7. — What I did affirm and maintain in 1836–7 was, that the long sea voyages by steam which were contemplated could not be maintained with that regularity and certainty which are indispensable to commercial success, by any revenue which could be expected from traffic alone, and that, without a Government subsidy of a considerable amount, such lines of steamers, although they might be started, could not be permanently maintained.

Steam navigation had till then, as has been already explained, been confined to the narrow seas which separate adjacent countries, — such as the Irish Channel, the German Ocean, and the Mediterranean. For such navigation steam ships have great and numerous advantages over sailing vessels, more especially for the transport of passengers.

In confined seas and in coasting, their superior safety was obvious. Independent in a great degree of the wind, a steamer fears no lee-shore. If pressed by stress of weather, she has that within her which in most cases will carry her into the safe shelter of any neighbouring port. Provided with convenient depots at short distances, she needs not to fill her tonnage with coals, and thereby limit the magnitude and power of her engines, or encroach upon the space which might be profitably occupied by passengers, or by objects of commerce. Supplied, therefore, with abundant mechanical power, she far outstrips all sailing vessels, and puts any such competition completely out of the question.

The steam engine, however, like an animal, requires that its periods of labour should be of limited duration, and that repose should be allowed at reasonable intervals, during which the machinery should be looked over, cleaned, oiled, and put to rights. The service to which steam vessels had been previously confined admitted of this, without interruption to the operation of the machinery; the frequent arrivals and the necessary time of remaining in port being generally more than sufficient for these purposes.

How different were the circumstances under which the Atlantic steamers were about to compete with sailing vessels. The dangers of confined seas and coasting navigation no longer menace the majestic ship, which in conscious security seems to triumph in the unlimited expanse of water around her, and to bound with gladness over the ocean swell. No threatening shore is present to call into requisition the peculiar powers of her mechanical rival, no shoals or sandbanks are encountered on which she may be driven by the disobedient wind, and from which her intractable helm and sails cannot save her, but among the intricacies of whose channels the powers of her rival can conduct her with unerring precision. On the other hand, designed expressly by her structure to encounter the tumultuous surface of the ocean, having the skill and experience of a hundred generations of men concentrated to confer on her security and defence from the perils of the deep, the sailing vessel has in the ocean storm some advantage as to safety, encumbered as the steamer is by her machinery, by the unwieldy projecting masses of her paddle boxes, and her chimney.

On the occasion now alluded to, — namely, in the public discussions which took place in the years 1836 and 1837, — I urged all these circumstances and others to demonstrate the necessity, in attempting the grand enterprise contemplated, of calling into requisition every source of safety and efficiency which the most consummate mechanical and nautical skill could supply, and that, although novel expedients should be regarded with caution, still, that the exigency of the case would render it in the last degree imprudent not to give every fair trial to those pretensions compatible with security.

But, independently of the considerations above stated, there were others not less imperatively demanding attention and consideration. To secure permanent success, safety, efficiency, and despatch, would not be enough. It was necessary, besides, that the enterprise should yield a fair profit on the capital it would absorb. I had had abundant professional experience in relation to steam navigation at that time to be aware of the great magnitude of the expenditure which the proper maintenance of steamships like those necessary for the Atlantic voyage would require, to ensure for them the necessary expedition in their competition with the finest sailing vessels in the world, — the Liverpool liners. It would be obviously necessary to supply them with a liberal amount of power in proportion to their tonnage; a very large portion of that tonnage would therefore be occupied by the machinery and fuel. It was therefore apparent that the freight of goods was a source of profit from which they would be almost excluded. Letters, packages, and a limited amount of light goods of such a kind as would bear a high rate of freight, and which demanded great expedition, were all that they could look to. Passengers must therefore be their chief source of revenue.

(208.) *Dr. Lardner insists upon the necessity of a government subvention to sustain such an enterprise.* — But still I contended that in the state in which the art of constructing steam vessels then was, even with all the prudence and skill that could be exercised, a permanent and regular line of steamers running through the year between England and New York, or any other port of the United States, could not be productive of that commercial profit which would be indispensable to sustain them, and that they must have some considerable revenue to fall back upon, especially in the winter part of the year, besides the utmost that could be expected from cargo and passengers. The source of such support was apparent, and I again and again at public meetings urged that the possession of the British Post-office contract for conveying the mails, would form an indispensable element in the successful issue of the project; but to obtain this, it was necessary that Halifax should be adopted as an intermediate station. The plan, therefore, that I advocated, both in Dublin, at the meeting of the British Association, in 1836, and subsequently in London, and other principal towns of England, and again at the meeting of the British Association at Bristol, where I have been charged with pronouncing the project impracticable, was to establish a line of steam communication between one of the western ports and Boston, touching at Halifax, and thereby securing the contract for the conveyance of the British mails. I proposed that a railway should be constructed between a starting point on the west of Ireland and Dublin, which, with the Dublin and Liverpool steamers, and the Liverpool, Birmingham, and London railway, would form one great continuous steam highway between the capitals of the New and the Old World. But whatever might be the ports of departure and arrival, I insisted upon the necessity of securing the conveyance of the mails and a liberal subsidy from the Post-office, as an indispensable condition for the commercial success of the enterprise.

(209.) *The practical results of the various projects prove the truth of his predictions.* — Now let us see what has been the practical result.

Eight steam ships, including the *Great Western*, were, soon after the epoch of these debates, placed upon the projected line between England and New York; the *Sirius*, the *Royal William*, the *Great Liverpool*, the *United States**, the *British Queen*, the *President*, the *Great Western*, and the *Great Britain*.

The *Sirius* was almost immediately withdrawn; the *Royal William*, after a couple of voyages, shared the same fate; the *Great Liverpool*, in a single season, involved her proprietors in a loss of 6000*l.*, and they were glad to remove her to the Mediterranean station. The proprietors of the *British Queen*, after sustaining a loss which is estimated at little less than 100,000*l.*, sold that ship to the Belgian government. The *United States* was soon transferred, like the *Great Liverpool*, to the Mediterranean trade. The *President* was lost. The *Great Western*, as is well known, after continuing for some time to make the voyage in the summer months, being laid by during the winter, and after involving her proprietors in a loss of unknown and unacknowledged amount, was sold. Of the *Great Britain*, the fate is well known.

* This vessel was not actually placed on the line, but was prepared for it. She was afterwards called the *Oriental.*

Thus it appears, in fine, that after the lapse of nearly fourteen years, notwithstanding the great improvements which took place in steam navigation, the project advanced at Bristol and there pronounced by me to be commercially impracticable, has signally failed.

(210.) *The Cunard steamers established on the conditions suggested by Dr. Lardner, have alone been successful.* — Meanwhile another project, based upon the conditions which I had indicated as essential to the permanence and success of the enterprise, was started.

Mr. Samuel Cunard, a Canadian, who had extensive experience in maritime affairs, being associated with some large capitalists who had confidence in his sagacity and skill, laid before the British government a project for a line of Post-office steamers, to ply between Liverpool and Boston, touching at Halifax. But Mr. Cunard insisted strongly on the necessity of providing a considerable fleet of steamers, to ensure that permanence and regularity which were indispensable to the success of the project. He demonstrated that the magnitude of the capital it must involve, and the vast expenditure attending its maintenance, were such as could not be covered by any commercial returns to be expected from it, and that, consequently, it could only be sustained by a liberal subsidy to be furnished by the government. After much negotiation, it was agreed to grant him an annual subsidy of 60,000*l.*, upon which condition the enterprise was commenced. Mr. Cunard, however, had hardly embarked in it, before it became evident that this grant was insufficient, and it was soon increased to 100,000*l.* per annum. Further experience proved that even this was insufficient to enable Cunard and his associates to maintain the communication in a satisfactory and efficient manner, and the annual subvention was in fine raised to its present amount, that is to say, 145,000*l.* sterling per annum.

(211.) *Voyages of these steamers, and relative amount of their subvention.* — Thus supported, the communication is now (1851) maintained throughout the year. During the four winter months, December, January, February, and March, there are two departures per month from each side, and during the eight other months of the year there is a departure once a week, making a total of forty-four departures from each side, or forty-four voyages going and returning.

These voyages make a total distance sailed of 272,800 geographical miles within the year. The subsidy, therefore, amounts to ten shillings and eight pence per mile sailed.

(212.) *Compelled to lower their fares on the returning passage.* — In the course of the discussions which took place in 1836–7, I showed that although the advantage of steamers over the sailing vessels in the outward passage must be considerable, and such as would probably attract a large proportion of passengers at high fares; yet that on the returning passage the same advantage would not be found, for that while the average outward passage of a sailing vessel was thirty-six days, the average homeward passage was less than twenty.* I contended, as will be seen by reference to the journals of the day, that steamers, wherever they might be established, must, on the return passage, lower their fares to the level of those of the sailing packets, or nearly so. This prediction, like the others, has been fulfilled to the letter. Notwithstanding the confidence inspired by the Cunard steamers, supplied as they are with the best machinery, manned and officered in the most efficient manner, checked by the *surveillance* of the British government, and surrounded with every provision and precaution which can inspire confidence of their safety and efficiency, they have, nevertheless, been compelled on the return passage to reduce their fares. While the passenger fare from Liverpool to Boston is thirty-five pounds, the fare on the returning voyage is only twenty-four.

(213.) *Force of the Cunard fleet.* — The following was the force of the fleet of steamers by which the Cunard Company maintained the service above mentioned in 1850: —

* In consequence of the westerly winds, which prevail in the northern latitudes with a permanency and regularity scarcely less than that of the trades near the Line.

| | Horse Power. | Tons. |
|---|---|---|
| The Arabia (building) - - | 950 - | 2500 |
| „ Persia (building) - - | 950 - | 2500 |
| „ Asia - - - - | 800 - | 2226 |
| „ Africa - - - - | 800 - | 2226 |
| „ America - - - | 650 - | 1826 |
| „ Canada - - - - | 650 - | 1831 |
| „ Europa - - - - | 650 - | 1834 |
| „ Niagara - - - | 650 - | 1824 |
| „ Cambria - - | - | 1423 |
| | 6100 | |

But, besides these, there are some subsidiary lines which require to be mentioned.

Thus there are two steamers, the *Admiral* of 929 tons and 388 horse power, and the *Commodore* of 800 tons and 350 horse power, which maintain a communication between Liverpool and Havre; and two vessels, the *Camilla* of 529 tons and 220 horse power, and the *Lyra*, 543 tons and 275 horse power, which maintain a communication between Liverpool and Glasgow. The *Margaret*, also, a vessel of 700 tons and 310 horse power, and the *Laurel*, a vessel of 428 tons and 180 horse power, are sometimes employed upon these subsidiary lines, though, commonly, the *Margaret* plies between Liverpool and the Mediterranean, and the *Laurel* plies between Belfast and Glasgow.

Thus this great enterprise is now (1851) maintained by a fleet of steamers, the power of which is 6100 horses for the main line and 1723 horses for the feeding and subsidiary lines. The subsidy which the enterprise receives from the British government is, therefore, at the rate of nearly 24*l.* per annum per horse power on the main line, and about 18*l.* per annum per horse power upon the whole fleet, feeders and subsidiary lines inclusive.

No official or authorised statement has been published of the financial condition of the Cunard Company. Its proprietors are limited in number, and generally to large capitalists, who arrange their interests in private meetings, the results of which are not made public. It seems probable, however, that the enterprise is not highly profitable.

It is certain that the company has been compelled from year to year to augment its capital, either to cover losses incurred, or to give such increased extension to the enterprise as competition forced on it.

(214.) *Estimate of capital absorbed in this enterprise.*— To estimate the amount of the capital, let the value of the ships be taken, in round numbers, at 120*l.* per horse power. Thus, for 7823 horse power we should have a capital of 936,760*l.* To this must be added the furniture, plate, &c. of the ships, the offices, warehouses, stations, &c. at the several ports with which they communicate, the capital engrossed by which, added to the amount just stated, will make a total which cannot fall short of 1,500,000*l.*

It follows, therefore, that this company, after having defrayed its current expenses, must have a balance of about 375,000*l.* before it can begin to enjoy any net profit, for it has resulted from the general experience in England, both by government and by commercial companies, that besides the current expenses of working a line of steamers, it is necessary to carry yearly to the account of the capital, to cover interest, sinking fund, insurance, &c., a sum equal to twenty-five per cent. of the total capital involved.

(215.) *Subventions allowed to other lines of steamers.*— Soon after the Cunard line of steamers commenced operations, it was proposed to establish, with government support, a transatlantic line of steamers communicating between Great Britain and its West India colonies. Ultimately the present West India Steam Packet Company was established, and obtained from the government a subvention greater still in amount than had been granted to the Cunard Company. The amount of this annual grant at present is 240,000*l.*

In fine, all the commercial enterprises for the establishment of lines of steamers, where the voyages are of any considerable length, have been and are sustained more or less by government grants, and these grants are proportionally great as the length of the voyage is increased, as will appear by the following statement of the sums paid annually to the six principal steam navigation companies which have undertaken such voyages:—

| | £ |
|---|---|
| The Cunard Company - - - - | 145,000 |
| „ West India Company - - - - | 240,000 |
| „ Pacific Company - - - - | 40,000 |
| „ Cape Screw Steam Ship Company - - | 30,000 |
| „ Peninsular and Oriental Company - - | 219,835 |
| „ East India Company, for the line between Suez and Bombay - - - - | 50,000 |
| | £724,835 |

It appears, therefore, that the opinion which I expressed publicly in 1837, that in the then existing state of the art of steam navigation, voyages of any considerable length could not be maintained with regularity and certainty by any commercial revenue which could be expected to result from them, and that it was only by government grants that their permanence and regularity could be secured, has not only been realised by subsequent experience, but that the same judgment may be applied to the present time, notwithstanding the great improvements which steam navigation has undergone in the fourteen years which have elapsed since that opinion was delivered. There does not exist at present a single line of steam communication of any considerable length, in any quarter of the globe, which is maintained by its commercial returns independently of Government support.

(216.) *American lines — Subventions allowed them.*—Some attempts have been and are still made by projectors, in the United States, to establish lines of steamers between New York and the several parts of Europe.

The first attempt of this kind was made by a company called the Ocean Steam Navigation Company, which undertook to establish a communication monthly, between New York, Southampton, and Bremen. Three steam ships, the *United States*, the *Washington*, and the *Hermann*, were intended for this line, and a subsidy of two hundred thousand dollars per annum, which is equivalent to about 40,000*l.*, being at the rate of about nine shillings a mile, was expected to render the undertaking profitable. The enterprise, however, was not successful. One of the vessels destined for it was sold to the Germanic Confederation, and the other two continued occasionally, and at irregular intervals, to run between Southampton and New York.

(217.) *Lines between Southampton, Havre, and New York.* — Another project was started which may be regarded as entering into indirect competition with the Cunard steamers. It was proposed to establish a line of steamers between Havre and New York. This line was to consist of four ships, to run monthly from each port. The steam ship *Franklin* made a trial trip from New York to Havre, with a view to induce French capitalists to take a share in the enterprise, and to persuade the French government to subsidize it. The republican authorities, and leading members of the Assembly, accepted an invitation to a banquet on board the steamer, but there the matter ended.

At the time we write (June, 1851), an announcement appears in the journals of the recommencement of the Southampton and New York line, by means of the coalition of the Ocean Steam Navigation Company with the New York and Havre Company, the former supplying their two remaining ships, the *Washington* and the *Hermann;* and the latter, two of the four ships which had been intended for the Havre line, the *Franklin* and the *Humboldt.* With these four vessels, it is proposed to start twice a month from each port. As, however, this enterprise is only just about to commence, we can say nothing as to its success.

(218.) *Collins line.* — Another attempt at competition with the Cunard line is now in progress, under the auspices of Mr. Collins, an enterprising merchant of New York, who has formed a company supported by eminent capitalists. The United States' government has come to the support of this enterprise by contributing largely to the capital, and by voting a subvention of 385,000 dollars, or about 81,000*l.*, being at the rate of about fourteen shillings per mile sailed; a subvention twenty-five per cent. greater than that allowed by the English government to the Cunard Company. Thus supported, five steam ships, the *Pacific*, the *Atlantic*, the *Baltic*, the *Arctic*, and the *Adriatic*, of 3000 tons measured capacity, and 800 horse power, were constructed and were placed on the line in April, 1850.

Much controversy took place in the journals on both sides of the Atlantic, on the comparative performances of the Cunard and Collins lines. Without entering into the merits of this question, it may be admitted that, in point of expedition, not much difference is observable between them; but, in point of regularity and security, it cannot be denied that all the advantage remained with the Cunard line. The American company commenced the undertaking with an insufficient supply of vessels. Although its fleet consisted nominally of five ships, one of them, the *Adriatic*, was not placed on the line. To make two voyages per month with four vessels, rendered it necessary that each should be so incessantly worked as to leave insufficient time for the repairs, cleaning, &c. in port after each passage, and the consequence has been that the regularity of the communication sustained an interruption. The *Atlantic* encountered a disaster in one of her late passages outwards, which obliged her to return to Cork Harbour, from whence her passengers and mails were brought to New York by one of the Cunard vessels.

Notwithstanding the subvention allowed by Congress to the Collins Company, it has been found insufficient, and an application has lately been made for an augmentation of it.

(219.) ***Probable extension of steam ships to the general purposes of commerce.*** — Great as the progress of steam navigation has been within the last quarter of a century, much still remains to be accomplished before that vast agent of transport can be regarded as having been pushed to the limit of its powers. Its superior speed, regularity, and certainty, comparatively with sailing vessels, have naturally first attracted to it passengers, despatches, and certain descriptions of merchandise to which expedition is important and which can bear a high rate of freight. The mechanical conditions which ensure expedition in long voyages, exclude, to a great extent, the transport of general merchandise; for a large part of the tonnage of the vessel is occupied by the machinery and fuel. The heavy expenses, therefore, of the construction and maintenance of these vessels, must be defrayed by appropriating the profitable tonnage to those objects of transport alone which will bring the highest rate of freight. While the steamer, therefore, has allured from the sailing vessel the chief part of the passenger traffic, the mails altogether, parcels, and some few objects of general traffic, the latter still continues in undisturbed possession of the transport business of general commerce.

The next step in the improvement of the art must therefore be directed to the construction of another class of steam vessels, which shall bear to the present steam ships the same relation which the goods trains, on the railway, bear to the passenger trains. As in the case of these goods trains, expedition must be sacrificed to reduce the cost of transport to the limit which shall enable the merchandise to bear the freight. If the steamer for the general purposes of commerce can be made to exceed the sailing vessel, in any thing approaching to the ratio by which the goods train on the railway exceeds the waggon or canal boat, we shall soon see the ocean covered with such steamers, and the sailing vessel will pass from the hands of the merchant to those of the historian.

(220.) *Auxiliary steam power the most probable means of accomplishing this.*—To render steamers capable of attaining these ends, it will be evidently advisable to adopt measures to combine the qualities of a sailing vessel with those of a steamer. The ships must possess such steaming power as may give them that increased expedition, regularity, and punctuality, which, in the existing state of the arts, can only be obtained through that agency; but it is also important that they accomplish this without robbing them, to any injurious extent, of their present capability of satisfying the wants of commerce.

No expedient appears to me so likely to accomplish this, in the present condition of the art, as one which would have for its object the removal of the paddle wheels now generally used, and the substitution of some description of subaqueous propeller. A great reduction in the dimensions of the machinery, and the surrender to the uses of commerce of that invaluable space which it now occupies within the vessel, are also essential. It is incumbent on the engineer who assumes the high responsibility of the superintendence of such a project, to leave the ship in the full and unimpaired enjoyment of its functions as a sailing vessel. Let him combine, in short, the agency of steam with the undiminished nautical power of the ship. Let him celebrate the marriage of the steam engine with the sailing vessel. If he accomplish this with the skill and success of which the project is susceptible, he may fairly hope that his name will go down to posterity as a benefactor of mankind, united with those of Fulton and Watt.

The actual progress of mechanical science encourages us to hope that the day is fast approaching when such ideas will be realised — when we shall behold a great highway cut across the wide Atlantic, not as now, subserving to those limited ends, the attainment of which will bear a high expense, but answering all the vast and varied demands of general commerce. Ships which would serve the purposes we have here shadowed out can never compete in mere speed with vessels in which cargo is nothing, expense disregarded, and expedition everything. Be it so. Leave to such vessels their proper functions; let them still enjoy to some extent the monopoly of the most costly branches of traffic, subsidized as they are by the British treasury. Let the commercial steam ships, securing equal regularity and punctuality, and probably more frequent despatch, be content with somewhat less expedition. This is consistent with all the analogies of commerce.

There is another consideration which ought not to be omitted. In all great advances in the arts of life, extensive improvements are at first attended with individual loss of greater or less amount. The displacement of capital is almost inevitably attended with this disadvantage. It is the duty, therefore, of the scientific engineer, in the arrangement and adoption of his measures, to consider how these objects may be best attained with the least possible injury to existing interests. To accomplish this will not only be a benefit to the public, but will materially facilitate the realisation of his own objects, by conciliating in their favour those large and powerful interests whose destruction would be otherwise menaced by them. If, then, in the present case, it is found practicable with advantage to introduce into the present sailing ships, more especially into those most recently constructed, the agency of steam, a very important advantage will be gained for the public, and the almost unanimous support and countenance of the commercial community will be secured.

(221.) *Subaqueous propellers necessary.* — To attain the objects here developed, it will be evidently indispensable to remove those impediments which at once disfigure the appearance and destroy the efficiency of the sailing qualities of the ship by the enormous and unsightly excrescences projecting from the sides in the shape of paddle wheels and the wheel houses or paddle boxes, as they are called. These appendages are attended with many evils, the least of which is perhaps the impediment which they present to the progress of the ship.

But the form, magnitude, and position of the propelling machinery, is far from being the only obstacle to the full success of the present steam vessels when directed to the general purposes of commerce. The engines themselves, and the boilers, from which the moving power proceeds, and the fuel by which they are worked, occupy the very centre of the vessel, and engross the most valuable part of the tonnage. The chimney, which gives efficacy to the furnaces, is also an unsightly excrescence, and no inconsiderable obstruction.

When long ocean-voyages are contemplated, such as those between New York and the ports of England, there is another serious obstacle, which is especially felt in the westward trip, because of the prevalence of adverse winds. When the vessel starts on its long voyage, it is necessarily laden with a large stock of fuel, which is calculated to meet, not merely the average exigencies of the voyage, but the utmost extremity of adverse circumstances of wind and weather to which it can by possibility be exposed. This fuel is gradually consumed upon the voyage; the vessel is proportionally lightened, and its immersion diminished. If its trim be so regulated that the immersion of its wheels at starting be such as to give them complete efficiency, they may, before the end of the voyage, be almost if not altogether raised out of the water. If, on the other hand, the efficiency of propulsion in the latter part of the voyage be aimed at, they must have such a depth at its commencement as to impair in a serious degree their propelling effect, and to rob the vessel of its proper speed. Under such circumstances, there is no expedient left but compromise. The vessel must start with too great and arrive with too little immersion. There is no alternative, save to abandon altogether the form and structure of the present machinery, and to awaken the inventive genius of the age to supply other mechanical expedients which shall not be obnoxious to these objections.

In fine, then, we look to the improvement of auxiliary steam power, and the extended use of submerged propellers, such as those invented by Captain Ericsson, or the screw, as the means which, in the existing state of the art of steam navigation, are most likely to extend the benefits of that agent of transport to general commerce. In long voyages, steam power need only be used in calms or against unfavourable winds. The vessel deriving such aid from steam will gain sufficient advantage over sailing vessels to secure a preference for freight, and the machinery and fuel will be so reduced in bulk as to encroach on the tonnage of the ship to no very injurious extent.

(222.) *Improved adaptation of steam power to vessels of war required.* — If the present form and structure of steam vessels be obnoxious to these many serious objections when considered with reference to the purposes of general commerce, they are still more objectionable when considered with reference to the purposes of national defence. It is undoubtedly a great power with which to invest a vessel-of-war, to be able to proceed at will, in spite of the opposition of wind or tide, in any direction which may seem most fit to its commander. Such a power would have surpassed the wildest dreams of the most romantic and imaginative naval commander of the last century. To confer upon the vessels of a fleet the power immediately, at the bidding of the commander, to take any position that may be assigned to them relatively to the enemy, or to run in and out of a hostile port at pleasure, or fly with the rapidity of the wind past the guns of formidable forts before giving them time to take effect upon them — are capabilities which must totally revolutionise all the established principles of naval tactics. But these powers at present are not conferred upon steam ships without important qualifications and serious drawbacks. The instruments and machinery from which they are immediately derived are, unfortunately, exposed in such a manner as to render the exercise of the powers themselves hazardous in the extreme. It needs no profound engineering knowledge to perceive that the paddle wheels are eminently exposed to shot, which, taking effect, would altogether disable the vessel, and leave her at the mercy of the enemy; and the chimney is even more exposed, the destruction of which would render the vessel a prey to the enemy within itself in the shape of fire. But besides these most obvious sources of exposure in vessels of the present form intended as a national defence, the engines and boilers themselves, being more or less above the water-line, are exposed so as to be liable to be disabled by shot.

A war steamer, to be free from these objections, should be propelled by subaqueous apparatus. Her engines, boilers, and all other parts of her machinery should be below the water-line. Her fuel should be hard coal, burning without visible smoke, so that her approach may not be discoverable from a distance. Her furnaces might be worked by blowers, so that the chimney might be dispensed with, and thus its liability to be carried away by shot removed.

(223.) *Mercantile steam navy available for national defences.* — The policy of the British government has been to rely on the commercial steam navy as a means of national defence in the event of the sudden outbreak of war. By the evidence given before a committee of the House of Commons in 1850, and the report founded thereupon, it appeared that commercial steamers in general are capable of war service, with no other previous alteration or preparation than such as are easily practicable and expeditiously executed. It was shown that all steamers of 400 tons and upwards would be capable, with some additional strengthening, to carry such pivot guns as are used in war steamers, and that there are few mercantile steamers of any size which might not carry an armament such as would render them useful in case of an emergency.

(224.) *Number, power, and tonnage of the commercial* steam marine.—By a return contained in the same report, it appeared that on the 1st of January, 1849, the number of commercial steamers registered was 1110, consisting of the following, classed according to their tonnage:—

| | |
|---|---|
| Under 101 tons - - - - | 529 |
| From 101 to 250 tons inclusive - - | 272 |
| „ 251 „ 400 „ - - - | 136 |
| „ 401 „ 600 „ - - - | 71 |
| „ 601 „ 1000 „ - - - | 67 |
| Above 1000 - - - - - | 35 |
| Total - - - - - | 1110 |

The total power of these vessels was estimated at 92,862 horses, and the total tonnage was 255,371 tons.

There were ten vessels of the largest class then in process of construction, and which (besides others) have since been completed. We shall, therefore, not overrate the number, power, and tonnage of the present commercial steam navy if we estimate it at 1150 vessels, having the total power of 110,000 horses, and the total tonnage of 275,000 tons.

# PART III.

## ROADS AND RAILWAYS.

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### CHAPTER I.

#### COMMON ROADS.

(225.) *What is a road.*—A road is a path carried over the surface of the ground, artificially constructed, so as to facilitate the movement of travellers and beasts of burden, but more especially of wheel carriages, from place to place.

(226.) *Necessary qualities of a road—Resistances to motion.*—To comprehend the qualities which ought to be imparted to such a surface, it is necessary in the first instance to inquire into the obstructions which resist the movement of carriages.

(227.) *Uneven surfaces.*—It is obvious that the first and principal of these arises from the asperities of the ground on which the carriage moves. A rut into which it would sink, or an obstacle which it has to surmount, produces a momentary resistance; and the continual repetition of such ruts or such obstacles produces a constantly acting resistance to the power of traction. It is clear, therefore, that the first quality necessary to be imparted to a road is evenness of surface.

(228.) *Acclivities.*—When an animal has to mount, and still more, when it has to draw a carriage up an acclivity, it must encounter, besides the resistance which would proceed from the asperities of the surface, another arising from the weight of the carriage which must be raised through the height by which the road ascends. Thus, if in an acclivity of one mile in length the summit be 20 feet above the foot, the tractive power must exert a force in surmounting such an ascent equal to that which would have been necessary to lift the entire weight drawn, including the carriage, through 20 perpendicular feet.

Acclivities, therefore, are another cause of resistance to the power of traction, and consequently to remove them the road must be rendered level, or as nearly so as possible.

(229.) *Softness causes resistance.* — If the surface on which a carriage is drawn be soft, so that the weight of the load will cause the wheels to sink, the progressive motion of the carriage will be resisted in nearly the same manner as it would be by a constant effort to draw it out of a rut or hollow equal in depth to the depression of the road under the wheel. Even though the material of the road surface should have sufficient elasticity to recover its form after such depression, the carriage will, nevertheless, suffer the same resistance to progressive motion in consequence of such depression under the wheel.

The road surface, therefore, ought to be sufficiently hard and unyielding to prevent the wheels from sinking in it or changing its form.

It appears, therefore, that a road will offer a diminished resistance to the tractive power in proportion as it can be rendered SMOOTH, LEVEL, and HARD.

(230.) *Curved direction produces resistance.* — But even though these three qualities were imparted to a road in the highest degree of perfection, another cause of resistance might arise from the absence of STRAIGHTNESS. Every moving body whatever, according to an invariable law of nature, when put in motion, has a tendency to continue to move in the same direction. When it is necessary to change its direction, an adequate force must be applied; and if the change of direction be continued, as would be the case when the road has a curve or bend, then a continual resistance would be produced, and a continual moving force would be required: straightness, therefore, is the fourth requisite for a perfect road.

(231.) *A perfect road should be smooth, level, hard, and straight.* — Were it possible to construct a road between two places, absolutely smooth, absolutely level, absolutely hard, and absolutely straight, then a carriage put in motion from one end of this road would move to the other end without any tractive force at all, except so far as the resistance of the atmosphere would require it.

(232.) *Art approximates to these conditions.*—But it is needless to say that this limit of perfection is one which, in practice, can never be attained. It is, however, the limit to which art continually endeavours to approach.

The materials of which roads are formed are two-fold, *stone* and *iron*, producing those great means of transport denominated common roads and railways. We shall consider each of these successively, and, for the present, shall confine our attention to the former.

(233.) *Means of approximating to a level road.*—To render a road perfectly level, it would be necessary to cut down the elevations of the ground encountered along the line to the proposed level, and to fill up in the same manner all vallies which are below the proposed level.

(234.) *Cuttings.*—The science of engineering supplies various expedients for the attainment of these ends. Elevations are removed by *cuttings*, a name given to excavations made forming a sort of artificial vallies with sloping sides, along the bottom of which the road is carried. Such excavations may be rendered impracticable or inexpedient from several causes.

The elevation may be so great as that the quantity of earth to be removed would render the work too costly; or no means may be found of disposing of the earth so removed; or, finally, the strata through which the cutting would have to be made, may be of such a material as to render the expense of the work unadvisable.

(235.) *Tunnels.*—In all these cases the object may be attained by another expedient. The hill or elevation may be *bored* through in a horizontal direction at the required level, and a TUNNEL may be constructed. The roof of this, if the strata require it, is lined with masonry, and on the base of it the road is constructed.

(236.) *Embankments.*—If the road is to be carried across a valley at higher elevation than the natural level of the ground, an EMBANKMENT is formed, on the summit of which the road is constructed: this embankment is usually formed of the earth which is taken from the nearest cutting. Its sides, like those of the cuttings, are made in a sloping direction, the acclivity of the slope depending on the material of which the embankment is formed, different materials being capable of standing at greater or less slopes.

(237.) *Relation between the cuttings and embankments.*— Thus it appears that the cuttings and embankments should be more or less accommodated to each other, the one supplying convenient means of disposing of the materials taken from the other.

(238.) *Spoil-banks and side-cuttings.*—When the cuttings supply more earth than is required by the embankments, it is customary to dispose of it in what are called *spoil-banks*, which are artificial mounds of earth formed in convenient places by disposing there the superfluity of the earth produced from the cuttings. When the embankments require more materials than are supplied by the cuttings, these materials are easily obtained from what are called *side cuttings*, which are excavations made in the ground, which lies immediately beside the proposed embankment.

It is evidently a part of the skill of the engineer, in laying out the line of road, to accommodate the cuttings and embankments to each other as nearly as possible, so that there shall be as little of spoil-banks on the one hand, or side cuttings on the other, as possible, such works having no direct connexion with the construction of the road.

(239.) *Viaducts.*—When an embankment, by reason of its height, or length, or other cause, becomes impracticable, or objectionably expensive, the road may be carried along the required level by means of a VIADUCT, which is a bridge supported on arches built with stone, or constructed of wood or iron, in the same manner as ordinary bridges.

An embankment, if formed of materials requiring gentle slopes, absorbs a considerable quantity of ground. In places where ground is expensive, this would become so objectionable, that a viaduct, however extensive, is preferable. A well-known instance of this is presented in the cases of the Greenwich and Blackwall Railways. In America, where timber is cheap and abundant, the viaducts are usually constructed of that material.

It is evident that by these and like expedients the engineer can bring a line of road as near to an absolute level as may be desired; but this, being attended with an expense proportionate to the number and magnitude of the works of art necessary for the purpose, can only be attempted in cases where a proportionate traffic will justify the expense. In general, it is necessary to admit more or less inequalities of level, so as to moderate the cost of the road, and bring it within expedient limits.

(240.) *Question of the compensating property of an undulating road discussed.*—It has been adopted as a principle by some road engineers, that a road undulating with acclivities, not exceeding a certain limit in steepness, is on the whole more easily worked by animal power than one which is constructed at a uniform dead level. It is contended that the varying resistance on such a road is favourable to the action of the animal power, that in ascending the acclivities a greater degree of force is required, and a certain set of muscles brought into play; that, in descending them, the animal is in comparative repose, and that other muscles are in action; that, in short, there is to a certain degree an alternate state of labour and comparative rest for the animal, which is more agreeable to its habits and organisation than would be one uniform state of muscular action, which would necessarily be required by a road constructed upon a dead level. This principle was maintained by Marshall, Walker, Paterson, and Telford, all eminent road engineers. Some of them went so far as to say that it would not be advisable, even though the country were naturally level, to construct a line of road for a single mile upon a dead level. Paterson affirms that it is a fact well known to most persons, and familiar to the experience of coachmen and waggoners, that where a horse, drawing a load over a long stretch of road quite level, will be exhausted with fatigue, the same length of road undulating with gentle acclivities and declivities alternately, will not fatigue the animal so much.

"On a road absolutely level (he says), the draught is always the same, without any relaxation; but on a gentle ascent one of the powers of the animal is called into exercise, and in the descent, another of his powers is called into action, and he rests from the exercise of the former: thus are his different muscular powers moderately exercised one after another, and this variety has not the same tendency to fatigue."

This theory, however, is by no means received without dissent. Several of the most scientific road engineers, and among others Mr. Stevenson, maintain, in opposition to it, that a perfectly level and straight road, when it can be obtained, is decidedly the best. In his report on the Edinburgh Railway, Mr. Stevenson says, "In an uphill draught, a carriage may be considered as in the state of being continually lifted by increments proportional to its rise or progress on the road. Every one knows that on a stage of twelve miles the post-boy generally *saves*, as it is termed, at least half an hour upon the level road, because on it he is not required to slacken his pace as in going up hill. Now, if he or his company would agree to take the same time to the level road that they are obliged to do upon the undulating one, the post-master would find no difficulty in determining which side of the argument was in favour of his cattle." With regard to the fatigue or ease of the horse, Mr. Stevenson, upon one occasion, submitted the subject to the consideration of a medical friend (Dr. John Barclay of Edinburgh, no less eminent for his knowledge than successful as a teacher of the science of comparative anatomy), when the Doctor made the following answer: — "My acquaintance with the muscles by no means enables me to explain how a horse should be more fatigued by travelling on a road uniformly level, than by travelling over a like space upon one that crosses heights and hollows, but it is demonstrably a false idea that muscles can alternately rest and come into motion in cases of this kind. The daily practice of ascending heights, it has been said, gives the animal wind, and enlarges his chest. It may also with equal truth be affirmed, that many horses lose their wind under this sort of training, and irrecoverably suffer from imprudent attempts to induce such a habit." In short, the Doctor ascribes "much to prejudice, originating with the man constantly in quest of variety rather than the horse, who, consulting only his own ease, seems quite unconscious of Hogarth's line of beauty."

To this it may be added, that the result of experimental inquiries conducted on a large scale, on the application of animal power in transport, has established as a general principle, that, for each species and class of animal, there is a certain relation between the load and speed which will enable the animal to work with the greatest possible amount of useful effect. By increasing the load or resistance, the speed is necessarily diminished, though in a different and greater proportion, and if an augmentation of speed be required, a diminution of load or resistance must take place. In short, a departure from that particular relation of speed and resistance which determine the maximum useful effect, whether by increase of resistance and diminution of speed, or increase of speed and diminution of resistance, will necessarily diminish the utility of the animal labour.

Now assuming this general principle, it is evident that an undulating road, as it must expose the animal power used upon it to changes of resistance more or less frequent, and consequently to change of speed, the power, if working at one time with its maximum of useful effect, must at other times, whether the resistance be increased or diminished, work with impaired effect.

On an undulating road, it is evident that the animal power provided for the traction of the load must be such that, without injury to the animal, it can work against the resistance of the steepest acclivity with the necessary speed. Such a power will in general be underworked on the level and still more so on the descending slopes.

If the power be adapted to work with the greatest advantage on the level, it will then be overstrained on the acclivities, and underworked on the declivities.

On this principle, therefore, a conclusion would follow in favour of an uniform level, in accordance with the opinion above stated of Mr. Stevenson.

(241.) *Difficulty of draining roads on a dead level.* — There is, however, another objection to a road upon a dead level, which is, that in wet weather it is always dirty and muddy, because the rain-water cannot run so freely off as it would do on a road having a sufficient fall. This objection is answered by giving the level road sufficient convexity to allow the water to run off laterally to the side drains.

(242.) *Best practical limit of acclivities.*—Since, however, roads cannot in practice be constructed in any case upon uniform dead levels, an important question arises as to the degree of acclivity admissible upon them. It is evident that such an acclivity has in all cases a practical limit. There is an acclivity of such steepness as to be impracticable to the moving power to surmount it, and to produce danger of precipitation in the descent.

(243.) *This limit varies with the perfection of the road.*—This limit will vary with the degree of perfection of the road, and the less perfect the construction of the road is, the greater will be the steepness of the acclivities admissible upon it. This, which may seem at first view paradoxical, admits, however, of easy explanation. To comprehend it, it is necessary first to consider the resistance to the tractive power offered by the road in question upon a level.

(244.) *The more perfect the road, the more narrow is this limit.*—When a carriage is placed upon a perfectly level road and a progressive motion is imparted to it, the first resistance opposed to the moving power is that produced by the inertia of the carriage and the load. In short, the moving power has to put the carriage into motion, and to give it the necessary momentum. This it would have to accomplish, even though the road should have the most absolute perfection, even though it were perfectly smooth, free from all asperities and friction, and though the resistance of the air were annihilated.

But when once the carriage with the load is put in a state of uniform progressive motion, then the tractive power has no other resistances to overcome than those produced by the asperities of the road, the friction of the axles of the wheels in the boxes, and the resistance of the air.

(245.) *Average amount of resistance to wheeled carriages on level roads.*—On ordinary roads and at common speeds, the chief part of the resistance is that which arises from the roughness or softness of the surface of the road. This varies within very wide limits, according to the material, the construction, and the state of repair of the road. It varies also more or less with the weather, according as the road is wet or dry.

This resistance to the tractive force is usually expressed by the proportion it bears to the gross weight of the carriage and its load. It is represented by the tension of the traces by which the carriage is drawn. Thus, if the gross weight of the carriage and load be thirty cwt., and the traces in drawing it at an uniform speed be stretched with the same force as would be produced upon them if one cwt. were directly suspended from them, then the force of traction is said to be the thirtieth of the load.

It must be understood in this case, that the moving power exercises upon the load of thirty cwt. precisely the same force as it would exert if it were employed to raise one cwt. vertically, by a rope passing over a pulley and carried horizontally, so that the horse, advancing in a straight direction, might raise the weight in the vertical direction.

(246.) *On roads of broken stone or gravel.*—This resistance on common roads made with gravel or broken stones reduced to a uniform surface, either by rollers or by the continual working of carriages upon it, is found to vary, according to the condition and material of the road, from the fortieth to the twentieth part of the load. On the worst description of road, the tractive force is seldom greater than the twentieth, and on the best description seldom less than the fortieth.

(247.) *On paved roads.* — On paved roads in general, the resistance to the tractive power is less than upon roads formed of gravel or broken stones. This is a fact contrary to what would be expected. On a common macadamised road, or a road formed into an even surface by fine gravel, hardened by wear or rolling, the motion of a carriage is much more smooth and easy than it is upon the paved streets of a town, and it might be, and generally is, imagined, therefore, that the former is more easy draught for the horse than the latter. Nothing, however, can be more contrary to the truth. Coachmen and drivers in general know this by experience, and it will be observed that on those roads on the Continent where the centre is paved, and the sides formed of gravel or broken stones, the drivers invariably prefer the centre as being the easiest work for their horses.

But, independently of this, the question has been practically tested in various ways, and no doubt remains as to the fact, that the hard surface of a paved road, even though it be uneven and produce a rough motion to the passenger, is easier of draught to the horse than the smooth surface of a macadamised road. It may be asked how this is compatible with the statement that smoothness is one of the requisites of a perfect road. The answer is that *hardness* is another requisite, and that what a paved road loses from want of smoothness, as compared with a macadamised road, it more than gains by its hardness.

(248.) *Amount of resistance produced by acclivities.* — The resistance offered to the power of traction in ascending an acclivity depends on the steepness of the acclivity. If a slope ascends at the rate of one perpendicular foot in fifty feet of length of road, then the resistance produced by the ascent alone, exclusive of any other cause of resistance, will be equal to one-fiftieth of the gross weight of the carriage and the load; if it ascend one perpendicular foot in forty, then the resistance due to the ascent will be one-fortieth part of the load, and so on. In short, the resistance produced by acclivities is expressed by a fraction of the load, in the same manner as we have already explained that the resistance produced by the road's surface is expressed.

(249.) *The angle of repose.* — There is a particular acclivity on all kinds of roads which enters in an important manner into the theory of their construction. It is that acclivity which produces a resistance in the ascent, by the effect of gravity, equal in amount to the resistance offered to the tractive power on a level road. This particular acclivity is called the "*angle of repose.*"

Thus if the construction of the road be such that the resistance which it offers to the tractive power in moving along a dead level is one-thirtieth part of the gross load, then the acclivity determined by the angle of repose on such a road will be one which rises at the rate of one foot in thirty.

(250.) *Such an acclivity doubles the resistance.*—In mounting such an acclivity, the tractive force has two sources of resistance to contend against. First, the ordinary resistance proceeding from the surface of the road, which it would have to encounter on a dead level; and, secondly, the resistance proceeding from the acclivity. In the present case these two are equal, being both one-thirtieth of the load, and consequently the total amount of resistance to the tractive power in ascending such an acclivity, will be two-thirtieths, or one-fifteenth of the load.

(251.) *In descending, the resistance is nothing.* — In descending such an inclination, the gravity which resists the tractive force in the ascent will, on the contrary, aid it, and a carriage will have a tendency to move spontaneously down the declivity, with a force equal to one-thirtieth of its gross weight. In other words, there will be a downward force due altogether to gravity, equal to a tractive force of one-thirtieth of the weight of the load. Now, as this is precisely the amount of tractive force necessary to overcome the resistance proceeding from the surface of the road itself, it follows that, in descending such acclivity, the gravity downwards balances the resistance of the road, and that, consequently, the carriage, if once put in motion downwards, will continue that motion, except so far as it may be resisted by the atmosphere.

(252.) *Declivities greater than the angle of repose, produce acceleration in the descent; and less, require a tractive power.* — It will be evident that in the case of any declivity of greater steepness than this, the gravity in the descent being greater than the resistance of the road, will cause accelerated motion, and that the carriage will descend with such accelerated motion, without any tractive force at all; and, on the other hand, in case of declivities of less steepness, the gravity will not be sufficient to overcome the resistance of the road, and a tractive force, amounting to the excess of this resistance above the gravity, will be necessary to keep the carriage in motion.

(253.) *Example. — Descent on a declivity greater than the angle of repose.* — To illustrate these two cases by example, let us again suppose a declivity which shall fall at the rate of two feet in thirty feet of length, on a road the surface of which offers a resistance equal to the thirtieth of the load. The tendency of the load to descend on such a declivity is, according to the principles of mechanics, two-thirtieths of its gross weight, the meaning of which is, that if there were no friction, or any other resistance, a rope attached to the carriage and carried parallel to the road in an upward direction, and attached to a fixed point, would be stretched with a force equal to two-thirtieths of the weight of the carriage, by the tendency of such carriage to descend. But one-thirtieth of this tendency is, in the case supposed, resisted by the friction or asperities of the road, and, consequently, such a rope would only be stretched by the balance, that is to say, by one-thirtieth of the load. If horses preceded such a carriage in the descent, it would press upon them by this force, and they would be compelled to exercise a backward power in resisting its descent equal to one-thirtieth of the weight of the carriage.

In the same manner the tendency in general to descend any declivity greater than the angle of repose may be calculated. It is only necessary to calculate first the total tendency of the load to descend by the rate at which the declivity falls, and then subtract from that the rate at which a declivity would fall determined by the angle of repose. The remainder will always represent the tendency of the load to descend with an accelerated motion, or the force which the backward action of the horse would have to resist, if not balanced by the action of the brake.

(254.) *Tractive force necessary in descending declivities, less than the angle of repose.* — It follows from this principle, that the acclivities upon roads which are less steep than the angle of repose, will require a certain tractive force in the descent as well as in the ascent. The tractive force requisite on a level will be a mean between these. It will be less than that which is required in ascending such an acclivity, and more than that which is required in descending, and it will be less than the one and more than the other by exactly the same amount.

Thus, if the tractive force upon a level required for a given load be one hundred pounds, and in ascending a certain acclivity it be one hundred and fifty pounds, then in descending the same acclivity it will be only fifty pounds.

(255.) *Compensation in ascending and descending.* — It is plain, therefore, that in all such cases of acclivities less steep than the angle of repose, there is a sort of compensating action required from the tractive force. If a greater intensity is exacted from it in ascending, a less intensity is sufficient in descending, and the mean of the two is equal to the force requisite on a level road.

Now, if animal power were so constituted that the excess expended in the ascent could be compensated by the diminution in the descent, such undulations would not, on the whole, demand a greater expenditure of power than an uniform level. There would be an alternate gain and loss, but on the whole the expenditure of power would be the same.

But the animal organisation is not thus constituted; although there is some relief from the diminished labour in the descent, it will not compensate for the excessive power exerted in the ascent. Still, it must be admitted, that the compensating principle is to some extent effected by the relief obtained by the animal in descending this gentle declivity, and must afford some degree of repose, or at least of relaxed action.

(256.) *No compensation when acclivity is greater than the angle of repose.* — But in the case of acclivities more steep than the angle of repose, one of two effects must ensue: either the carriage must press injuriously on the horses, whose force will be expended in an unnatural manner by backward action; or a brake must be used, which can never be so nicely adjusted in its action as to balance exactly the descending tendency, and in such case rather overacting than otherwise, will throw a certain draught on the horses. In all cases, such declivities, while they exact an excessive exertion of power in the ascent, afford nothing approaching to adequate compensation in the descent.

(257.) *Parliamentary limit of acclivities on mail coach roads.* — Hence it is that in the acts of parliament regulating the construction of some of the great mail coach roads a limit has been imposed on the steepness of the acclivities.

On the assumption that the average resistance on the level may be taken at somewhere between one-thirtieth and one-fortieth of the load, it has been enacted that no ascent or descent should exceed the rate of one in thirty-five, save in exceptional cases, where the ground renders such an acclivity absolutely impracticable.

Thus, in the great mail coach road carried through North Wales, and constructed under the superintendence of the late Mr. Telford, the general inclinations are regulated in the above proportions. There are one or two examples where a steeper acclivity was inevitable. In one case, for a considerable distance, there is an inclination of one in twenty-two, and another for about two hundred yards, still more steep, of one in seventeen. In these two cases, extraordinary expenses had been incurred to render the surface of the road smooth and hard, so as to facilitate the ascent, the brake being used in the descent.

(258.) *Why more perfect roads receive less acclivities.* — I have already observed that the more perfect the road is, the less steep must the general character of the acclivities be. The reason of this will now appear obvious. The tractive power supplied to carriages of every description is necessarily regulated with a view chiefly to the resistance opposed to it on a level road. It is found that, in practice, a greater resistance than twice this cannot be conveniently overcome by this power. Now the acclivity which will produce this double resistance is, as has been explained, the angle of repose. But the more perfect the road is, the less will be the resistance on a level, and as the angle of repose is the acclivity which by its gravity produces a resistance equal to this, it will be less steep in the same proportion. Thus if the resistance upon the level road be one-fortieth part of the load, the angle of repose will be one in forty, and such must be the limit of the acclivity on such a road. But if the road be made so perfect that the resistance on the level is only a sixtieth part of the load, then the angle of repose will be one in sixty, and such, in that case, would be the limit of the prevailing acclivities.

(259.) *Example of the application of this principle in railways.* — This principle is strikingly illustrated, as will be seen hereafter in railways. On railways the resistance is extremely small, less, for example, than the three-hundredth part of the load. The angle of repose is consequently proportionally small, and acclivities which would be scarcely considered as being practically different from a dead level on common roads, will upon railways require more than double, or even triple the power required for a level.

However paradoxical it may appear, that acclivities which do not injuriously affect an ordinary road are altogether inadmissible upon the most perfect class of roads, there is nothing in it which is not consistent with analogy. The more perfect any mechanical instrument whatever is, the more inadmissible will be small defects. Imperfections of the edge which would be of no account in a carving-knife would utterly destroy the utility of a razor.

(260.) *Inconvenience of a dead level.* — Although a dead level may be admitted to be the best form on a road when the power of draught upon it alone is considered, there are in common roads other circumstances to be considered, and the decision of the engineer is generally the result of a balance of disadvantages. In a common road a dead level, as well in its longitudinal as in its transverse section, is attended with this disadvantage, that there would be no escape for surface water. After a fall of rain the water would rest on the surface of the road, it would collect in shallow pools wherever inequalities are found by reason of the wear of the surface. Water and friction united are a formidable source of wear, and the carriages rolling over such a road would soon destroy it.

(261.) *Expedients for surface drainage.*— Two expedients suggest themselves to remove this difficulty. The first is to render the road so convex in its cross section as to afford sufficient lateral fall to enable the water to descend into side drains. This expedient is, however, not without countervailing disadvantage. The wheels of a carriage never can roll over such a surface without continued abrasion, except when the carriage runs in the very centre of the road on the summit of the curve. Besides this, the tendency of the wheels is always to make channels or tracks running parallel to the direction of the road, and these channels must fill with water to overflowing before it can run off laterally.

(262.) *Departure from dead level recommended.*—Although, therefore, a certain slight convexity is still given to the cross section of roads, it is considered by good road makers advisable to depart from a dead level in a sufficient degree to enable the surface water to discharge itself by running longitudinally along the road. A fall of one foot in eighty or ninety is sufficient for this, and this adds so slightly to the tractive force in the ascent, that the compensation in the descent, to a great extent, takes effect, and the road may on the whole be considered practically equal to a level, while the purposes of drainage are attained.

(263.) *Method of conducting roads through mountainous districts.* — In laying out acclivities through a mountainous district, the limit imposed on the acclivities is maintained by several expedients.

Cuttings, tunnels, embankments, and viaducts have been already mentioned, but, if no other expedient were resorted to, in certain cases these would not only be unavailable, but even when available would be attended with an inadmissible expense. Two other expedients are accordingly resorted to. The road either winds along the sides of precipices, being cut into the form of a sort of shelf upon their brows, or, if it must face the acclivity, it is made to wind along in a serpentine course to the right and to the left; the sinuosity being greater in proportion to the steepness of the hill to be surmounted on the one hand, and to the lowness of the limit of the acclivity on the other.

(264.) *Example of the Simplon.* — One of the most conspicuous examples of the practical application of this expedient, is afforded by the celebrated road of the Simplon, carried across the Alps by order of Napoleon. Notwithstanding the immense height of the ridge over which this road has been carried, the maximum acclivity allowed upon it is one in thirty-six. On this line of road is found a variety of expedients, for maintaining the necessary limit of acclivity, which engineering science has supplied.

(265.) *Art of road making.* — The art of forming the surface of a road, so as to possess the requisite qualities of smoothness, hardness, strength, and durability, has largely engaged the attention of modern engineers. Nor has the extension of railways seriously diminished the importance of this problem; for, although these more perfect lines of communication have superseded extensive tracts of common road, they have, at the same time, called into existence numerous lines of common road, which, before their construction, were not necessary.

The railways will probably form the great arteries of intercourse through countries; but they must have tributaries at innumerable points where the traffic is not sufficiently considerable to sustain branch railways, and these tributaries will necessarily be common roads.

(266.) *Preparation of the surface, and formation of the road.* — In preparing the natural surface of the ground for a common road, its inequalities are first removed, and the surface is reduced to the requisite width, and levelled; drains and other expedients are adopted to render it dry, so as to admit of being compressed and hardened by the weight of the road material and the action of the traffic thereupon. Upon the surface thus prepared and levelled, the material for forming the road is laid in a succession of strata, and rolled hard, either by rolling machines expressly used for this purpose, or by the operation of the ordinary traffic upon it.

(267.) *Material of road crust.—Imperfection of flint roads.* — It is evident that the material forming the crust of the road should be such as to be capable of binding into a hard coherent mass, as impermeable as possible to water. The first roads were formed of gravel and loose stones thrown together in their natural size and form. These stones were more or less round, such as they are found in gravel pits. The crust of a road thus formed can never effectually bind. The round stones of which it is composed, great and small, have a tendency to be continually changed in their position by the rolling of the carriages upon them, and by mutual friction to be rendered more and more round. If a surface is attempted to be formed by strewing over the crust formed by such stones gravel and sand, such gravel and sand, aided by the operation of the surface water infiltrating through, will be gradually washed down through the interstices between the round stones, and, after a time, the road will become first rough, the larger stones coming to the surface, and later, these stones, loosened from their position, will be scattered on the road so as to render it almost impassable.

(268.) *Crust of broken stone.* — These difficulties soon became apparent on roads where much traffic was carried on. The expedient by which these defects were removed was by substituting fragments of stone, broken by a hammer, for the round pieces of stone taken from gravel pits. These angular stones, when placed in a stratum and worked down by traffic, were soon found to bind into a compact and coherent mass; the surface was worn down by work to a sufficient degree of smoothness, the matter abraded falling into the interstices.

When this method was first adopted, the substratum of the road was usually formed of stones of a larger size, over which one or more strata of broken stones of a smaller size were strewed. The effect, however, of this was, that, after the road had been worked for a certain time, the superior strata of small stones worked down through the interstices of the substratum of large stones, and the latter coming up to the surface formed a bad road.

(269.) *Macadamisation.* — The celebrated McAdam was the first engineer who pointed out this defect and removed it. He constructed all his strata, from the natural basis of the road upwards, of broken stones of uniform and regular size. Their uniformity was secured at first by gauges supplied to the road makers. Rings were used through which the stones must pass before they could be admitted to be applied to the road. Directions were sometimes given that no stone should be put aside from the hammer which was not small enough to go into a man's mouth. In short, the size of the stones composing the strata of the road was such as would measure about one and a half inch in their diagonal. Labourers, supplied with hammers, were employed at the side of the road breaking the stones to this size. Convenient recesses were provided at intervals along the road, in which heaps of these stones were constantly accumulated for repair. The road contractors were required, by constant inspection, to observe the places where cavities on the surface were formed by unequal wear, and to fill them up as they occurred.

In the original formation of the road, a stratum of this broken stone, several inches thick, was laid upon the basis of the road. This was rolled down into a compact mass either by rollers, or by the operation of the ordinary traffic.

Another similar stratum was then superposed, of a like thickness, and again rolled down in the same way, and this was continued until the crust of the road attained the necessary strength and thickness. After this the repair of the road was maintained by spreading a fresh stratum of broken stone from time to time, so as to keep the surface at the required level, the crust at the necessary thickness, and to give the road the requisite form and smoothness.

(270.) *McAdam admits a soft substratum.*—A remarkable disagreement was signalised between two of the most eminent road engineers of modern times, relating to one of the most important qualities of a road — its hardness.

McAdam not only maintained that a road should not be absolutely hard and unyielding in its surface, but that such a quality is expressly to be avoided. He maintained that the best road is that whose crust rests upon a soft bed, and even that it may be questioned whether a properly made road, resting on a bog which yields by its elasticity, will not last longer than one constructed on a solid and unyielding surface. He says also that a soft substratum, provided it be well drained, is always preferable; and he places no intervening material between the crust of the road and such substratum, even though it were a bog, provided it have sufficient tenacity to enable a man to walk upon it. He gives an instance in Somersetshire, where the substratum of a road was so extremely soft, that when a carriage was moved upon it the water was seen trembling in the ditches on either side, and, after a slight frost, the vibration of the water in the side ditches, produced by the motion of an ordinary carriage on the road, was so great as to break the young ice. "I never," says McAdam in one of his examinations before parliament, "use large stones on the bottom of a road. I would not put a large stone on any part of it, or faggots, or any material larger than stones weighing six ounces. If a road be made smooth and solid it will be one mass, and the effect of the substratum, whether it be clay or sand, can never be felt by carriages going over it, because a road well made unites itself in a body like a piece of timber or a board."

(271.) *Telford requires a hard and solid substratum.*—On the other hand, Mr. Telford maintained that the basis of a road should always be of the strongest and most unyielding quality. In roads constructed to carry a great traffic, and where the extraordinary expense could be afforded, that engineer formed an artificial base of paving, composed of regularly squared blocks of stone of considerable magnitude, flat at the bottom and sides, but not dressed at the upper surface. These were laid in courses precisely similar to the paving of a street, the interstices being filled up with splinters of stone driven in between. An arched form was given to the whole structure in the same manner as is customary in the paving of streets. The upper surface, however, presented, as has been just explained, great inequalities, owing to the points and irregularities of the blocks not having been removed. Upon this basis, thus prepared, and having the strength and character of an arch, Telford laid down the usual courses of broken stones, which, being rolled down as in the process called Macadamisation, the road was ultimately formed.

(272.) *Telfordisation.* — This system, which may not inappropriately be designated by the name of *Telfordisation*, as contradistinguished from the system of M^c^Adam, has been practised in many of the principal mail-coach roads, constructed under the superintendence of the late Mr. Telford and his pupil and associate, Mr. (now Sir John) M'Neil.

It may be asked how so remarkable a difference could have arisen between two engineers, both so eminent.

(273.) *Cause of this difference between Telford and M^c^Adam.* — The attention of M^c^Adam was directed exclusively, as is evident from his writings and his evidence given before parliament, to the smoothness and durability of the road, and to the ease of the passengers in the carriages which rolled upon it. An elastic road fulfilled this condition, provided its crust were sufficiently impermeable to water.

A carriage moving on such a road seemed as though it moved over velvet. But M^c^Adam omitted the consideration of a most important element which was brought under investigation by Telford and M'Neil.

The consideration of M^c^Adam. bestowed sufficiently upon the comfort of the passengers, does not appear to have extended to the horses, and he does not seem to have inquired how far the resistance opposed by the carriage to the tractive power was affected by the elasticity of the road which excited his admiration so much.

This point, however, received much attention from Messrs. Telford and M'Neil, the latter of whom invented and applied an instrument by which the average resistance of different roads to the tractive power was indicated and registered. The result of a series of experiments, made upon elastic and inelastic roads, established, in a most satisfactory manner, the conclusion, that a hard and unyielding road opposed a less resistance to the tractive power than an elastic road such as McAdam recommended, however smooth and perfect the surface of the latter might be.

It is true that the motion of the carriage over the hard road of Telford is not as agreeable as its motion over the elastic road of McAdam, and it is probable (though I am not aware that the fact has been established by experience) that the superficial abrasion and wear, with the same amount of traffic, may be greater on the hard than on the elastic road. But if it be thus, it is more than compensated for by the saving effected in the moving power.

(274.) *Effect of the form of the tires of the wheels on the road.* — The resistance produced by the rolling of the wheels of a carriage upon a road is affected, to a considerable extent, by the form and magnitude of the tires of the wheels which press upon the road. The tire of a wheel is, or ought to be, a cylindrical band of iron, which, as the wheel progresses, is applied in contact with the road by a rolling motion. This will be the case if the surface of the tire be that of a cylinder, the geometrical axis of which is the centre round which the wheel revolves.

The resistance to the rolling motion of such a wheel will depend upon the number and magnitude of the asperities over which it has to pass, and, on a given road, the number of these will evidently be proportionate to the breadth of the tire. Broad wheels will therefore, in general, offer more resistance to the progressive motion of the carriage than narrow wheels.

(275.) *Effect of broad tires.* — As, however, the weight of the carriage is, or ought to be, distributed uniformly over he surface of pressure, it follows that the intensity of the pressure, at any point of the road, will be less in proportion o the breadth of the tire; for the same weight with a broad ire being distributed over a greater surface, the intensity of he pressure at such point of the surface will be proportionally less.

Broad wheels, therefore, although they offer a greater resistance to the tractive power, will produce a less wear upon the road.

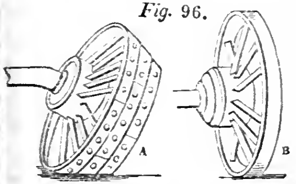
Road makers generally agree that, in heavily laden waggons, he breadth of the tires of the wheels ought never to be less han *four* inches, and that they would be better if constructed vith a breadth of *six* inches; and further, that the proportion of weight resting on each wheel should not be greater than a ton.

(276.) *Effect of double or triple tires.* — It has been generally the practice to shoe the wheels with two or more ires, side by side, instead of a single broad tire. This practice is injurious to the road, which it has a tendency to cut nto grooves corresponding to the form and pressure of the several tires, whereas a single broad tire would act the part of a roller, and, provided it were not overloaded, would have a tendency to compress and harden the road.

(277.) *Effect of conical tires.* — In the construction of vheels of waggons and other carriages intended for the ransport of heavy loads, it has sometimes been the practice o give the surface of the tires the form of a cone rather than that of a cylinder.

The axle, which must be the geometrical axis of the cone, s in this case bent downwards from the longitudinal direction, at such an angle as to make the side of the cone rest upon he road. The apparent object of this expedient is to give a greater space for the carriage between the wheels above the level of the axles, without augmenting the distance between the lines of contact of the wheels upon the road.

*Fig.* 96.




Such an arrangement will be understood by the annexed diagram, in which is represented at B a wheel with a cylin- drical tire, and at A a wheel, such as we have just described, with a conical tire.

(278.) *Objections to them.* — This construction of wheels (B) is not only injurious to the road, but also opposes an in- creased resistance to the tractive power. A conical wheel i set in motion will have a tendency to revolve in a circle, th centre of which is the point on the ground to which its axi is directed.

This will be understood if a common cone, such as the ex- tinguisher of a candlestick, be set in motion on a table. It motion will be circular, and the same circular motion woul be maintained if, instead of being a complete cone, it wer truncated, or cut off at any point of its length; in which cas the truncated part would represent such a wheel (B) as i here described.

But this conical wheel being compelled by the progressiv motion of the carriage to advance in a straight direction, al parts of its tire moving progressively forwards with the sam velocity, it will follow that its motion on the road must con sist partly of a rolling and partly of a sliding or scrapin motion. This will be more clearly understood if it be con sidered that the diameters of the circles formed by differen parts of the tire are of different lengths. Let us suppos that the circumference of the outer edge of the tire measure *fourteen* feet, and that of the inner edge *fifteen*. Now if th carriage be advanced progressively through *fifteen* feet, s that the inner edge of the tire revolve once, applying itsel to the road with the usual rolling motion, the outer edge o the tire must not only revolve once, but must be carried for wards with a scraping motion through a part of the road for in revolving once it would only roll over *fourteen* feet o the road, whereas it is carried forwards by the progressiv motion over *fifteen* feet of the road. Over the fifteenth foot therefore, it must be carried with precisely the same effec as if a brake were applied to it.

In the same manner, the different parts of the tire betwee the outer and inner edge being less in circumference tha *fifteen* feet, they will be severally carried over a length o the road equal to that space by which they fall short of *fiftee* feet in their length, in the same manner as if a brake had been applied upon them.

From these circumstances the injurious effects above mentioned obviously ensue. The tire being more or less scraped upon the road produces unnecessary wear and abrasion in the action, similar to that of a brake, and opposes a considerably increased resistance to the moving power.

(279.) *Dished wheels.* — This form of tire ought not, however, to be confounded with a form in wheels technically expressed by the term *dishing.* A dished wheel may, nevertheless, have a cylindrical tire. The dishing consists in giving the spokes the conical arrangement as they diverge from the boxes, so that the circle formed by the tire of the wheel will have its centre outside the circle of the boxes in which the spokes are inserted.

(280.) *Narrow tires used on light carriages for rapid motion.* — In the lighter class of carriages intended for the transport of passengers, where there is comparatively small pressure on the tires, and where speed and, consequently, diminished resistance are paramount objects, the tires of the wheels are made very narrow, so that they may encounter the least possible amount of resistance upon the road.

In the fastest stage-coaches they are even made semicircular in their section, so that, strictly speaking, they touch the road in a line of infinitely small breadth.

As, however, the load upon these coaches seldom exceeds *two* tons, and frequently falls much short of that limit, the pressure upon each wheel does not exceed half a ton. Still it must be admitted that wheels of this form have a tendency to cut up the road.

The nails by which the tires of wheels are secured upon the felloes should have their heads *countersunk* in the tires, so that the tires should present to the road an even surface; all projecting heads being not only injurious to the road, but having a tendency to augment the resistance of the carriage to the drawing power.

(281.) *Advantages of common stone roads. — Cost of their construction.* — Common stone roads have many advantages over other methods of intercommunication, and they are, of all other methods of transport, those which are most universally used, and which are most universally necessary. The cost of their construction is less, in a considerable ratio, than any other species of road.

(282.) *French roads.* — In France, where they have been constructed by the state, and where, therefore, there are exact reports of their cost, it is found that the royal roads, measuring about *forty* feet in width, constructed on the system of McAdam, cost about *twenty thousand* francs per kilometre, which is about 1,400*l.* a mile. This is about *seven* times less than the cost of canals, and *fifteen* times less than the average cost of railways in the same country.

Common stone roads also adapt themselves more readily to the irregularities of the ground; they take less soil from profitable cultivation; and they are, of all other means of communication, those which are most capable of penetrating into every locality. They have the further advantage of admitting of a greater variety of means of transport.

On the other hand, the chief disadvantage which attends them is, that they require a greater moving power for the transport of a given load in a considerable proportion than is necessary by other and more improved methods.

(283.) *Cost of transport on them.* — The cost of transport upon ordinary roads, in their ordinary state of repair, in France, is estimated at *two pence* per ton per kilometre, which is equal to *three pence and one-third* per ton per mile, the rate of transport being from *fifteen* to *eighteen* miles a day. Transported at the greater speed of *forty* miles a day, the cost is about *five pence half-penny* per ton per mile; and by diligence, at the rate of *five* to *seven* miles an hour, the cost is about *one shilling* per ton per mile.

Travellers by this latter conveyance pay at the rate of from *one penny farthing* to *two pence half-penny* per head per mile, according to the places they occupy. The coaches which carry the French mails have the average speed of about *ten* miles an hour, being the most rapid conveyance on common roads.*

* For a notice of the influence of improved transport on civilisation and a retrospect of its progress, see Railway Economy, chaps. i. and ii.

## CHAPTER II.

### ORIGIN AND PROGRESS OF RAILWAYS.

(284.) *Road surface must be adapted to the tractive power.* — To be perfect, a road ought to possess qualities adapted to two species of action which are continually at work upon its surface, that of the wheels of carriages rolling over it, and that of the feet of horses acting upon it, either in the transport of loads, or in the drawing of carriages. Now, it so happens, that these two modes of action require different and even contrary qualities in the road. It has been already explained that the action of the wheels of carriages requires that the road should be smooth and hard, and it will be so much the more perfect in relation to this action, as these qualities of smoothness and hardness are imparted to it.

(285.) *Hard and smooth road unfit for the action of the feet of horses.* — Now, on the contrary, a road absolutely smooth and hard, or even smooth and hard in a very high degree, would be utterly unfit for the action of the feet of horses.

Such a road would not only shake the structure of the animal, but would not afford to his feet the purchase necessary to give him progressive motion.

It is plain, therefore, that a road must be to some extent rough and soft, to enable horses to act upon it.

A road, then, cannot be perfect, or even nearly perfect, for both purposes.

(286.) *Common roads imperfectly adapted both to the carriage and the tractive power.* — In common broken stone roads a compromise between the two principles is made. They are rendered as smooth and hard as is compatible with the preservation of the health and soundness of the horses which act upon them.

(287.) *Streets of towns more adapted to carriages than to horses.* — In towns, where the labour of the animal is not so incessant as in the performance of long journeys over common roads, the qualities demanded by the wheels are more looked to than those required by the horses. The streets are accordingly paved so as to enable the carriages to roll on them with less resistance than on a road of broken stone. This pavement is more injurious to the horses, but this is a necessity imposed by the conditions of the case.

(288.) *Various expedients for improving pavement.*—Innumerable experiments have been resorted to, especially in the much frequented thoroughfares of great cities, to combine in the construction of the road, the incompatible qualities just referred to, demanded by the action of the wheels, and by that of the horses. Independently of its injurious effect upon the animal power, stone pavement has the further disadvantage in towns of producing a nuisance by noise, not only to the foot passengers, but to the inhabitants of the streets. It is well known that in the front rooms of houses in Fleet Street, the Strand, and Holborn, in London, and in the Rue de Rivoli and the Rue St. Honoré, in Paris, and in general in the leading thoroughfares of other great cities, persons cannot hear each other speak with the windows open; and, even with the windows closed, the noise of the streets is a serious inconvenience.

(289.) *Macadamisation adopted to prevent the intolerable noise.—Its inconvenience.*—An expedient was resorted to to remedy this inconvenience by Macadamising some of these thoroughfares. This, however, was found to be subject to the inconvenience of mud in wet, and dust in dry weather; independently of which, a Macadamised road was found to be worn out so rapidly under heavy traffic as to require constant and inadmissibly expensive repair.

(290.) *Wood pavement.—Its inconvenience.*—Another expedient was resorted to from which sanguine hopes were at first entertained. Instead of paving the streets with square blocks of stone, a floor of carpentry was laid down, consisting of accurately formed blocks of wood properly jointed together.

This expedient also failed. Among other inconveniences which attended it was one that might have been anticipated. Although it was not too hard for the action of the feet of horses, nor even, strictly speaking, too smooth, it was dangerously slippery when a little moistened by rain, and in fine it proved that it did not afford sufficient purchase for the horses' feet.

Independently of this, the structure of the flooring soon gave way under the traffic, and, when once deranged, the road became intolerably bad. The experiment, as is well known, has been tried without success in London. It has equally failed in New York.

(291.) *Wood pavement in Paris.* — In particular places its use is still continued to a limited extent. The road passing along the Rue de Richelieu, near the Théâtre Français, in Paris, is floored with a wood pavement, the noise of stone pavement being found inconvenient to the audience. Although the length of this pavement does not exceed some hundred feet, and it is kept in perfect repair, accidents are frequent, owing to the horses slipping upon it. A thin stratum of sand is, from time to time, thrown upon it, which in some degree counteracts this effect.

(292.) *Expedient of making separate parts of the road for the wheels and for the horses.* — The question whether both qualities may not be imparted to the same road, the smoothness and hardness necessary for the wheels, and the roughness and softness necessary for the horses, by making separate roads or paths for the wheels and horses, is one which could not fail to suggest itself at an early period in the progress of the art of transport. It was sufficiently evident that wheel tracks might be laid down at a width corresponding to the distance between the wheels of common carriages, a horse-path being made between them.

(293.) *Wooden tracks for wheels.* — This was the fundamental idea of a railway. At a very early period, an expedient of this kind was used in stone quarries, where tracks were made by laying down beams of timber for the wheels of trucks and waggons to roll upon, the path for the horse being left between them.

By this expedient, the resistance of the waggons was diminished in a very considerable ratio, and the efficacy of the animal power proportionately increased.

(294.) *Flagstone tracks — used in cities of Italy.* — Tracks formed of flagstones are harder still and more durable than timber. This expedient was also adopted extensively, and even at a much earlier epoch than that which has just been adverted to. Stone trackways for wheels were used by the Romans, and in several of the Italian cities the same expedient has long been and still is in use. Flag trackways are seen in several of the streets of Milan, Florence, and other Italian towns.

(295.) *Commercial Road, Whitechapel.* — A well-known case of this is presented in London. The Commercial Road, running from Whitechapel to the West India Docks, was laid down, in 1829, with wheel tracks formed of large blocks of granite, five or six feet in length, sixteen inches wide, and twelve inches deep, the space between these blocks being paved to form a horse path. It was found that the resistance offered by this road to a well-constructed loaded waggon was not more than the 180th part of the load, being about one-fifth of the resistance offered by a good Macadamised road.

(296.) *Iron tramways.* — It is obvious that tracks formed of iron plates would offer still less resistance, in proportion to their greater smoothness and hardness, than stone; but if such were used, the cost of the material would render it necessary that they should be of limited width.

Now if they were of limited width the wheels would have a constant tendency to run off at the one side or the other, owing to the action, inevitably irregular, of the tractive power. If iron were used, therefore, some expedient should be adopted to confine the wheels, so as to prevent them from escaping laterally from the plates.

This would be accomplished if grooves lined with iron were laid down upon the road for the wheels to run in; but it is evident that one side only of such grooves would be necessary. The inner side of the groove provided for the wheels on the left would prevent the waggon deviating to the right, and the inner side of the groove provided for the wheels on the right would prevent the carriage deviating to the left.

The object, therefore, was attained by casting on the side of the iron plate on which the wheel was intended to roll, a ledge of iron, which, when the plate was laid down, would have a tendency to press on the inside of each wheel. In this way the wheels on the right-hand side of the carriage were prevented from escaping from the plate towards the left, and, in like manner, the wheels on the left-hand side of the carriage were prevented from escaping on the right.

Iron trackways, constructed in this manner, were laid down at an early period in all the mining districts, and especially in the coal districts. This species of railroad was called a *Tramway.* One of the earliest of these was constructed at the great foundry of Colebrook Dale, in Shropshire, in 1767. The rails in this case were made of cast iron.

(297.) *Inconvenience attending them.* — One of the many objections to this system was, that the rail was liable to be constantly covered with dust or gravel, or other impediments, which had the effect of augmenting the resistance, so as to render the rails little better than a common road.

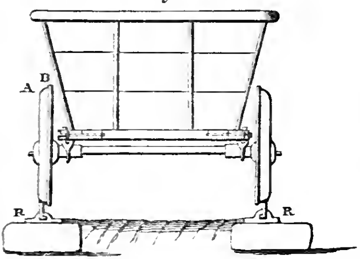
(298.) *The edge rails.* — The next great step in the progress of railways consisted in applying the ledge, which checked the lateral motion of the carriage, and prevented its escape from the rail, to the wheel instead of the rail. The tire of the wheel was constructed with a projecting ledge or flange on the inside, while the rail on which the wheel rested was constructed without such a flange.

When the wheel rested upon the rail, the flange of the wheel descended below the surface of the rail, on the inside of it.

Thus, the flange of the left-hand wheel prevented the escape of the carriage to the left, while the flange of the right-hand wheel prevented its escape to the right.

The rails in this case are elevated sufficiently to leave room for the flanges to descend below their surface on the inside.

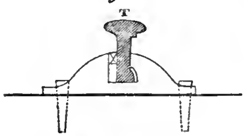
*Fig.* 97.




A pair of such flanged wheels resting on the rails is presented in the annexed figure, where A represents the tire, and B the flange formed upon it. R R represent the rails.

(299.) *Their various forms.*—The form given to these rails has been very various, according to the loads they have to bear, and the manner in which they are supported. In some cases they have been mere bars of iron, fastened by nails to planks of timber; but in the best constructed railways, such as those in operation in most parts of Europe, they are bars of rolled iron of considerable weight and strength, the section of which resembles the letter T, from which they are sometimes called the T rail. The transverse section of one of these is represented in the annexed figure, where T is the upper surface of the rail on which the wheel rolls.

*Fig.* 98.




The weight of these varies from fifty to seventy or eighty pounds per yard, according to the traffic expected upon the road, and to the distance between their points of support.

(300.) *Chairs.* — The rails are supported on props called *chairs*, one of which is represented in section in the figure. The distance between these chairs is more or less, according to the strength of the rail. Seventy-five pound rails are often supported on chairs at five feet asunder, sixty pound rails on chairs at four feet asunder, and so on.

(301.) *Sleepers.*—The chairs themselves are now usually supported on beams of wood called sleepers, which extend across the road at right angles to the rails, and which also serve the purpose of keeping the rails in gauge, which means, to preserve them at the proper width.

(302.) *Stone blocks.*—When the modern railways were first brought into general operation, after the construction of the Liverpool and Manchester line, the chairs were attached to large stone blocks, each chair being supported on a separate block. These blocks were usually two feet square and one foot deep. Transverse sleepers of timber were only used on embankments where the ground was expected to subside and settle, and where, consequently, the rails would require to be re-adjusted from time to time. These sleepers were regarded as merely temporary expedients, to be finally replaced by stone blocks.

(303.) *Why discontinued.*—Experience, however, soon proved, what, indeed, ought to have been foreseen, that the wooden sleepers were much better permanent supports for the rails than stone blocks, and they have accordingly, in general, superseded them.

(304.) *First railways constructed in the collieries.*—Railways constructed upon this principle were in operation towards the close of the last century, in most of the principal collieries in the north and west of England. In some cases their application was limited to the transport of the coals from the mouth of the pit to the port of shipment, and this being, in general, a declivity, the load moved down the railway by its gravity, without the application of any moving power, and when the declivity had sufficient steepness for the purpose, the loaded waggon, in descending, drew up the empty waggons by means of a rope passing round a pulley at the summit of the inclination. In some cases the declivity was not sufficiently steep for this, and then it was necessary to apply either horse power or steam power to draw the empty waggons up.

(305.) *Stockton and Darlington Railway.*—The first case of the application of railways to the purpose of general traffic, and in particular to the transport of passengers, was that of the Stockton and Darlington Railway, which was completed in 1825, and the length of which was thirty-seven miles. This line was worked by horses. The advantages, as compared with common roads, were rendered very apparent, one horse being able to do more than the work of four horses, but still the countervailing disadvantages were found to be so serious that no extension of the application took place.

(306.) *Origin of the Liverpool and Manchester Railway.—Canal monopoly.*—While these improvements in railways were in progress in the mining districts, the commerce of England, increasing in a rapid proportion, had begun to feel the insufficiency of the means of internal transport supplied to it by the canals, then almost the only available means.

The Bridgewater Canal, which was commenced about the year 1767, was attended, as is well known, with great advantage to its proprietors, and other companies were soon formed, by whose enterprise and capital was constructed the extensive system of inland navigation which soon overspread the country, and served the purposes of commerce.

Protected from all competition by the imperfect nature of the public roads and the injurious operation of the turnpike tolls, these companies soon monopolised the entire inland traffic of England, and began to realise immense profits. It was in vain that rival lines of water communication were in some instances constructed. The instinct of common interest soon produced a combination of the companies, extinguished competition, and left the public victims to monopoly and exorbitant prices.

The commerce of England supported this system of extortion long and patiently. It was not forgotten by the merchants and manufacturers that, before the construction of the canals, they had no practicable means whatever for internal traffic; and the companies were allowed to continue in the enjoyment of their revenues. At length security engendered negligence. The service of transport was not only extravagantly charged for, but ill performed. Petitions were presented to parliament in 1825, in which it was stated, and evidence offered, that the cotton which was transported three thousand miles across the Atlantic, from New York to Liverpool, in twenty days, took six weeks to be carried from Liverpool to the mills of the spinners at Manchester—a distance of only thirty miles! This was more than even the phlegmatic temperament of Englishmen could endure, and it was resolved to construct a railway to perform the service.

Roused from their apathy, the wealthy and powerful canal companies at once resolved to propitiate the merchants by a reduction of their tariff. It was, however, too late. The decision was taken: the new project had been well considered, and its advantages were rendered too plain. Conciliation failing, and compromise rejected, the inland navigation interest rallied its partisans in parliament to oppose the act authorising the construction of the railway, and for two years succeeded. The commerce of Liverpool and Manchester, however, was too deeply involved in the enterprise to submit to be repulsed, and at length, in the year

1828, the act to incorporate the railway company received the royal assent.

Such was the origin of that singular advancement in the art of transport over land, which has formed so remarkable an event in the present age, and which has spread its influence, more or less, over all that portion of the terrestrial globe to which civilisation has extended. The unprecedented degree in which capital has been attracted to this improvement, the extraordinary manner in which it has engrossed the attention of every enlightened people, and more especially that of our own country, the great interests which are consequently involved in it, and, above all, the imperfect means of information which have been afforded to the public respecting it, combine to render it a subject of the most profound interest.

(307.) *First intended only for the transport of merchandise.*—As originally designed, the sole object of the Liverpool and Manchester Railway was the transport of merchandise between these important towns. Manchester, a great manufacturing district, received its raw material from distant quarters of the globe by the port of Liverpool; and, on the other hand, shipped at the same port the manufactured produce of its mills and factories to its customers in every part of the world. The reciprocal transmission of these articles was the main object to which the new company looked, as the means of affording an adequate return for the capital they were about to expend.

(308.) *Question of the moving power to be used upon it.*—As the enterprise advanced towards completion, the method of conducting the traffic upon it came to be considered. The project was originally regarded as an ordinary road, and the owners were authorised to demand toll from all who might desire to transport goods upon it. This method of proceeding would have been admissible, if the line were to be worked by horse power like a common road; and such, at one time, was the view of the matter taken by many who were interested in it. The engineer, however, Mr. George Stephenson, who had been employed to make the line, recommended the use of steam as an agent superior in economy and efficiency to animal power.

(309.) *Locomotive or stationary steam power.* — There were two methods in which the agency of steam might be used. A rope might be carried on rollers along the line between the rails, to which the waggons containing the merchandise might be attached; and this rope being, at certain stations, coiled round large drums or cylinders, the waggons might be drawn from station to station by fixed steam engines, applied to keep these drums or cylinders in revolution. Such was called the system of *stationary engines.*

The second method was that of smaller and lighter engines, which should be provided in greater number, and which should travel with the load as horses do with a waggon. This was called the system of *locomotive engines.*

(310.) *Reports of engineers.* — Horse power being definitively rejected, the choice between these two systems of steam power was doubtful, and the directors of the company were divided in opinion upon it. It was accordingly agreed that the best and most experienced practical engineering authorities should be commissioned to inquire and report upon the question. Accordingly, in the spring of 1829, Messrs. George Stephenson, Joseph Locke, James Walker, and John U. Rastrick, all professionally conversant with railways and steam power, were appointed to visit the different coal districts, and collect information on the subject. The result was a report inclining in favour of the locomotive system, which at length, and not without much hesitation and doubt, it was decided to adopt.

(311.) *Passenger traffic suggested.* — Hitherto the transport of passengers on the proposed railway had not entered into the contemplation of the projectors, or, if it did, it was regarded as practicable only to a limited extent, and as altogether secondary to the traffic in merchandise. It was now, however, suggested that locomotive engines might *possibly* be so constructed as to draw the waggons with a speed of *ten or twelve miles an hour!* and, in that case, that it was worth while to consider whether the passenger traffic between Liverpool and Manchester might not be attracted to the railway.

(312.) *Incredulity of engineers as to the capabilities of locomotive engines.* — *Decisive experiment.* — It is curious to observe, now that the consequences of this great enterprise are before the world, how completely they were unforeseen. The idea of a steam engine drawing a load twelve miles an hour (which was thrown out with some timidity by Mr. Stephenson) was received with ridicule by most of his engineering contemporaries. One well-known writer on railways, who resided in the midst of a coal country, and under whose windows locomotives had been working for years, indignantly disavowed any participation in such extravagant speculations, and has left his disclaimer on record in a published work. He begged "that he might not be confounded with those hot-brained enthusiasts who maintained the possibility of carriages being drawn by a steam engine on a railway at such a speed as twelve miles an hour!" Within a few months after the publication of this remarkable disclaimer, amidst the incredulity and ridicule of the majority of the engineering profession, and to the astonishment of the scientific world, the railway was traversed by the 'Rocket' with a speed of upwards of twenty-nine miles an hour.

(313.) *Opening of the railway.—Passenger traffic engrossed by it.*—This fact altogether changed the aspect of the enterprise. It was evident now that the projectors had at their feet the traffic in passengers, the most profitable species of transport; and that goods, hitherto regarded as the chief source of profit, must take a subordinate place. The railway was opened to the public in 1830; and immediately, of the thirty stage-coaches which had previously run daily between Liverpool and Manchester, one only remained on the road; and that was supported solely by passengers to intermediate places not lying in the direction of the railway.

(314.) *Vast increase of this traffic.*—The comparatively low fares and extraordinary expedition offered by the railway had the effect which might have been expected. Previously, the number of travellers daily, by the coaches, was about five hundred; it was immediately augmented above three-fold. Sixteen hundred passengers per day passed between these towns. If the traffic in passengers exceeded all anticipation, the transport of goods, on the contrary, fell short of what was expected. The canal lowered its tariff to the level of the railway charges and increased its speed and its attention to the accommodation of customers. The canal, moreover, winding through Manchester, washed the walls of the warehouses of the merchants and manufacturers. At the other end it communicated directly with the Liverpool docks. The goods were therefore received directly from the ship, and delivered directly to the warehouse, or *vice versâ;* without the cost, delay, and inconvenience of intermediate transhipment and cartage. These considerations went far to counterbalance the superior speed of the railway transit for goods; yet, notwithstanding this inconvenience and obstruction, the company soon found themselves carriers of merchandise at the rate of a thousand tons per day.

(315.) *Rapid construction of other lines.*—Thus, the problem of the rapid transport of passengers by steam on railways was solved in 1830, and the profitable character of the enterprise soon became apparent. Dividends of 10 per cent. were declared, and the shares were greedily bought up at 120 per cent. premium. Then followed in rapid succession those results which must necessarily have ensued. Other lines of railway, connecting the chief centres of population and industry with the metropolis, and with each other, were projected. In the four years which elapsed from 1832 to 1836, about 450 miles of railway were completed, and 350 miles were in progress of construction.

*Remarkable deficiency of engineering skill.* — Meanwhile, the practical skill and the experience of the engineering profession did not keep pace with the increasing demands of the public, and the avidity of capitalists. Enterprises were pushed forward before time had ripened the results of the earlier attempts into general principles; and it was still undecided on what plan and by what methods these novel lines of intercommunication, and the machinery to work upon them, might best be constructed. The very limited number of engineers who, having already been employed in the coal districts of the northern counties, were presumed to have had some experience in railway works, were soon engrossed to the full extent of their time and powers. Great enterprises, consequently, fell under the superintendence of persons having neither the peculiar knowledge nor experience which they required. It was fortunate for the country that the first important line of railway had been intrusted to the consummate practical skill and experience of Mr. George Stephenson. The Liverpool and Manchester line, which will descend to succeeding ages as a monument to his memory, happily served as a model railway for those which more immediately succeeded it. His son and his pupils were intrusted with the execution of several of the most important lines; and the same successful results which had attended the first railway, were secured for those which came into operation afterwards.

In other cases, however, the superintendence of great enterprises fell into less scrupulous and more presumptuous hands. The rashness of ignorance and inexperience prompted the adoption of fantastic novelties, which had no discoverable purpose save the acquisition of notoriety; and the spurious reputations thus obtained, combined with some tact in the management of boards of directors, led to results, the penalty for which has since been paid in the shape of large calls, heavy loans, and small dividends. Such cases, however, have been only exceptional; and, on the whole, the country and the world have reason to rejoice that an improvement so extensive and sudden has been effected with so few important failures and drawbacks.*

(316.) *Improvements attained through a succession of errors.* — It was impossible for any human skill or foresight to provide, in a series of enterprises so novel, against all the contingencies which must arise in their practical operation. We accordingly find, in tracing their progress, the same gradual advancement through a series of errors, which has marked the progress of every improvement in the arts and sciences. When the Liverpool and Manchester line was in progress of construction, a form of rail, called the "fish-bellied" rail, had acquired much favour among engineers; and great praises were lavished on the scientific perfections of its form, in which the varying strength was so beautifully adapted to

* So great was the ignorance, even among the most eminent engineers, respecting railways and their machinery, so recently as 1837–8, that one gentleman in the highest rank of the profession, being examined before a committee of the House of Commons was unable to say whether the wheels of locomotives turned *with* their axles or *upon* them!

the varying action of the loads which passed upon it. The railway was accordingly laid down with "fish-bellied" rails. Experience, however, soon showed that the form so beautiful in theory was most defective in practice; and these rails have since been consigned to a place in the *history* of engineering, the original "parallel" rail having superseded them in all parts of the world.

The proper weight and strength of the rails was as little foreseen as their form. The Liverpool and Manchester line was originally laid with rails weighing thirty-five pounds per yard. This has been increased successively from year to year to forty, fifty, sixty, and even to eighty pounds. The distance between the supports has been likewise varied. Forty pound rails on three feet bearings, sixty pound rails on four feet bearings, and seventy-five pound rails on five feet bearings, have been adopted on different railways, and on different parts of the same railway. The nature of the supports themselves has undergone a revolution. Originally the rails were sustained on square stone-blocks, measuring two feet on the side, and twelve inches deep. Cross sleepers of timber were only used as temporary supports on embankments, until their settlement and consolidation should be effected by time and work. The stone blocks are, however, now every where abandoned, and the cross sleepers of timber permanently and universally established.

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## CHAPTER III.

### STRUCTURE AND OPERATION OF THE LOCOMOTIVE ENGINE.

(317.) *The tractive power requires a reacting surface.* — Whatever power be used to draw or impel a load upon the surface of a road, some adequate expedient must be provided to enable such power to react upon the road with a force equal to the momentum imparted to the load. Such reaction is indispensable according to the established laws of mechanics. It is a universal principle of physics that a moving force cannot be imparted to any mass of matter in any one direction, without at the same time imparting an equal moving force to some other mass of matter in the contrary direction. In the case of a load transported over the surface of the earth, this force of reaction is imparted to the earth itself, the immense comparative magnitude of which renders it inappreciable. It is not, however, the less real.

Whatever, therefore, be the moving power, the road upon which it acts must be such as to enable it to afford the reaction thus indispensable to the progressive motion of the load. In the case of animal power, the reaction is effected by the feet of the horses, or other animals, which draw the load. The road must therefore be sufficiently rough to prevent the feet from slipping backwards, and thus failing to receive the necessary power.

(318.) *The reaction of the engine acts upon the rails.* — In the application of mechanical power, the method of reaction which naturally suggested itself was by means of the wheels themselves. The moving power was made to act upon the wheels either by a crank or winch, an endless band, or some other of the well-known contrivances for imparting a motion of rotation.

The wheel once put in rotation, provided it did not slip upon the road, must make the carriage advance through a space equal to that portion of the tire of the wheel which revolves. One revolution of the wheel would, therefore, carry forward the carriage through a space equal to the circumference of the wheel. But if the purchase of the wheel upon the road, or upon the rail, was insufficient for such reaction, then the wheel would slip upon the road or rail, and would revolve without causing any progressive motion of the carriage.

The moving power would in such case be expended upon the friction produced between the slipping or sliding tire of the wheel and the road or the rail.

(319.) *The purchase of the wheel on the rail is pro-*

*portionate to the weight upon the wheel.* — The purchase of the wheel upon the rail, other things being the same, would be proportionate to the weight resting upon the wheel. By augmenting that weight therefore, the power of reaction would be proportionately increased.

(320.) *Manner in which the steam engine imparts motion to the driving wheel by connecting rod and cranks on axle.* — The manner in which the power of steam is made to impart revolution to the wheel of a carriage does not differ in principle from that in which it keeps the ordinary fly-wheel of a steam engine in motion. The piston, which is driven backwards and forwards by the force of steam in a cylinder, gives, in the first instance, alternate motion to its rod, which passes, steam-tight, through an aperture in the cover of the cylinder. To the end of this rod is fastened a bar of iron, called a connecting rod, the other end of which is jointed upon a crank constructed upon the axle, which passes through the wheels to which revolution is to be imparted, and which in this case are keyed upon the axle, so that they cannot revolve upon it, but must revolve when the axle is turned. When, under these circumstances, the piston is made to move backwards and forwards by the steam in the cylinder, the connecting rod acts upon the crank, and makes it revolve in the same manner as the arm of a man would act upon a winch. The revolution of the crank produces the revolution of the axle, and the revolution of the axle produces the revolution of the wheels.

(321.) *By connecting rod acting on a pin on the wheel.* — The same effect may also be produced by placing the cylinder and connecting rod outside the wheel, and attaching the connecting rod by a joint to one of the spokes, at a distance from its centre, equal to one-half the stroke of the cylinder. In this case, the portion of the spoke between the joint of the connecting rod and the centre plays the part of the crank.

(322.) *Action of connecting rod varies with position of crank.* — In such an arrangement the action of the piston upon the crank will vary according to the position of the crank. When the connecting rod is at right angles with the crank, the effect of the steam to turn the wheel is greatest;

when it is oblique to the crank, the action of the steam is less efficacious; and when the connecting rod takes the same direction as the crank, then the action of the steam becomes altogether lost.

In short, all the circumstances already explained (82.), respecting the action of the connecting rod on the crank in the common stationary steam engine, are equally applicable to the locomotive, and need not therefore be repeated here.

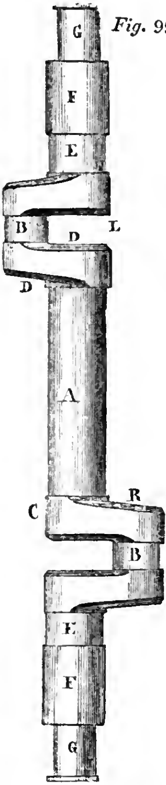
(323.) *Method of producing uniform action by two cranks.* — As the action, therefore, is subject to continual variation, and its energy at two extreme points becomes altogether inefficient, it would produce a varying progressive motion, and the carriage would, if thus impelled, move by starts. This inequality, however, is effaced by the expedient already explained in the case of marine engines. Two cylinders, pistons, and connecting rods are provided, acting on two cranks placed at right angles to each other; or, if they act outside the wheel, then the spokes to which they are attached are at right angles. By this means, when one of the cranks is in its attitude of greatest energy, the other is at its dead point, and *vice versâ*. In this way, the sum of the simultaneous actions of the two cranks is always nearly the same, and the progressive motion of the carriage is consequently uniform.

(324.) *Position of the cylinders — between or outside the wheels.* — The cylinders may either be placed between the wheels and under the engine, or outside the wheels and at any convenient elevation beside the engine.

(325.) *Between the wheels and under engine.* — If they are placed between the wheels and under the engine, they are usually fixed in a horizontal position between those wheels of the engine which they do not drive. The piston rods play horizontally, being directed towards the axle of the driving wheels. On that axle two cranks are constructed, opposite to the pistons of the two cylinders, and connected with them by the two connecting rods.

(326.) *Form of a double cranked axle.* — A double cranked axle of this sort is represented in *fig.* 99., the cranks being seen in a position oblique to the plane of the diagram. The connecting rods are understood to be attached to the cranks at B, and the wheels, which are to be driven, are keyed upon the extremity of the axle at G.

*Fig.* 99.




(327.) *Volume of steam necessary for each revolution of wheels.* — From what has been explained it will be understood, that to enable the wheels to make one revolution, each piston must be driven once backwards and forwards in the cylinder, and consequently the boiler must supply to the cylinders four measures of steam. In this way, the consumption of steam necessary for a given progressive speed of the carriage may be calculated. Thus, if the circumference of the driving wheels be thirty feet, four cylinders full of steam will be consumed for each thirty feet through which the carriage advances. It is apparent, therefore, that the ability of the engine to move the load with any requisite speed is resolved into the power of the boiler to produce steam of the requisite pressure at this required rate.

(328.) *Speed of engine depends on rate of evaporation.* — Let it be supposed that it is desired to transport a certain load at the rate of thirty miles an hour, which is at the rate of half a mile, or 2640 feet per minute. Let us suppose that the circumference of the driving wheels is twenty-six feet and four-tenths. These wheels will revolve one hundred times in moving over 2640 feet, or half a mile, that is to say, one hundred times per minute. But since each revolution requires the boiler to supply four cylinders full of steam, the consumption of steam per minute will be four hundred times the contents of the cylinder.

(329.) *Resistance of load determines the pressure of the steam.* — The pressure of the steam will depend upon the resistance of the load. By the common principles of mechanics, the power acting upon the pistons necessary to balance a given resistance at the circumference of the wheel can be easily calculated, and thus the necessary pressure of the steam ascertained. In this manner it can always be determined how much steam, of a given pressure, the boiler must produce, in order to enable the engine to carry a given load with any required speed.

The mechanism being properly constructed, it follows, therefore, that the efficacy of the engine must depend ultimately on the evaporating power of the boiler.

Tables have been already given (138.), by which it is shown what quantity of water is necessary to produce a certain volume of steam of a given pressure. By these tables, the quantity of water which the boiler must evaporate to produce any required speed, with a given resistance, can always be determined.

(330.) *Circumstances which limit the weight and bulk of a locomotive.*—In the case of the locomotive engine there are particular conditions which limit the magnitude and weight of the machinery, and create impediments and difficulties in the construction of the machine, which are not encountered in stationary engines. As the engine itself is transported, and travels with its load, it must necessarily be subject to narrow limits as to weight and bulk. It has to pass under bridges, and through tunnels, which circumstance not only limits its general magnitude, but almost deprives it of the appendage of a chimney so indispensable to the efficiency of stationary steam engines.

(331.) *Expedients for obtaining great evaporating power in a small weight and bulk.*—It follows that this limitation of weight and bulk can only be rendered compatible with great power of evaporation by expedients which shall produce, in a small furnace, an extremely intense combustion, and which shall ensure the transmission to the water completely, and immediately, of the heat developed in such combustion.

(332.) *Form of fire-box.*—The heat developed in the combustion of fuel in a furnace is propagated in two ways. A part radiates from the vivid fuel in the manner, and according to nearly the same laws which govern the radiation of light. These rays of heat, diverging in every direction from the stratum of burning fuel spread upon the grate, strike upon all the surfaces which surround the furnace. Now, as it is essential that they should be transmitted immediately to the water in the boiler, it follows that in such an engine the furnace ought to be surrounded on every side with a portion of the boiler containing water; in short, a hollow casing of metal, filled with water, ought to surround the fire-place. By this expedient, the heat radiating from the fuel striking upon the metal which forms the inner surface of such casing, will enter the water, and become efficient in producing evaporation.

Whatever then be the particular form given to the engine, the furnace must be surrounded by such a casing. This casing is called the *fire-box*. The bottom of it is occupied by a grate, which should consist of bars sufficiently deep to prevent them from being fused by the fuel which rests upon them, having sufficient space between them to allow the air to enter so freely as to sustain the combustion, but not such as to allow the unburned fuel to fall through them.

(333.) *Tubes through boiler.* — The limited magnitude of locomotive boilers renders the construction of the extensive flues used in stationary boilers impracticable; and accordingly, in the early engines, a great waste of heat was occasioned, owing to the flame and heated air being permitted to issue into the chimney before their temperature was sufficiently reduced by contact with the flues.

At length an admirable expedient was adopted which completely attained the desired end. The boiler was traversed by a considerable number of small tubes of brass or copper, running parallel to each other from end to end, the furnace being at one end of the boiler, and the chimney at the other. The flame and heated air which passed from the furnace had no other issue to the chimney except through these tubes. It was thus driven, in a multitude of threads, through the water. The magnitude and number of the tubes was so regulated, that when the air arrived at the chimney, it had given out as much of its heat as was practicable to the water.

(334.) *Their great efficacy.* — The full importance of this expedient was not appreciated until long after its first adoption. In the first instance, the tubes traversing the boiler were small in number, and considerable in diameter, but as their effects were rendered more and more evident by experience, their diameter was diminished and their number increased, and at length it was not uncommon for the boiler to be traversed by one hundred and fifty tubes of one inch and a half in internal diameter.

The heat was thus, as it were, strained out of the air before the latter was dismissed into the chimney.

These tubes were necessarily kept below the surface of the water in the boiler, so that they were constantly washed by the water, and the heat taken up from them was absorbed immediately by the bubbles of steam generated at their surface, which bubbles continually rose to the top of the boiler and collected in the steam chamber.

(335.) *Evaporating power determined by magnitude of fire-box and tube surface.* — It will be understood from these observations, that the evaporating power of the locomotive boiler was determined by the quantity of surface exposed to the radiant heat in the fire-box and the quantity of surface exposed to the action of the heated air in the tubes. The expression of the quantity of this surface in square feet was the usual test of the evaporating power of the boiler.

(336.) *Coke used as fuel.* — Much of the efficacy of these boilers depends on the quality of the fuel. As the engines travelled through districts of the country more or less populous, the evolution of smoke was considered inadmissible in consequence of the nuisance it would produce. It was, therefore, resolved to use coke as fuel instead of coal.

(337.) *Its great efficiency.* — Another advantage, however, attended the use of this fuel. Coke being composed chiefly of carbon, to the exclusion of the more volatile constituents of coal which produce flame in the combustion, the chief part of the heat developed acted by radiation. No flame issued from the furnace, and heated air only passed through the tubes. It was more easy, therefore, to extract the heat, than would have been the case if flame were developed. In short, with this fuel, the portion of the heat developed in the furnace was much greater than that which would have been developed in the combustion of coal. The surface of the fire-box became relatively more efficient, and the flues less so than in stationary engines where coal was used.

Independently, therefore, of the advantage of developing no smoke, the coke was a form of fuel better adapted to the condition of the locomotive engine.

(338.) *Method of producing the necessary draft.* — To sustain a rapid and intense combustion on a grate necessarily small, a proportional force of draft was indispensable. In stationary engines, as is well known, the draft in the furnace is usually produced by a chimney of corresponding elevation; but this being inadmissible under the conditions of the locomotive engine, it was necessary to adopt some other expedient to produce the necessary current of air through the tube. A blower, or fanner, working in the funnel or in any other convenient position, would answer the purpose; but a much better expedient was adopted at an early period in the history of the locomotive.

The steam, after driving the piston, was allowed to escape, but in order to turn it to profitable account, instead of being dismissed into the atmosphere, where it would produce a cloud of vapour around the engine, it was conducted through a pipe to the base of the funnel, where it was allowed to escape in a jet directly up the chimney. In this manner a puff of waste steam escaping from the cylinders as the pistons arrived at the one end or the other, was injected into the chimney, and a constant succession of these puffs took place, four being made for every evolution of the driving wheels. These continual puffs of vapour maintained in the chimney a constant current upwards, by which the air and gases of combustion were drawn from the fire-box through the tubes.

(339.) *The blast pipe.* — The pipe by which these jets were directed up the chimney, called the *blast pipe*, served the purpose of a most efficient bellows.

Those who are not familiar with steam machinery will not find it difficult to comprehend, upon proper reflection, that a bellows would produce the same effect on the fire if it acted in the chimney, or even at the top of the chimney, as if it were applied at the grate bars, provided only that the mouth of the chimney near the fire be closed by a door, as it always is in steam engines.

(340.) *The tender.*—To keep the locomotive boiler supplied with water, and its furnace with fuel, it is accompanied by a carriage called a *tender*, which bears a supply of fuel, and a cistern of sufficient magnitude, containing water.

(341.) *Appendages of engine.*—This cistern is connected with the interior of the boiler by pipes and force-pumps. The force-pumps are worked by the engine. The engineer is supplied with a lever, by which he can suspend the action of the pumps at pleasure; so that, if he finds the boiler becoming too full, he can, to use a technical phrase, "cut off the feed." Gauges are provided, by which he can at all times ascertain the quantity of water in the boiler, or, which is the same, the position of its surface. He is accompanied by a stoker or fireman, who from time to time opens the door of the fire-box and feeds the furnace.

(342.) *General delineation and description of a locomotive.* — This general description of the locomotive engine will be better understood by reference to the annexed series of drawings.

*Fig.* 100. represents the longitudinal section of a locomotive engine. The following are its parts:—H, the cylinders; X, the piston; V, the piston rod; B, the connecting rod; C′ C′, the cranks constructed on the axle of the driving wheels. D, the grate bars, with the fire-box over them, the fire-box being surrounded by water, except at the door *g*, where the fireman feeds it; E E are the tubes traversing the boiler, the heated air passing through them to the smoke box F; *p* is the blast pipe; G, the funnel; K, the force-pump for feeding the boiler; U′, the stage surrounded by a railing, on which the engineer and stoker stand; S, the steam pipe leading to the cylinders.

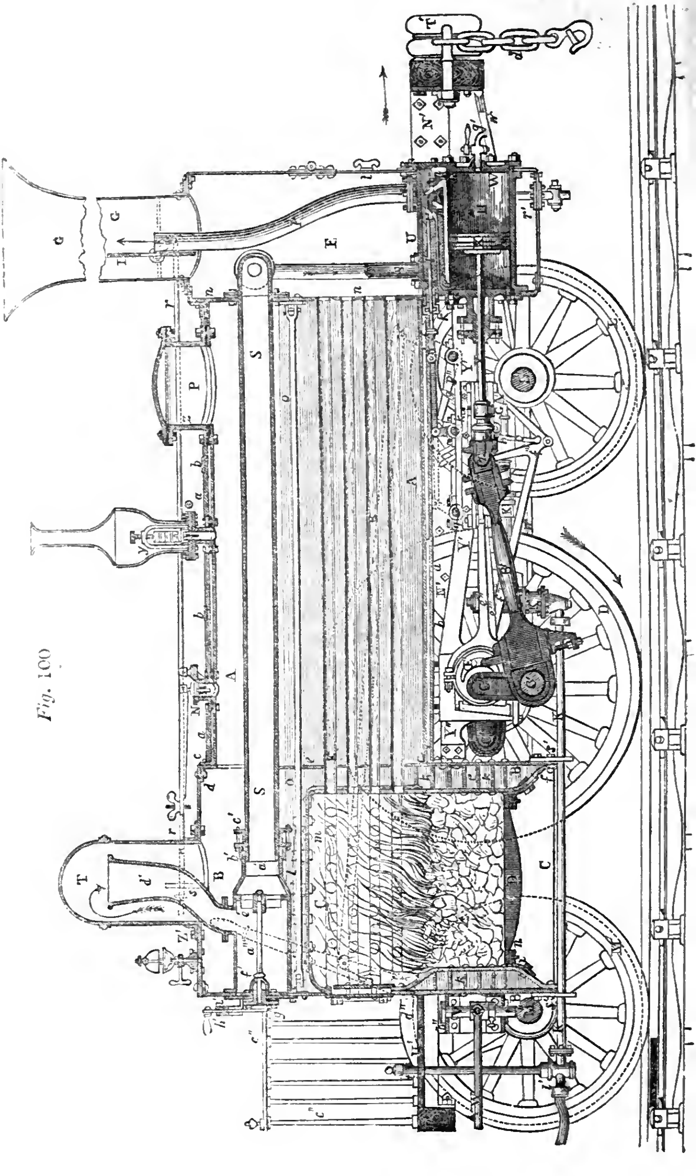
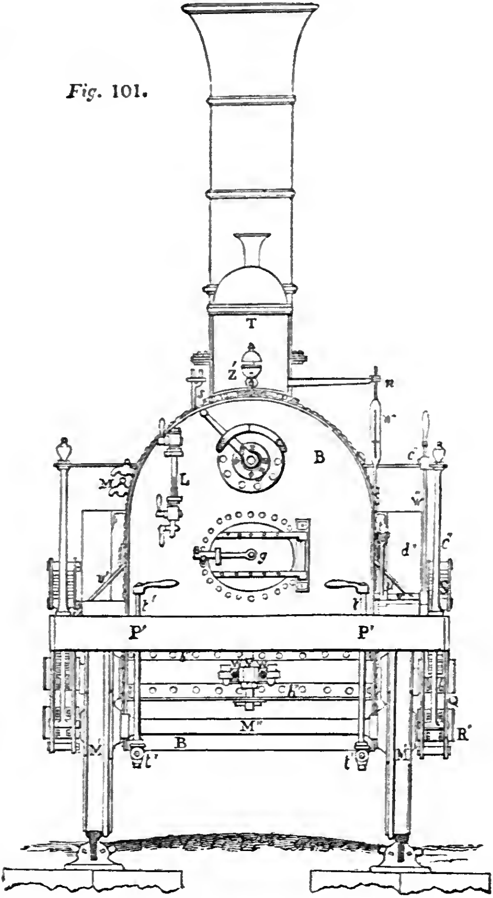


*Fig.* 100

*Fig.* 101. is the end view of the engine at the place where the engineer and fireman stand: — C, the fire-box; L, the

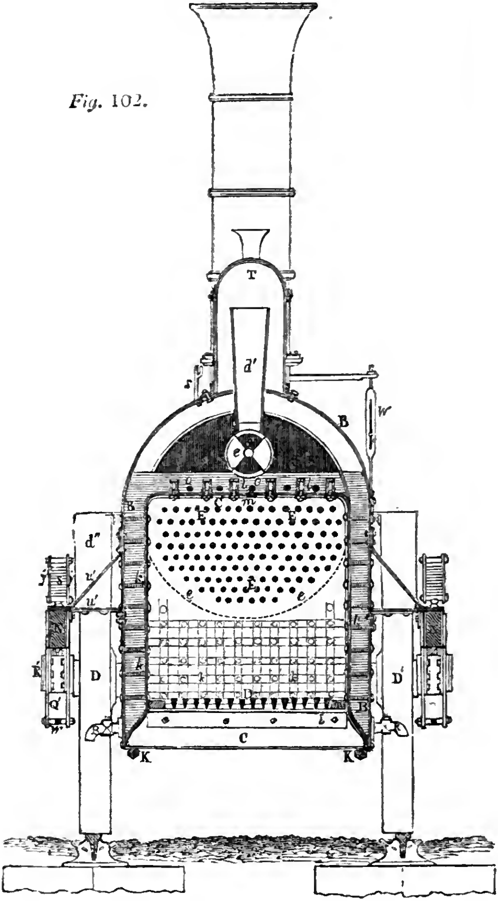
*Fig.* 101.




ELEVATION OF THE HINDER END OF A LOCOMOTIVE ENGINE.

water gauge, being a glass tube communicating above and below with the interior of the boiler, in which the water stands at the same level as in the boiler; M, gauge cocks, intended for the same purpose as the gauge L, the upper cock being above the proper level of the water, and the lower below it.

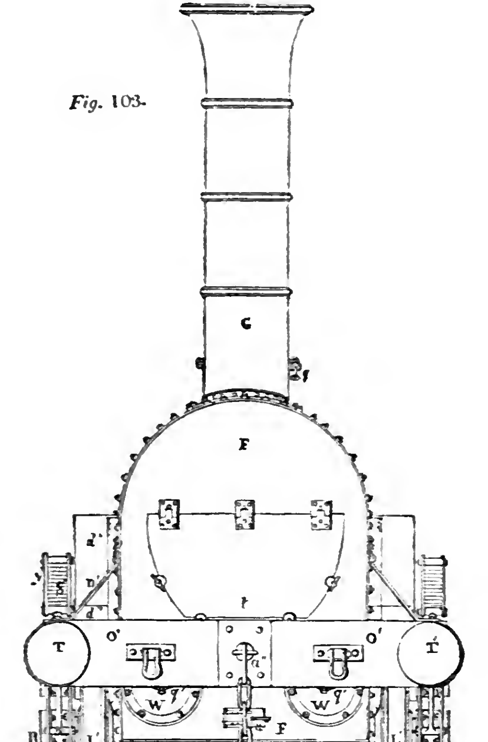
*Fig.* 102.




CROSS VERTICAL SECTION OF THE ENGINE THROUGH THE FIRE-BOX.

If the water be at the right level, steam would issue on opening the upper cock, and water on opening the lower. If water issue from the upper cock, the feed must be cut off. It should be kept on so long as steam issues from the lower cock.

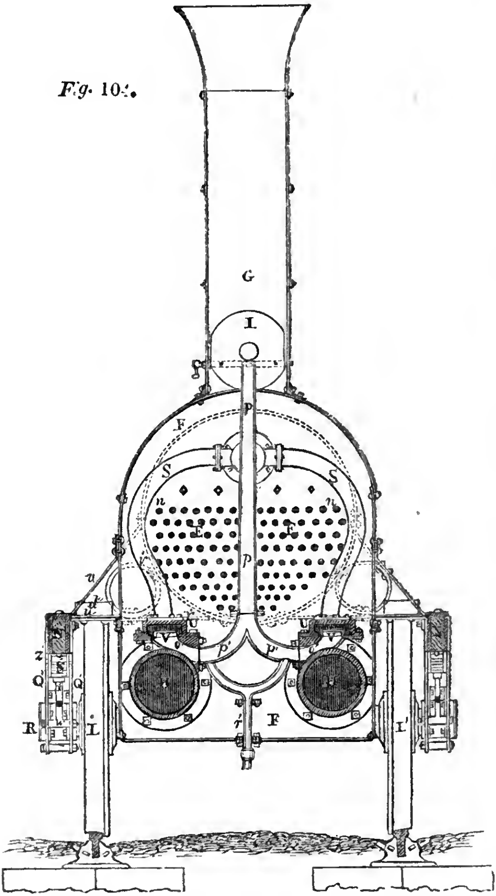
*Fig.* 103.




ELEVATION OF THE FOREMOST END OF THE ENGINE.

*Fig.* 102. is a transverse section of the engine made through the fire-box, showing the tubes, the grate bars, and the casing of water surrounding the fire-box, also the bolts or stays by which the fire-box is strengthened, these stays being secured by nuts or heads outside and inside.

Fig. 102.




CROSS VERTICAL SECTION OF ENGINE THROUGH THE SMOKE-BOX.

*Fig.* 103. is a view of the foremost end of the engine next the chimney :—W W are the ends of the cylinders; T T′ are circular cushions or buffers, which react against spiral springs, and have the effect of relieving the collision when the engine meets another engine or carriage, or encounters any other obstacle.

*Fig.* 104. is a transverse section made through the smoke-box of the engine, showing the ends of the tubes from which the heated air issues, as well as the cylinders H and the blast pipe P.

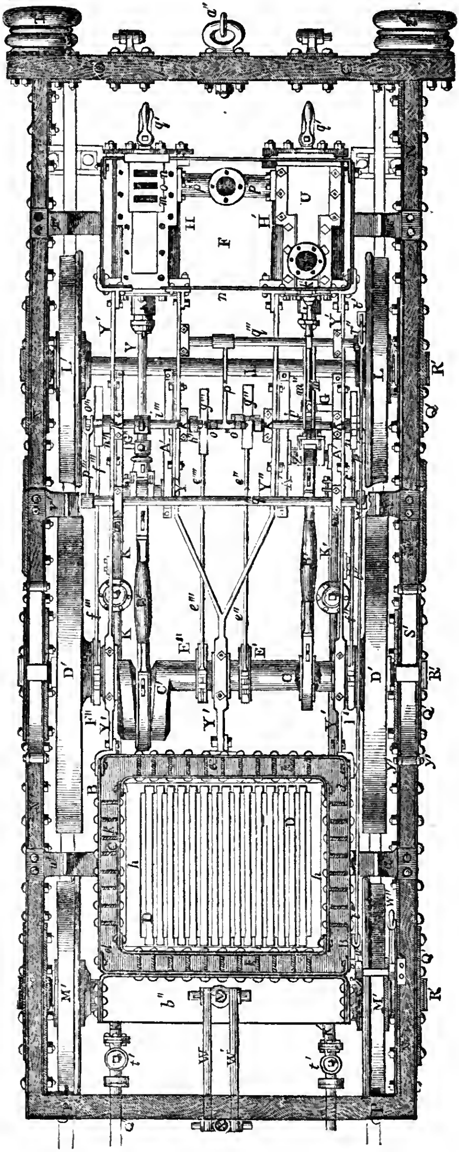
*Fig.* 105. exhibits a plan of the machinery under the boiler:—D′ D′ are the driving wheels; D D, the grate bars; U U, the cylinders; Y, the piston rods; B′, the connecting rods; C′, the cranks; C, the fire-box.

*Fig.* 106. is a longitudinal section, and *fig.* 107. a plan of the tender, where the coke is contained in the space B R″, surrounded by a tank I″, containing the water to feed the boiler. The feed of the boiler is conducted from the tank through a pipe descending downwards in a curved direction, P″ and Q″, to the boiler. A cock is provided at P″, by which the supply of water may be cut off at pleasure.

(343.) *Operation of the locomotive at high speed.*—When the extraordinary speed sometimes imparted to the loads drawn by locomotive engines on the English railways is considered, it will not be uninteresting to explain what operations the machinery of the engine must perform in order to accomplish such effects.

Let us take the example, not uncommon, of a train of coaches carried upon a railway, at a rate of sixty miles per hour. Assuming, as in a former example, that the circumference of the driving wheel measures $26\frac{4}{10}$ feet, these wheels, as already explained, will revolve one hundred times in passing over half a mile, and therefore two hundred times in passing over a mile. The speed of sixty miles an hour is that of a mile per minute. The driving wheels will, therefore, revolve two hundred times per minute. But it has been already explained that to produce one revolution of the wheels each piston is moved once backwards and forwards in each cylinder, and each cylinder must be twice filled with steam from the boiler, and that steam must be twice discharged from each cylinder through the blast pipe. It follows that to accomplish the speed above mentioned, the

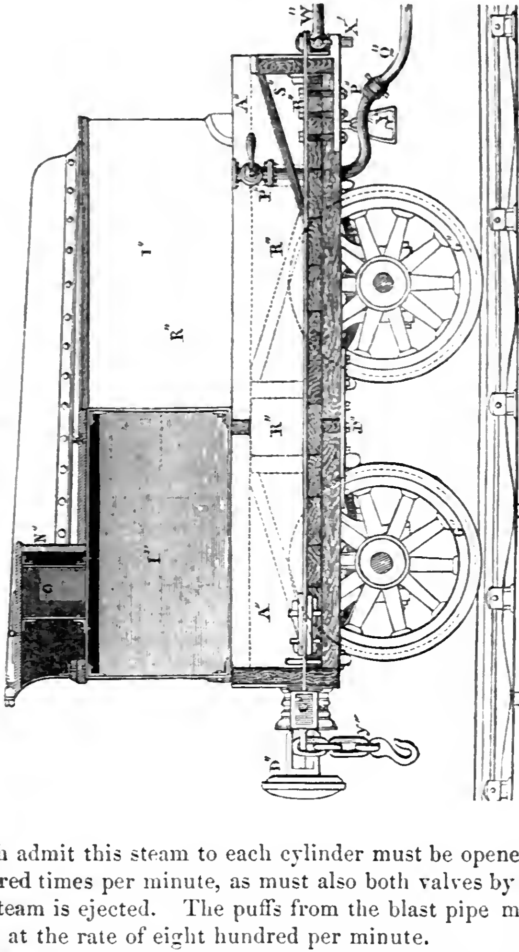
*Fig.* 105.



PLAN OF THE WORKING MACHINERY OF A LOCOMOTIVE ENGINE.

boiler must supply to the cylinders eight hundred measures of steam of the requisite pressure per minute. The valves

Fig. 106.



LONGITUDINAL VERTICAL SECTION OF THE TENDER

which admit this steam to each cylinder must be opened four hundred times per minute, as must also both valves by which the steam is ejected. The puffs from the blast pipe must be made at the rate of eight hundred per minute.

If we assume that the contents of each cylinder is one cubic foot and a quarter, then the boiler must supply to the cylinder per minute 1000 cubic feet of steam. If this steam be assumed to have a pressure of 50 lbs. per square inch, then one cubic foot of water evaporated will produce about 500

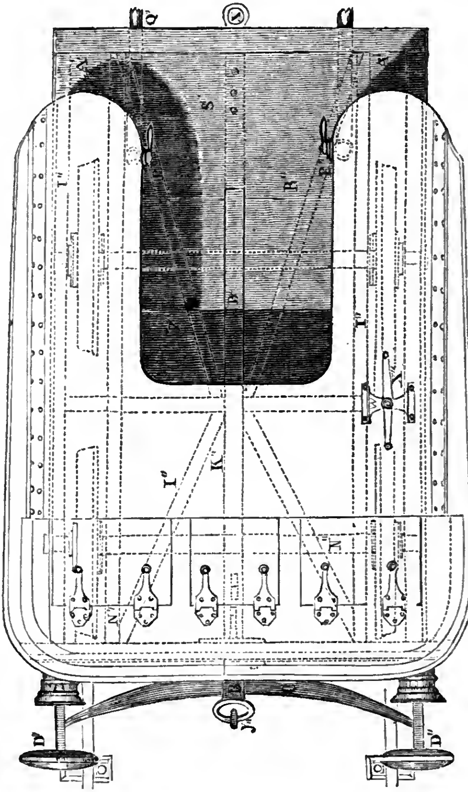


Fig. 107.

PLAN OF THE TENDER.

cubic feet of such steam; and consequently, to supply 1000 cubic feet of steam per minute to the cylinders, the boiler must evaporate 2 cubic feet of water per minute, or 120 cubic feet per hour. This is a rate of evaporation which would correspond to a stationary boiler of a nominal power of 120 horses.*

* For various details of the performance of locomotive engines in England and on the Continent, see "Railway Economy."

## CHAPTER IV.

### RETROSPECT OF THE PROGRESS OF THE LOCOMOTIVE ENGINE.

It must not be imagined that the locomotive engine attained all the efficiency indicated by the arrangements above described, without passing through a long succession of abortive trials, and encountering many failures. A short retrospect of these will not be without interest.

(344.) *Locomotive of Cugnot*, 1770. — So far back as the year 1770, a French engineer, Nicholas Cugnot, constructed a small carriage, which was moved by the force of steam.

This experiment attracted much attention at the moment, and the government of that day, hoping to render it available for the purpose of war, supplied the engineer with means to carry his invention into practice on a large scale.

Experiments were accordingly made at the arsenal of Paris, which were to a certain extent successful; but as the machinery in question was not worked on a railway, sufficient means of governing the direction of its motion were not provided, and it ran against an obstacle by which it was deranged and broken. The project was then abandoned as impracticable. The original machine, which the French claim to be the patriarch of locomotives, is still preserved in the museum of the Conservatoire des Arts et Métiers.

(345.) *Locomotive of Trevithick and Vivian*, 1804. — The first practical locomotive, however, which is recorded as having been brought into operation, was constructed on the railway at Merthyr Tydvil, in South Wales, by Messrs. Trevithick and Vivian, in 1804. In this machine, the piston rod was made to work cranks, which gave revolution to two cogged wheels: these worked in others, by which their motion was communicated finally to cogged wheels fixed on the axle of the hind wheels of the carriage, by which this axle was kept in a state of revolution. The hind wheels being fixed on the axletree, and turning with it, were caused to revolve; and so long as the weight of the carriage did not exceed that which the friction of the road was capable of propelling, the carriage would thus be moved forwards. On this axle was placed a fly-wheel to continue the rotatory motion at the termination of each stroke. The fore wheels are described as being capable of turning like the fore wheels of a carriage, so as to guide the vehicle. The projectors appear to have contemplated, in the first instance, the use of this carriage on common roads: but that notion seems to have been abandoned, and its use was only adopted on the railroad before mentioned. On the occasion of its first trial, it drew after it as many carriages as contained ten tons of iron, a distance of nine miles; which stage it performed without any fresh supply of water, and travelled at the rate of five miles an hour.

(346.) *Singular error respecting the adhesion with the rail.* — It is a singular fact in the history of this invention, that considerable time and great ingenuity were vainly expended in attempting to surmount a mechanical difficulty, which a single experiment would have proved to have been purely imaginative. This obstacle, nevertheless, retarded for years the progress of the invention.

It has been already explained, that all carriages propelled by a moving power, must have an adequate point of reaction for that power; and that, in the present locomotive engine, this point of reaction is the point where the driving wheels rest upon the rails. The early inventors of locomotives assumed, without subjecting the question to the test of experiment, that the adhesion of the wheel to the rail was so trifling as to supply no adequate purchase for the propulsion of the load; and that force applied to turn the wheels would cause them to slip round in contact with the rail without impelling the carriage.

It is singular that it should never have occurred to the many ingenious persons who for several years were engaged in such experiments and speculations, to ascertain by experiment the actual amount of adhesion in any particular case between the wheels and the road.

(347.) *Trevithick's expedient to supply the supposed want of adhesion.* — To remedy this imaginary difficulty, Messrs. Trevithick and Vivian proposed to make the external rims of the wheels rough and uneven, by surrounding them with projecting heads of nails or bolts, or by cutting tranverse grooves on them. They proposed, in cases where considerable elevations were to be ascended, to cause claws or nails to project from the surface during the ascent, so as to take hold of the road.

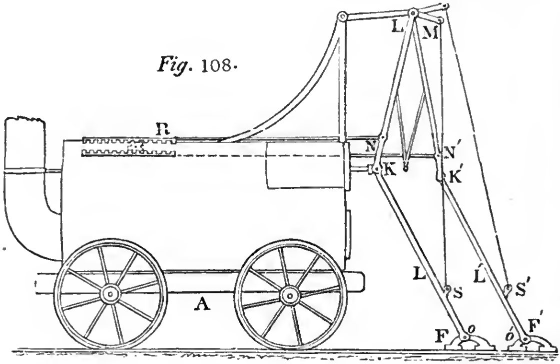
(348.) *Blinkensop's locomotive*, 1811. — In seven years after the construction of the first locomotive engine by these engineers, another was constructed by Mr. Blinkensop, of Middleton Colliery, near Leeds. He obtained a patent in 1811, for the application of a rack rail. The railroad thus, instead of being composed of smooth bars of iron, presented a line of projecting teeth, like those of a cog-wheel, which stretched along the entire distance to be travelled. The wheels on which the engine rolled were furnished with corresponding teeth, which worked in the teeth of the railroad, and in this way produced a progressive motion in the carriage.

(349.) *Chapman's*, 1812.—The next contrivance for overcoming this fictitious difficulty was that of Messrs. Chapman, who, in the year 1812, obtained a patent for working a locomotive engine by a chain extending along the middle of the line of railroad, from the one end to the other. This chain was passed once round a grooved wheel under the centre of the carriage; so that, when this grooved wheel was turned by the engine, the chain being incapable of slipping upon it, the carriage was consequently advanced on the road. In order to prevent the strain from acting on the whole length of the chain, its links were made to fall upon upright forks placed at certain intervals, which between those intervals sustained the tension of the chain produced by the engine. Friction-rollers were used to press the chain into the groove of the wheel, so as to prevent it from slipping. This contrivance was soon abandoned, for the very obvious reason that a prodigious loss of force was incurred by the friction of the chain.

(350.) *Walking engine*, 1813.—The following year, 1813, produced a contrivance of singular ingenuity, for overcoming the supposed difficulty arising from the want of adhesion between the wheels and the road. This was no other than a pair of mechanical legs and feet, which were made to walk and propel in a manner somewhat resembling the feet of an animal.

A sketch of these propellers is given in *fig.* 108. A is the carriage moving on the railroad, L and L′ are the legs, F and F′ the feet. The foot F has a joint at *o*, which corresponds to the ankle; another joint is placed at K, which corresponds to the knee; and a third is placed at L, which corresponds to the hip. Similar joints are placed at the corresponding letters in the other leg. The knee-joint K is attached to the end

*Fig.* 108.




of the piston of the cylinder. When the piston, which is horizontal, is pressed outwards, the leg L presses the foot F against the ground, and the resistance forces the carriage A onwards. As the carriage proceeds, the angle K at the knee becomes larger, so that the leg and thigh take a straighter position; and this continues until the piston has reached the end of its stroke. At the hip L there is a short lever L M, the extremity of which is connected by a cord or chain with a point S, placed near the shin of the leg. When the piston is pressed into the cylinder, the knee K is drawn towards the engine, and the cord M S is made to lift the foot F from the ground; to which it does not return until the piston has arrived at the extremity of the cylinder. On the piston being again driven out of the cylinder, the foot F, being placed on the road, is pressed backwards by the force of the piston rod at K; but the friction of the ground preventing its backward motion, the reaction causes the engine to advance; and in the same manner this process is continued.

Attached to the thigh at N, above the knee, by a joint, is a horizontal rod N R, which works a rack R. This rack has beneath it a cog-wheel. This cog-wheel acts in another rack below it. By these means, when the knee K is driven *from* the engine, the rack R is moved *backwards;* but the cog-wheel acting on the other rack beneath it, will move the latter *in the contrary direction.* The rack R being then moved *in the same direction with the knee* K, it follows that the other rack will always be moved *in a contrary direction.* The lower rack is connected by another horizontal rod with the thigh of the leg L F′, immediately above the knee at N′. When the piston is forced *inwards,* the knee K′ will thus be forced *backwards;* and when the piston is forced *outwards,* the knee K′ will be drawn *forwards.* It therefore follows, that the two knees K and K′ are pressed *alternately backwards* and *forwards.* The foot F′, when the knee K′ is drawn forward, is lifted by the means already described for the foot F.

It will be apparent, from this description, that the piece of mechanism here exhibited is a contrivance derived from the motion of the legs of an animal, and resembling in all respects the fore-legs of a horse. It is however to be regarded rather as a specimen of ingenuity than as a contrivance of practical utility.

(351.) *Sufficiency of the adhesion discovered.*—It was about this period that the important fact was first ascertained, that the adhesion or friction of the wheels with the rails on which they moved was amply sufficient to propel the engine, even when dragging after it a load of great weight; and that the progressive motion would be effected without any slipping of the wheels. This showed the inutility of all the contrivances for giving wheels a purchase on the road, such as racks, chains, feet, &c. The experiment by which this was determined appears to have been first tried on the Wylam railroad; where it was proved, that when the road was level, and the rails clean, the adhesion of the wheels was sufficient, in all kinds of weather, to propel considerable loads.

(352.) *First locomotives used in the collieries.* — After it was discovered that the adhesion of the driving wheels with the road was more than sufficient for the purpose of propulsion, locomotive engines of a comparatively rude form were constructed for the purpose of drawing the coal waggons upon railways in the neighbourhood of the collieries. These machines moved at a slow rate, but for their purpose were sufficient. A tube of four or five inches diameter formed the flue, and being carried through the boiler from one end to the other, was recurved and brought back to the smoke funnel placed over the fire-box.

(353.) *First locomotives placed on the Liverpool and Manchester Railway.* — When the railway between Liverpool and Manchester was brought into operation, the engines placed upon it resembled more closely those now in use. The "Rocket," the first of these engines, was limited in weight by the conditions imposed by the company. The boiler was only six feet in length; it was traversed by twenty-four tubes three inches in diameter. In the fire-box only six square feet of surface were exposed to the action of the radiant heat.

As I have already stated, the tubes which perform the office of flues were, as the engine was improved, augmented in number, and diminished in diameter. In the improved engines above described their number varied from 125 to 150, their internal diameter being $1\frac{5}{8}$ths of an inch, and the space between tube and tube being only three quarters of an inch.

The practical inconvenience which limits the size of the tubes is their liability to become choked by cinders and ashes, which get wedged in them when they are too small, and thereby obstruct the draft and diminish the evaporating power of the boiler. The tubes now in use, of about an inch and a half internal diameter, not only require to be cleared of the ashes and cinders, which get fastened in them after each journey, but it is necessary throughout a journey of any length, that the tubes should be picked and cleaned by opening the fire door at convenient intervals.

The first engines used upon the Liverpool and Manchester Railway rested on four wheels, one pair of which was driven by the pistons, and were thence called the *driving* wheels. Experience indicating the advantage of constructing engines of increased power and weight, it was afterwards resolved to distribute the weight upon six wheels. In some cases one pair only of these were used as driving wheels, but in other cases, especially with engines employed to carry heavy loads of merchandise at low velocities, two pair of the wheels were used as drivers, being coupled together in such a manner that the engine imparted motion to both pairs simultaneously. The advantage of this arrangement was that a greater purchase was obtained for the impelling power, inasmuch as it acted upon the points of contact of both pairs of wheels with the rails.

In the earlier engines the cylinders were placed outside the wheels, and impelled them by the means already described. Afterwards they were transferred to a position under the boiler and between the wheels, and made to act on a double cranked axle, as already described. The advantages claimed for this combination were,

1st. That the impelling power, being placed nearer to the centre of gravity of the engine, produced less lateral strain in its action.

2d. That the cylinders were less exposed to the cold air in passing along the road, and therefore that there was less waste of heat by cooling; and,

3dly. That the cylinders being buried in the smoke box at the foremost end of the engine, were kept warm, so as to produce a further economy of heat.

The obvious disadvantage attending the arrangement was the necessity of constructing on the axle of the driving wheels two cranks, thus breaking the axle at two points near its centre, and the consequent difficulty of fabricating such an axle with sufficient strength and soundness.

After having been almost exclusively used for many years, this arrangement has been lately, in many cases, laid aside, and the cylinders are now again very frequently placed outside the wheels.

## CHAPTER V.

### RAILWAY GRADIENTS.

(354.) *There is a certain speed at which a locomotive produces the greatest effect.* — A steam engine, when applied to transport, is, like an animal, endued with a certain amount of strength or power, by which it is enabled to transport a certain load at a certain velocity. The resistance which it can oppose may be varied within certain practical limits, but in departing from the average more or less disadvantage is incurred in the application of the power. This is the same with the animal. There is a certain load and a certain speed which can be exerted, and which, if exerted, will produce the most profitable result of the animal's labour. The load may be diminished and the speed increased, or the load may be increased and the speed diminished, and the animal will still work with a certain useful result, but this useful result will be diminished in a rapid proportion by a departure from that average which is best adapted to the animal power.

The same observation may, with equal truth, be applied to the steam engine. But the practical limits of the variation of its power, and the injurious effects arising from such variation, are more serious than in the case of animal power; nor is it wonderful, considering who made the one machine, and who made the other, that we should find this comparative imperfection.

(355.) *The railway must be adapted to the limit within which the engine can vary its speed.* — It is evident, therefore, that a road upon which steam power is intended to work, ought, in its construction, to be adapted to those limits within which such power can act advantageously, otherwise a waste of power must be incurred.

If, for example, the resistance produced on one part of the road be many times greater than the resistance produced on other parts, the steam engine intended to work upon it must be constructed so as to be capable of working against this excessive resistance. On the other parts of the road such an engine would be working under its power, and consequently to disadvantage, unless, indeed, a separate engine or a separate power were appropriated to work upon such part of the road where such an excessive resistance is to be encountered.

(356.) *Necessity of ascertaining the variation of the resistance.* — Hence it will be perceived how very important an element in the construction of railroads the resistance encountered in the traction of loads upon them must be.

(357.) *Prevalent ignorance of it.* — Yet it is a strange fact in the history of the progress of railways that these lines of communication had not only been constructed but worked for many years before any definite experiments were made by which the circumstances and conditions affecting the resistance opposed by the load to the tractive power were determined; on the contrary, most erroneous notions on this subject prevailed, and not only were engines built upon such fallacious data, but railways of great extent and involving an immense expenditure of capital, were constructed upon them.

(358.) *Erroneous estimates of it.* — For several years after the Liverpool and Manchester railway was brought into operation, it was universally assumed among engineers that the resistance opposed to the tractive power upon railroads was the same at all velocities. No one was ignorant that the atmosphere must oppose more or less resistance to bodies moving through it, but it was considered that the amount of this resistance in the case of railways was inconsiderable compared with other sources of resistance to the tractive power; and that in the practical calculations necessary to determine the power of locomotive engines, it might be wholly disregarded, or at least, that a small allowance for it, made in the average speed of the trains, would be amply sufficient for all practical purposes.

(359.) *Causes of resistance to the tractive power.* — The sources of resistance which a locomotive engine has to overcome, exclusive of that of the atmosphere when it draws a load upon a level line, are —

1st. The resistance produced by the friction of the wheels in their boxes;

2dly. The resistance produced by the rolling motion of the wheels upon the rails; and

3dly. The friction and resistance peculiar to the moving parts constituting the mechanism of the engine.

(360.) *Their estimated amount.* — It was generally estimated that the gross amount of these resistances was about the two hundred and fiftieth part of the gross weight of the load drawn. Some engineers estimated it at the two hundred and twentieth, and others at the three hundred and thirtieth part; but a two hundred and fiftieth part of the gross load may be fairly taken as a mean between all the various estimates of that day.

Assuming such an estimate to be correct, it would follow that a railway train placed upon a declivity falling at the rate of one foot in two hundred and fifty, would, when once put in motion, descend spontaneously without any moving power by its tendency to move downwards in virtue of gravity.

(361.) *Erroneous doctrines deduced from this wrong estimate.* — It was therefore generally assumed, that, in laying out railways, no acclivities ought to be allowed, in general, which would exceed from sixteen to twenty feet per mile, and that even these ought to be avoided where it was practicable to do so.

(362.) *The gradients and graduation of railways.* — The acclivities, according to which railways were laid out, came to be called by the name of *gradients*, and the line was said to be *graduated* at the rate of so many feet per mile, meaning thereby that the prevailing acclivities were regulated according to that rate of inclination.

It was held by some engineers, that gradients, even within the limits above mentioned, were so disadvantageous, especially on lines where great speed of transport was contemplated, that flat gradients or a nearly level line should be obtained at almost any practicable cost.

(363.) *Method of concentrating the ascent to obtain a generally level line.* — Where the natural form of the country through which a line of railway was carried required an ascent from one general level to another, it was held by some engineers that it was more advisable to concentrate the ascent at one place, making the remainder of the line nearly level, and effecting the ascent by one steep inclined plane instead of distributing it more equally over the line by a series of more gentle gradients. Under such a system, the single inclined plane into which the ascent would be concentrated, and which would form as it were a *step* from the lower to the higher level, would be worked by stationary engines and ropes, or by some other exceptional power.

(364.) *The question of gradients raised in parliamentary committee.*—These two systems were brought into direct contest when the project for constructing the London and Southampton railway, since called the *South Western*, was brought forward.

When the company applied to parliament for its sanction in 1836, it was opposed by the Great Western Railway Company, and one of the grounds of opposition turned upon the question of gradients. The Great Western railway was laid out so as to be in general nearly a dead level, with the exception of a single inclined plane of considerable length and steepness, situate near Box hill, in the neighbourhood of Bath: it was proposed at that time to work this inclined plane by a stationary engine and rope.

The Southampton line, on the other hand, was laid out so as to undulate with a series of gradients, the prevailing acclivity of which was one in two hundred and fifty, or about twenty feet a mile.

The great contest on this question took place before a committee of the House of Lords.

I was employed on this occasion by the London and Southampton Company, for the purpose of investigating, by such means as theory and experiment might supply, the actual effects of such an undulating line upon the moving power.

(365.) *Arguments of the partisans of the Great Western line.* — It was maintained by the partisans of the flat gradients of the Great Western, that the Southampton line must be worked under disadvantages so enormous, owing to the resistance which would be produced by its gradients, that it would be expedient, if not indispensable, to avoid such gradients altogether, by taking a circuitous course, rendering the line longer, but thereby securing a nearly level line, like the Great Western. In short, a portion of the Great Western itself was to form a part of such circuitous route; and thus the interests of that company happened, in this case, to fall in with the theory of the engineer.

(366.) *Dr. Lardner advocates the South Western system.* — At the time of this investigation a sufficient extent of railway had not been brought into operation to afford the means of any extensive series of experiments, to determine directly the manner in which the resistance of railway trains to the moving power was governed, and especially how it was affected by gradients.

(367.) *Demonstrates the compensating effect of certain limited gradients.* —I was therefore compelled, in the investigation I had undertaken, to depend chiefly on theory. I maintained, however, as will be seen by reference to the printed parliamentary reports, that upon the undulating line there would be a compensating power in descending the acclivities, which would, to a considerable extent, balance the disadvantages in ascending them; that in a journey to and fro, on such a line, the total expenditure of power would not be much greater than upon a dead level; that the average speed would not be much less, although in the course of the complete journey it would be much more variable; that on the ascending gradients the engine would have to overcome a greater resistance, to expend more power, and to move slower, but that this expenditure of power and loss of time would be, in a great measure, made up in the descending gradients, where the resistance would be less considerable, and the speed greater.

(368.) *The partisans of the Great Western fail.* — This *theory*, as it was then not unjustly called, for as yet it could not have been brought to the test of experimental verification, was stigmatised as altogether erroneous, was fiercely attacked, and covered with ridicule; nevertheless, it prevailed with parliament, the bill for the South Western Company was passed, and the line was finally constructed, and worked with the success which is well known.

(369.) *The principle of compensating gradients established by experiment.* — While these disputes were in progress, the practical construction of railways was continued, and, at a later period, in the year 1838, an opportunity presented itself to me of submitting the question of the resistance to railway trains to experiment upon a large scale.

I induced the British Association to appoint a committee, and to appropriate funds for a series of experiments on this subject. It happened at the same time that a question raised by some of the principal railway companies rendered a similar inquiry necessary, and I was appointed by them to conduct an extensive series of experiments, and, having likewise the direction of the inquiry instituted by the British Association, I was enabled to obtain means of experimenting which would have been otherwise unattainable.

(370.) *Method of measuring the resistance to the tractive power.* — The first object was to obtain an efficient means of measuring the resistance which a railway train, moving with considerable speed, opposed to the tractive power.

Mechanical instruments interposed between the engine and the train, by which the force of traction might be measured, were found quite inapplicable, owing to the continual inequalities of the resistance. After various failures in the application of means such as those, I resolved on adopting gravity itself as the measure of the resistance.

The manner in which I applied it depended on the following mechanical principle.

It is demonstrated in mechanics, that if a body impelled or driven by a moving force is maintained at a uniform velocity, then the energy of the moving force must be precisely equal to the resistance which the body opposes to it. If the motion be accelerated, that is to say, if the speed of the body moved be continually increased, then the energy of the moving force must be greater than the resistance of the body moved; and, finally, if the speed of the body moved be continually diminished, then the energy of the moving force must be less than the resistance of the body moved.

From this principle it is clear that if we possess any means of knowing the exact measure of the moving force, and can observe at the same time the velocity of the body moved, we can always determine, by the uniformity of the velocity, the amount of the resistance, for the resistance will be in such case equal to the moving force.

For example, if a railway train descend an inclined plane, impelled by no other force than its tendency to move by gravity down the plane, and in its descent is found to have a perfectly uniform velocity, it is certain from the principle above explained that the resistance which the train offers is exactly equal to that portion of gravity which impels the train down the plane. If such a plane fall at the rate of one foot in one hundred, then the resistance of the train would be the one hundredth part of its weight.

It follows, therefore, that such a train moved on a level *with the same uniform velocity* would require a tractive force equal to the one hundredth part of the gross weight of the train.

(371.) *Method of experimenting.*—To apply this principle experimentally, it was necessary to select among the railways in operation a number of inclined planes having different declivities, and to start from the summit of such planes with a sufficiently great speed.

This was accomplished in the following manner:—

The train being placed at some distance from the summit of the plane, was impelled by an engine placed behind it towards the summit, and arriving there was deserted by the engine, and allowed to go down the plane with no other impelling force than the gravity of the descent.

In order to observe with accuracy the speed of the motion, on which, in this case, every thing depended, the plane was previously staked out with posts at intervals of a hundred yards. The time of passing each post was accurately taken by two observers, each furnished with a watch beating seconds, so that with a little practice it was not difficult to bisect a second so as to take to half a second the moment of time at which the train passed each post, the two observers checking each other.

(372.) *Remarkable result of the experiments.* — This arrangement being made, a train of coaches, properly loaded, was started at high velocities, and descended down a variety of inclined planes. The result was as remarkable as it was unexpected.

Instead of being perpetually accelerated down these declivities, as it should have been, according to all the notions previously received, it was found that the train was *gradually retarded*, that the interval of passing over every successive hundred yards was greater as the train proceeded, until at length it attained a certain uniform speed, with which it moved down the remainder of the declivity with all the uniformity of the hand of a clock.

This uniform speed attained by the train was different on different planes, according to their steepness, and also according to the weight with which the trains were loaded. It was also found to vary with the sort of carriages or waggons that composed the train. Thus trucks loaded with iron went down with a greater velocity than passenger coaches; and the velocity of the latter was greater according to the load they carried.

(373.) *All former estimates of resistance proved erroneous.* — All these circumstances suggested at once the conclusion that the principle generally received by engineers, that the resistance to railway trains was independent of the speed, was altogether erroneous, and that, on the contrary, that resistance varied in a very high ratio with the speed of the train. Indeed, it was evident that the chief part of that resistance at high speeds was produced by the atmosphere; but for practical purposes it was not at all material whether it were produced by the atmosphere alone, or by that combined with mechanical causes. It was at all events evident, whatever might be its causes, that it augmented with the speed.

Let us now see how these experiments indicated the actual amount of the resistance, and how they affect the question of high or low gradients on railways.

A train of passenger coaches, weighing forty tons gross, was started down an inclined plane, falling at the rate of one foot in ninety. The speed with which it was dismissed from the summit was about forty miles an hour. As it went down, this speed was gradually diminished, until it was reduced to thirty-one miles an hour. At that rate the train descended to the bottom of the plane with a velocity accurately uniform.

Now the impelling force given to the train in this case was a ninetieth part of its weight, and it consequently followed that such a train, if moved on a level at thirty-one miles an hour, would require a tractive force amounting to a ninetieth part of its weight, or about twenty-five pounds per ton gross.

How much at variance these results were with the doctrine previously received will be understood, when it is remembered that the resistance given by this doctrine for such a train was a two hundred and fiftieth part of the load, or about *nine pounds a ton !*

By similar experiments made with a coach train of fifty tons weight, it was found that the resistance which it opposed to a tractive power when moved at twenty-two and half miles an hour, was the two hundreth part of the weight moved, or eleven and a half pounds a ton; at thirty-one and a half miles an hour, it was the one hundred and fiftieth part of the weight, or $17\frac{6}{10}$ lbs. per ton; and at forty-four miles an hour, it was the one hundreth part of its weight, or $22\frac{4}{10}$ lbs. per ton.

(374.) *Resistance proved to increase in a high ratio with the speed.* — It appears then, from these experiments, that, in the case of the particular train on which they were made, the resistance was nearly doubled by doubling the speed.

In the case, however, of other experiments made on the same principle with other passenger trains, it was found that the resistance increased in a considerably higher ratio than the speed; while, on the other hand, experiments made with waggons carrying heavy merchandise showed that the resistance did not increase in so high a ratio as the speed. But in all cases, without exception, there was found to be an augmentation of resistance, more or less considerable, with the augmentation of speed.

(375.) *Principle of compensation more fully confirmed.*— The principle of compensation, which I had previously advanced only upon theoretical principles before the House of Lords, was confirmed and established practically by the results of these experiments.

It was evident, not only from the particular experiments to which I have here adverted, but from many others made under a great variety of circumstances, that the resistance opposed by a train to the tractive power increased, in general, in a high ratio with the speed. It is true that the exact arithmetical expression of this ratio was not obtained, nor, indeed, was it possible, seeing that it was different with different sorts of trains. Thus, in a light coach train of about forty tons, the increase of resistance was very considerable with the increase of velocity. I have explained that such a train moving upon a level, at thirty-one miles an hour, produced a resistance equal to a ninetieth part of the load, or about twenty-five pounds a ton; while another coach train, weighing fifty tons, and moving at forty-four miles an hour, produced a resistance equal to the one hundreth part of the load, or $22\frac{4}{10}$ lbs. per ton.

It was thus found, in general, as might indeed have been expected, that the more heavily laden a train is, the less will be the resistance, in proportion to its weight, at a given velocity.

(376.) *Resistance increases nearly as velocity.*—It appeared, from a variety of experiments, that by varying the velocity of an ordinary coach train, the resistance it opposed to the tractive power was very nearly in the proportion of the velocity.

Thus in the case already cited of a coach train weighing fifty tons, moved successively with the velocities of $22\frac{1}{2}$, 30, and 44 miles an hour, the resistances were, respectively, $11\frac{1}{2}$ lbs, $17\frac{6}{10}$ lbs., and $22\frac{4}{10}$ lbs. per ton. The latter numbers do not vary much from the proportion of the former.

(377.) *Experimental trip to verify the principle of compensation.*—In order to submit this principle of compensation to a still more decisive practical test, and to establish it by a sort of "experimentum crucis," I resolved to make a trip of considerable length, with a heavy load, upon an undulating railway, observing, and recording with the last degree of accuracy, the varying speed of the train in ascending and descending the several gradients; and also observing the corresponding rate of evaporation of the boiler and the consumption of fuel in the furnace.

A coach train weighing eighty tons was accordingly prepared, and a trip was made from Liverpool to Birmingham, and back from Birmingham to Liverpool, over a line of railway 95 miles in length, which gave a total distance travelled of 190 miles. The gradients upon this line have a variety of steepness, from a level to thirty feet a mile. The experiment took place in July, 1839, the train being propelled by the engine called the Hecla.

The following table shows the uniform speeds with which the train ascended and descended the several gradients, and also the mean of the ascent and descent in each case, as well as the speed upon the level parts of the line: —

| Gradient. | Speed. | | Mean. |
|---|---|---|---|
| | Ascending. | Descending. | |
| *One in* | *Miles per Hour.* | *Miles per Hour.* | |
| 177 | 22·25 | 41·32 | 31·78 |
| 265 | 24·87 | 39·13 | 32·00 |
| 330 | 25·26 | 37·07 | 31·16 |
| 400 | 26·87 | 36·75 | 31·81 |
| 532 | 27·35 | 34·30 | 30·82 |
| 590 | 27·37 | 33·16 | 30·21 |
| 650 | 29·03 | 32·58 | 30·80 |
| Level - | - - | - - | 30·93 |

From this table it is apparent that the gradients do possess the compensating power with respect to speed already mentioned. The discrepancies existing among the mean values of the speed are only what may be fairly ascribed to casual variations in the moving power. The experiment was made under favourable circumstances: little disturbance was produced from the atmosphere; the day was quite calm. In the same experiment it was found that the water evaporated varied very nearly in proportion to the varying resistance, and the amount of that evaporation may be taken as affording an approximation to the mean amount of resistance. Taking the trip to and from Birmingham over the distance of 190 miles, the mean evaporation per mile was 3·36 cubic feet of water. The volume of steam produced by this quantity of water will be determined approximately by calculating the number of revolutions of the driving wheels necessary to move the engine one mile. The driving wheels being 5 feet in diameter, their circumference was 15·7 feet, and consequently in passing over a mile they would have revolved 336·3 times. Since each revolution consumes four cylinders full of steam, the quantity of steam supplied by the boiler to the cylinders per mile will be found by multiplying the contents of the cylinder by four times 336·3, or 1345·2. The cylinders were $12\frac{1}{2}$ inches diameter, and 18 inches in length, and consequently their contents were 1·28 cubic feet for each cylinder: this being multiplied by 1345·2 gives 1721·86, or 1722 cubic feet of steam per mile. It appears, therefore, that supposing the priming either nothing or insignificant, which was considered to be the case in these experiments, 3·36 cubic feet of water produced 1722 cubic feet of steam, of the density worked in the cylinders. The ratio, therefore, of the volume of the steam to that of the water producing it, was 1722 to 33·6, or 51·25 to 1. The pressure of steam of this density would be 54·5 pounds per square inch. Such, therefore, was the limit of the average total pressure of the steam in the cylinders. In this experiment the safety-valve of the boiler was screwed down to sixty pounds per square inch above the atmospheric pressure, which was therefore the major limit of the pressure of steam in the boiler; but as the actual pressure in the boiler must have been less than this amount, the difference between the pressure in the cylinder and boiler could not be ascertained. This difference, however, would produce no effect on the moving power of the steam, since the pressure of steam in the cylinders obtained by the above calculation is quite independent of the pressure in the boiler, or of any source of error except what might arise from priming. The pressure of 54·5 pounds per square inch, calculated above, being the total pressure of the steam on the pistons, let 14·5 pounds be deducted from it, to represent the atmospheric pressure against which the pistons act, and the remaining forty pounds per square inch will represent the whole available force drawing the train and overcoming all the resistances arising from the machinery of the engine, including that of the blast pipe. The magnitude of a $12\frac{1}{2}$ inch piston being 122·7 square inches, the total area of the two pistons would be 245·2 square inches, and the pressure upon each of forty pounds per inch would give a total force of 9816 lbs. on the two pistons. Since this force must act through a space of three feet, while the train is impelled through a space of 15·7 feet, it must be reduced in the proportion of 3 to 15·7, to obtain its effect at the point of contact of the wheels upon the rails: this will give 1875 pounds as the total force exerted in the direction of the motion of the train. The gross weight of the train being eighty tons, including the engine and tender, this would give a gross moving force along the road of about 23·4 pounds per ton of the gross load, this force being understood to include all the resistances due to the engine.

It appears from this, that a coach train such as the above, weighing eighty tons and moving at the rate of thirty-one miles an hour on a level, would offer a resistance to the moving power equal to a ninety-fifth part of the load; and consequently, that an inclined plane, the ascent of which would double the resistance on the level, would be one which would ascend at the rate of one to ninety-five instead of one in two hundred and fifty, as had been previously supposed and assumed.

The results of this series of experiments had not long become known, when various circumstances were brought to light which were before unnoticed, and which abundantly confirmed them. Among these may be mentioned the fact, that in descending the Madeley plane on the North Western railway, which falls for above three miles at the rate of twenty-nine feet a mile, the steam had never been cut off. But, on the other hand, to maintain the necessary speed in descending, the power of the engine is always necessary. As this plane greatly exceeds that which would be sufficient to cause the free motion of the train down it, the power of the engine expended in descending it, besides all that part of the gravitating power of the plane which exceeds the resistance due to friction and other mechanical causes, must be worked against the atmosphere.

(378.) *Series of experiments proving that the resistance at a given velocity depends mainly on the volume of the train.* —That part of the resistance opposed by a railway train to the tractive power, which is properly called *friction*, arises altogether from the rolling motion of the tires of the wheels upon the rails, and from the revolution of the axles of the wheels in their boxes.

This resistance is, according to all the established rules of mechanics, the same, whatever be the speed; and from the experiments which I have already alluded to, it follows that it bears a very small proportion indeed to the total resistance at any considerable velocity.

The results of the experiments showed, that with different trains, and on different lines, and on different parts of the same line, it was subject to considerable variations.

This, however, was just what ought to have been expected. That part produced by the rolling of the wheels on the rail would vary with the condition of the road, and that part produced by the revolution of the axle in its bearings would vary with the condition of the fittings and of the lubrication. But although variable, the total amount of this proportion of the resistance was at most so small compared with the whole, that the uncertainty, or rather the irregularity, to which it is subject, is of comparatively small importance.

According to my own experiments, confirmed by those of M. de Pambour, it may be assumed that in ordinary cases these sources of resistance do not amount to more than the four hundredth part of the load, or about five pounds per ton.

The other portion of the resistance, which augments in a high ratio with the speed, and which depends upon the effect of the atmosphere on the volume of the train, constitutes the most important subject of enquiry, since at high speeds it forms the chief portion of the resistance to the moving power.

I accordingly instituted, with the assistance of Mr. Edward Woods, and Mr. Hardman Earle, one the engineer, and the other a director of the Liverpool and Manchester railway, a most extensive series of experiments, made with a view to ascertain what were the circumstances in the weight or bulk of the train which affected this resistance.

It had been affirmed that experiments made without placing the engine in front of the train, caused a greater resistance from the air than if the engine had been used, inasmuch as the engine would act as a sort of cut-air or bow, after the manner of the bow of a ship in passing through the water.

I accordingly tested this in several ways. The engine was placed in front of the train, and it was found that it did not produce the effect ascribed to it; but in order to reduce more directly to experiment the question of the shape of the front of the train, I caused a pointed end to be constructed in wood, and to be attached to the foremost carriage, the engine being removed. The train thus presented to the air a very acute wedge. It was found, however, by repeated experiments, that the resistance to the motion of the train was precisely the same whether this pointed wedge was placed upon it, or it were allowed to move with the flat end of the foremost coach presented to the atmosphere.

On the other hand, it was desired to ascertain how far the resistance would be affected by enlarging the flat frontage of the foremost coach. A front was therefore constructed of boards, which extended two feet beyond each side of such coach, and two feet above its roof. The train being impelled with this enlarged frontage, it was again found that no effect whatever was produced upon the resistance. In fine, the train offered precisely the same resistance, whether moved with the flat end on the foremost carriage, or with the pointed wedge, or with the enlarged flat frontage last mentioned.

It has been suggested that the resistance of the atmosphere would be affected by the form of the hinder surface of the last carriage of the train, inasmuch as when the train was moved with a great speed, a momentary vacuum, or partial vacuum, would be produced behind the train, which removing the atmospheric pressure on that side would augment its effect in front.

Although it was easy to show by theory the fallacy of this, it was thought better to test it by experiment. The pointed end was therefore attached to the back of the last carriage, and the experiments were repeated without the slightest difference in the results.

It had been also suggested that the great resistance which had been found at high speeds, might be produced by the open space between the successive carriages forming the train.

To test this, this space was stopped by canvass extended between every pair of coaches, so that the entire train was converted into one continuous parallelopiped, and the experiment was repeated without variation in the result.

It followed, therefore, that neither the magnitude of the frontage, nor the shape of the frontage, nor the magnitude or shape of the hinder end of the train, nor the space between the successive coaches, had any relation to the resistance produced by the air.

All these results led me to infer that the amount of the resistance depended on the *volume of air displaced by the train*, and that consequently, other things being the same, this resistance would be proportional to the volume of the coaches composing the train.

To test this experimentally, a train of waggons was prepared and loaded with iron, so as to be brought to the weight of passenger coaches carrying their full load. Movable sides, ends, and roofs were made on them, which being erected and put together, gave them the form of passenger coaches; but which also could be taken down and laid flat upon the waggons, so as to reduce the volume of the train to that of the waggons themselves.

The train of waggons thus prepared was submitted to experiment, being moved successively with the sides, ends, and roofs erected, and with the same laid flat on the waggons. The result proved that the resistance was greatly increased when the waggons had the bulk of the coaches compared with its amount when reduced to the form of waggons.

*Thus was established the general principle, that the resistance of the atmosphere to railway trains, other things being the same, depends on the volume or magnitude of the coaches.*

Those who may be curious to examine the details of these experiments, will find them in the published proceedings of the British Association for 1838, page 197; and 1841, page 205.

(379.) *Cause of the rolling and rocking motion of a train at high speed explained.* — A rocking motion from side to side, which is felt in trains moving at very great speed, is often complained of as inconvenient and disagreeable to passengers, and a source of serious alarm and danger. When such an oscillation takes place, the flanges of the wheels strike alternately against the rails right and left; and if they encounter an uneven joint, a weak or defective rail, or a chair imperfectly fixed, or, in a word, any other slight defect, there is a great liability of the wheels escaping from the rails; or if they do not escape, the fracture or other injury they may produce will prepare the place for an accident on the passage of a succeeding train.

The cause most generally assigned for these oscillations felt by railway travellers, and especially those who go by express trains, is usually the flanges having too much play between the rails, and this no doubt has some share in producing it; but I apprehend it arises chiefly from a circumstance which does not appear to have much attracted the attention of engineers, although it was ascertained in the course of the experiments just referred to, and pointed out in more than one report which I then and afterwards published.

From a variety of experiments made with other views, I was led to suspect that in laying down the rails the contractors of the line had not sufficiently attended to the adjustment of the two rails to the same level, nor even to preserve with sufficient precision a uniform level in either rail.

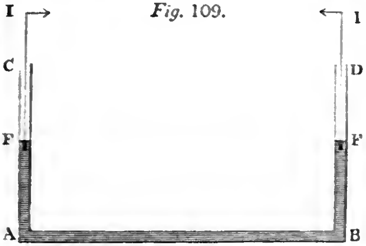
Any irregularity in the level would evidently tend to produce a rocking motion of the carriage much more than would too much play between the flanges; and such irregularity would in fact greatly augment the evil arising from such excess of play. Thus let us suppose that for one hundred feet of a line, the right-hand rail was half an inch above the level of the left-hand rail, and that for the next hundred feet the left-hand was half an inch above the level of the right-hand rail, and so on alternately. It is evident that such an alternate difference of level would give the carriage a tendency to press towards the right and the left by turns; and that in great speeds, when the intervals would be passed over rapidly, the carriage would acquire the oscillating or rocking motion complained of, and that this would be aggravated by the play given to the flanges.

(380.) *Instrument to ascertain the relative level of the rails.* — In order to ascertain how far such a defect prevailed in laying down the rails, I constructed a sort of mercurial level in the following manner. An iron three-quarter inch pipe A B, *fig.* 109., of a length equal to the gauge of the railway, had attached to it two rectangular pipes A C and B D, of the same diameter, placed vertically.

Mercury was poured in so as to fill the horizontal pipe

A B, and a portion of the vertical legs A C and B D. Floats F with index rods I were supported on the surface of the mercury, so that the rise or fall of the column in each leg was rendered visible by the movement of the index I, and could be registered by a point or pencil attached to such index.

*Fig.* 109.




(381.) *Singular results of experiments made with it.*—Proper means were taken of marking the position of the index when the pipe A B was truly level. This instrument was placed across a railway truck, and so arranged that when the wheels of the truck rested on level rails, the index I pointed to the 0 of the scale annexed to it. The truck was then advanced with a very slow motion along the rails, and it was found that the index rose and fell alternately through very considerable spaces, thus proving incontestibly that the rails on the one side and the other were laid down with very considerable deviations from an uniform level.

(382.) *Difference of level of rails produces undulation of train.* — It cannot be doubted, therefore, that this is one of the causes, if not the chief cause, of the oscillating motion.

(383.) *This effect less on the wide gauge.* — It must be observed that the same degree of irregularity in the level of the rails will have a less tendency to produce oscillation, in proportion to the magnitude of the gauge. If one rail be an inch higher than the other, with a gauge of fifty-six and a half inches, the corresponding inclination of a carriage resting upon them will be greater than the same difference of elevation would render it on a gauge of eighty-four inches, in the ratio of eighty-four to fifty-six and a half.

This will explain a fact reported by the gauge commissioners, as a result of their experiments on the wide and narrow gauges. They affirm that they found the movement on the broad gauge at high speeds was more easy and equal than on the narrow gauge.

This is precisely the consequence that would ensue upon the supposition that the same inequalities of level were incident to both gauges, the greater width of the one rendering its tendency to produce oscillation proportionately less than the other.

(384.) *Express trains aggravate the danger.* — The attention of engineers to this circumstance is more imperiously required since the adoption of high speeds with the express trains. When the motion of the carriages is more moderate, the alternate rising and falling on the one side or the other does not fling the mass of the carriages with such dangerous force to the right and to the left, as is the case with the high speeds of the express trains.

(385.) *Cause of the pitching motion.*—I have here noticed only such irregularities of level in the rails as give the carriage an inclined position alternately to the one side and to the other, and thereby produce a rocking motion. There is, however, another modification of irregular levels which produces the pitching motion so often complained of on railways, and which is also attended with considerable danger.

Let us suppose that the alternate elevation and depression of the two rails correspond to each other for any distance along the line, both rails rising and falling together, or nearly so. The carriage will thereby have a motion such as would be produced in passing over a succession of ridges, ascending and descending with an undulating pitching motion. If the elevation and depression be long, this pitching will not be sensible except at high velocities, when the carriage takes but a short time to pass through the hollow, and over the crest of each successive elevation.

At the time at which I made the experiments above mentioned, upon the variations of the levels of the two rails taken transversely, I had no opportunity, nor have I since had, of testing, experimentally, the variations of the level of each rail separately; but an experiment is the less necessary, inasmuch as such variation necessarily follows from the former one.

The small variations of level which thus produce the rolling and pitching motion of carriages, even if they do not exist in well constructed railways, will soon be produced by the unequal subsidence of the substratum under the sleepers, an effect which it is impossible to avoid. After a continuance of rainy weather, when the substratum becomes saturated with water, the effect of the traffic upon it will be to depress the sleeper; and as different effects will be produced at different points of the line, according as they are in cuttings or embankments, and according to the material of the subsoil, the subsidence will necessarily be variable.

The inequalities of the rails thus produced ought to be corrected, from time to time, by raising such sleepers as have subsided, by forcing gravel or some other packing beneath them. It is certain, however, that the uneasy motion of the carriage, by rolling and pitching, and the consequent danger of the engine or carriages escaping from the rails, will be augmented in proportion as these inequalities are increased.

(386.) *The power of the engine varies with the gradients.*— A railway, undulating with gradients of a certain steepness, will require to be worked by engines of greater power than would be required on a dead level, or a railway with very low gradients. In the one case there is nearly a uniform resistance to encounter, and an engine of corresponding power is provided; but in the other case an engine must be used possessing sufficient power to ascend the acclivities with the required speed, being worked below its power on other parts of the line.

In short, in the one case the engine does not require to vary its power by increasing or diminishing it, but in the other case it does, and its capabilities must accordingly be suited to the maximum power required from it.

(387.) *The evaporating power of the engine must be augmented in the ratio of the square of the speed.*— If it be assumed that the resistance to an ordinary coach train, moving on a level, is augmented nearly in proportion of its speed, it follows that the quantity of steam necessary to be supplied to the cylinders per mile, being in the direct ratio of the resistance, must vary also as the speed. A double speed, therefore, will involve the consumption of a double quantity of steam in performing any given journey. But this double quantity of steam must be produced by the boiler in half the time, inasmuch as the speed, being double the journey, is performed in half the time.

From these considerations it follows, that if we desire to double the speed with which a train is moved on any given railway, we must provide an engine having four times the evaporating power, and consequently having all its dimensions of corresponding magnitude.

It follows, therefore, that the power of the engine must be increased in proportion to the square of the speed which it is required to impart to a given load.

(388.) *Singular error which had hitherto prevailed in constructing railways.* — It is curious to observe how completely opposite to the truth the conclusions were upon which engineers generally proceeded in the construction of railways, and the adaptation of locomotive power to them. It was assumed that where an extreme speed of transit, such as is desired with light passenger trains, was the chief object, the railway ought to be laid down with as low gradients as could be obtained even at the sacrifice of a great outlay of capital; but that where the traffic expected was chiefly merchandise or other commerce, requiring but moderate speed with heavy loads, that then higher gradients might be admitted.

By what has been explained above, it is demonstrable such principles are precisely the reverse of the truth.

Heavy trains, moved at slow velocities, require a nearly level line ; the increased resistance produced by ascending gradients cannot be compensated by diminution of a speed already sufficiently slow.

In working a heavy and slow traffic, therefore, on high gradients, it would be necessary to provide engine power sufficient for the ascent, which, in the descent and on the level, must be worked to more or less disadvantage.

But with a light passenger traffic, to be worked at high velocities, the diminution of speed on the ascending gradients may be compensated for by increased acceleration on the descending gradients, so that the time of transit between terminus and terminus of the line, will be the same, or nearly so, as on a dead level.*

* For gradients and other details of Foreign Railways, see "Railway Economy."

# CHAPTER VI.

## RAILWAY GAUGE.

(389.) *Magnitude and capacity of a railway.* — Railways, like all other structures, vary in magnitude and capacity, according to the purpose to which they are applied, and the work to be done upon them.

By magnitude and capacity we must not, however, understand length, because a railway of insignificant magnitude and inconsiderable traffic may have great length. The magnitude and capacity of a railway depend upon those of the loads which can be transported upon it, and these are obviously proportionate to the magnitude and capacity of the carriages which bear them, and the power which impels them.

(390.) *They depend upon the gauge.* — Other things being the same, this capacity will depend on the distance between the rails, which, in the technical phraseology of engineering, is called the *gauge* of the railway.

This topic has acquired unusual interest from the accidental circumstance of the disputes between the Great Western Railway Company and the remainder of the railway interests throughout England.

Nothing can more strongly demonstrate how profound and general is the interest with which every thing connected with railways is regarded by the public, than the bitterness which has marked a contest, in which dispassionate and disinterested parties would find it difficult to discover any ground for a reasonable doubt as to the proper decision to be adopted.

The distance between the rails corresponds, necessarily, to the distance between the wheels of the carriages which roll upon them; and, although with wheels of any proposed gauge, the body of the carriage may admit of more or less variation and magnitude, there are still practical limits which cannot be exceeded; and it may be stated generally, that the magnitude of the carriage, other things being the same, will be augmented, as the gauge of its wheels and consequently that of the railway on which it moves, is increased.

(391.) *The gauge has been varied according to the place and circumstances of the railway.*—Railways were first used extensively in collieries and quarries. The trucks and waggons upon them were impelled sometimes by manual labour, and sometimes by horse power. Railways are extensively constructed through the subterranean workings of mines, and are there worked sometimes by horses, and sometimes by manual labour. It is evident that the magnitude of the trucks or waggons must be regulated by this power: where horses are used there may be a greater capacity than where they are impelled by manual labour.

The width of the rails, and the consequent magnitude of the waggons, is, in many cases, also limited by the available width of the way. In the working of mines especially, and sometimes in quarries, the vein or working is narrow, and the rails must be limited to a corresponding width.

In such cases the railways have been constructed with the width of from eighteen to twenty inches. In these and like cases, the waggons are usually impelled by manual labour.

The gauge varies according to circumstances, twenty-four inches and thirty inches being very common widths.

(392.) *Is the same in the same system of lines.*—But whatever be the gauge, it must be the same throughout the same system of working, whether of mines or quarries, for the trucks and waggons built for one gauge cannot be used upon another.

(393.) *Gauge regulated by the tractive power.*—In cases where the gauge is not limited by the limitation of the width of way, it is regulated partly by the nature of the impelling power, and partly by the work to be done. According as the impelling power is manual labour or horse power, the gauge is more or less capacious.

In the great coal districts of the North of England, besides the railways constructed in the workings of the mines, others are formed between the mouths of the pits from which the mineral is raised, and the port, river, or canal where it is embarked. These being worked above ground, admit of the application of the locomotive engine; and where the work to be done is sufficiently extensive, this power has been applied.

The greater efficacy of steam power admitted of greater loads, and the width of the rails was accordingly increased, when such power was first applied.

(394.) *Gauge of first lines worked by locomotives.* — The circumstances which determined the gauge of the rails upon which the first locomotive engines were applied, is not recorded, but it could scarcely have been merely accidental. The gauge adopted was fifty-six inches and a half, a fractional length which it is impossible to suppose could have been adopted, except under the exigency of some particular circumstances. It was probably the greatest width which could be conveniently obtained in the particular locality where the first engines were required to work. Be this as it may, fifty-six inches and a half was the gauge of the first railways on which locomotive power was applied.

(395.) *Mechanism of the engines adapted to this gauge.* — The wheels, axles, and other parts of the engines first constructed, were, as a mechanical consequence, adapted to this gauge. The designs, patterns, and castings, and other mechanical arrangements of the engine builder, were all prepared in accordance with it.

(396.) *Why this gauge became general.* — It may be easily conceived, therefore, that when colliery after colliery adopted the use of locomotive power, there was an obvious convenience in adhering to the gauge first adopted. On the other hand, there was no adequate object in departing from it. Hence, the uniformity of this gauge in the colliery railways, in which locomotive power was worked.

(397.) *Its adoption on the Liverpool and Manchester line explained.* — When the Liverpool and Manchester railway was projected, the engineer under whose superintendence it was placed, was Mr. George Stephenson, who had previously obtained a reputation as a railway engineer in the collieries, in which he was specially conversant with the locomotive engine. It has been already explained that the first design of the Liverpool and Manchester railway was for the transport of goods between the two great markets forming its termini, and from which it took its name. Its analogy to the colliery railways in a mechanical point of view was therefore obvious; and it was natural that Mr. Stephenson, prompted, on the one hand, by the advantage to the locomotive builder already mentioned, and seeing, on the other, no special reason for a departure from the established gauge, should have adopted it. The first passenger line was, therefore, laid down with the fifty-six inch and a half gauge.

(398.) *Its consequent adoption on other communicating lines.* — The branches diverging from this, one to Warrington on the south, and the other to Bolton on the north, together with one or two others of minor importance, were necessarily constructed with a similar gauge, since, otherwise, the carriages, waggons, and engines could not pass from one to the other.

At a later period, Birmingham was connected with Warrington, and, consequently, with Liverpool and Manchester, by the Grand Junction railway. The same gauge was, of course, adopted on this, in order that the trains might run without interruption through the entire system.

Later still, the London and Birmingham line was constructed, which joining the Grand Junction of Birmingham, still rendered the same gauge necessary. In a word, the entire network of railways, of which the London, Birmingham, and Liverpool lines may now be regarded as the trunk, gradually came into operation, and necessarily assumed the same gauge.

(399.) *Its general adoption.* — Even in cases where lines of railway did not immediately communicate with this extensive system, future and probable points of contact were anticipated, and hence the fifty-six inch and a half gauge was generally adhered to.

(400.) *Increase of the magnitude and weight of the loads.* — As the art of railway transport progressed, it was found advisable to augment the power, and consequently the magnitude and weight of the locomotive engine. Small and light trains, consisting of a few waggons or carriages, were first contemplated. It was soon found more profitable and more expedient to carry larger and heavier trains, with greater and more powerful engines.

(401.) *Increase of speed, and consequently increased power of engines.* — Ultimately, also, a greatly augmented speed was desired, and this demanding a proportional evaporating power, rendered a still larger and heavier engine necessary.

(402.) *Limits of gauge produce inconvenience.* — Meanwhile, among the numerous improvements made in the machinery, was that already adverted to, in virtue of which the cylinders, cranks, eccentrics, and all the other working gear, were placed under the engine, and between the wheels. The crowding of so much machinery within the space limited by the gauge of the rails, produced some inconvenience to the engine builder, and also rendered the operation of cleaning and repairing somewhat difficult and tedious, and regret was expressed by the engineers that a few inches more had not been given to the gauge in the original construction of the railway.

(403.) *These difficulties surmounted.* — Time and experience, however, gradually surmounted these difficulties, and removed these inconveniences, and means were found, by which machinery of sufficient magnitude and power could be constructed, without widening the gauge. It was, however, generally agreed that it would have been more convenient, all circumstances considered, if a few inches more had been originally allowed, and that instead of fifty-six inches and a half, the railway had been laid down with a gauge of sixty inches. The idea, however, of a change in the gauge did not occur to any one, the necessity of uniformity being universally admitted.

(404.) *Width of carriages greater than gauge.* — According to the mode of construction of the carriages used upon these railways, their width was not limited to that of the gauge. The wheels being fixed upon the axles, the bearing of the carriages upon them, instead of being between the wheels, as in ordinary carriages, was outside the wheels. The axles being continued through the wheels, and projecting for a sufficient length outside it, the carriage rested upon the axle by means of a sort of fork, so that the pressure of the carriage, instead of being exerted beneath the axle, was exerted above it. Grease boxes were provided over the axle, in the fork just mentioned, by which the axle in its bearing was kept constantly lubricated by a mixture of oil and tallow.

(405.) *Advantages of outside bearings.* — It was considered that this mode of suspension was more effectual in keeping the wheels square to the carriage, and in preventing them from slipping from the rails, than would be the method ordinarily used in carriages upon common roads.

The outside bearing, also, had the advantage of giving to the carriage a greater width and capacity.

(406.) *Rapid construction of railways after the Liverpool and Manchester line.* — Within the three years which succeeded the opening of the Liverpool and Manchester railway, lines of railway were projected and in progress of construction, intersecting a great part of the north of England, as well as of the counties between London and the principal ports, from the Isle of Wight to the mouth of the Thames.

(407.) *Project of the Great Western Railway.* — Nothing, however, was yet done for the more exclusively agricultural districts of Berkshire, Wiltshire, Somersetshire, Devonshire, and Cornwall. In 1833, however, a project was announced for a great trunk line, extending from London to Bristol, an enterprise which was received and patronised with extraordinary ardour by the commerce of the latter place. According to the original plan, this line was to have had its London station beside that of the London and Birmingham line, with which it was to be connected at London, and consequently to be constructed on the same gauge as had been uniformly adopted throughout the country. Through the opposition, however, of the authorities of Eton and Oxford, and a great portion of the landed proprietors along the proposed line, the bill was thrown out.

(408.) *Mr. Brunel proposes an exceptional gauge.* — The next session it was reproduced in parliament, but in the meanwhile Mr. I. K. Brunel, the son of the engineer of the same name, who had obtained celebrity by the construction of the Thames Tunnel, the block machinery at Portsmouth, and other great engineering works, to whom the engineering department of the proposed railway had been confided, suggested to the directors the project of constructing the line with a gauge of eighty-four inches. Such a project naturally startled the directors, who resolved, before consenting to it, to submit it to the more matured railway experience and superior judgment of Mr. Robert Stephenson, the engineer of the London and Birmingham line.

(409.) *Mr. R. Stephenson, being consulted, opposes it.* — Mr. Stephenson reported unfavourably to the project, and a schism arose between the two directions of the London and Birmingham and the Great Western lines. Mr. Brunel, notwithstanding his acknowledged inexperience in railways, never having been, directly or indirectly, employed on any work of that description, succeeded in gaining the confidence of the Great Western directors, and induced them to sanction the project of an eighty-four-inch gauge. The idea of having a common London station was consequently abandoned; and the Great Western Company, with the advice of their engineer, selected the present Paddington station.

(410.) *Mr. Brunel's project adopted. — His advocacy of it.* — Mr. Brunel supported and defended his project of this wide gauge in several reports addressed to the directors. He maintained in these, that the country would ultimately be resolved into separate and independent railway districts, over each of which a great company would preside, formed, probably, by the agglomeration of the companies directing the smaller lines; but that between district and district there would probably be little or no railway communication.

He admitted that, in a continuous line of traffic, a departure from the established gauge would be an undoubted inconvenience; that in the case of the Great Western railway it would amount to a prohibition of communicating with any railway running north from London; but that the Great Western railway, breaking ground in an entirely new district, in which railways were before unknown, could have no connexion with any other of the main lines, and that the principal branches were all well considered and formed a part of the original plan, and that they could not be dependent on any other existing line for the traffic they would bring to the main trunk. He held, therefore, that the Great Western Company might adopt such form of construction as might be suitable to their particular district, and the traffic expected in it, which, according to him, would be a large passenger traffic, with but little mineral or merchandise. He maintained that it was therefore expedient to prepare for a speed much greater than had theretofore been attained or contemplated, and that therefore the line should be mode as nearly level, and as straight as possible. He proposed to ensure extreme speed by using large driving wheels on the engines, and to provide for increased safety by placing the bodies of the carriages between the wheels instead of giving them outside bearings. He maintained even that the exclusion from communication from other railways by difference of gauge, would be advantageous, inasmuch as it would be the means of securing a monopoly of railway communication for the West of England and South Wales in the hands of the Great Western Company.

(411.) *Great Western line constructed.* — In fine, the sanction of parliament being obtained for the project, and the assent of the company to the extension of gauge and other novelties suggested by the engineer, the construction of the railway commenced, and it was completed.

(412.) *Great Western a more capacious railway than others.* — From what has been already observed, it will be understood that, so far as relates to its gauge, the Great Western railway and its branches is neither more nor less than a railway on a larger scale than the other lines which prevail throughout England. The carriages, waggons, and engines are all constructed on dimensions proportionally stupendous. The turnplates, sheds, stations, and engine houses all partake of the same scale. The cuttings and embankments are of proportional width, and, of course, of proportional cost; the bridges are of proportional span, the tunnels of proportional calibre, and the viaducts of proportional breadth. In a word, all the dimensions of the railway, and of all the machinery connected with it, are increased in a manner corresponding with the increase of gauge; and the railway, after all is said that can be said about it, is merely a railway of greater magnitude and capacity than the other railways which prevail throughout England.

(413.) *The expediency of the project depends on the relative amount of traffic.* — The question whether it has been expedient to adopt this stupendous gauge resolves itself into the other question, whether the commerce presented by the tract of country through which it is carried be such as to demand the great power of transport thus afforded to it.

If it could be proved that the prevailing gauge is insufficient for the traffic of the rest of the kingdom, then it would not be necessary to show that the traffic of the district served by the Great Western is such as to demand its more capacious railway; but a superabundance of evidence has been adduced to establish the sufficiency of the prevailing gauge for the traffic of the other parts of the country.

It must then be admitted either that a superfluous power of transport has been provided and a superfluous expenditure of capital incurred in the district served by the Great Western; or that this district has a vastly greater commerce, requiring such increased power of transport, than the northern counties.

(414.) *Peculiar construction of the Great Western railway.* — As the Great Western railway was projected and brought into operation, it presented other novelties of construction besides its great scale of magnitude. The structure of the way was, in many respects, different from the other railways of the kingdom. It will be recollected, from what has been already explained, that the rails elsewhere were supported, at regular intervals, by props called chairs, which were firmly attached either to beams of timber, called sleepers, which extended across the line, and served as a tie to keep the rails in gauge, as well as to support them, or upon square blocks of stone.

The distance between chair and chair varied according to the strength of the rail and the weight of the loads which were to pass over it.

This system was altogether abandoned in the Great Western railway.

The rails were considered as necessary to guide the wheels rather than support them. They were so formed as to admit of being attached by screws to the surface of strong beams of timber, which were extended longitudinally under them, and with these formed the more immediate substratum of the rails.

These longitudinal timbers were held together, at regular intervals, by transverse beams, to which they were attached by bolts, and which served also to keep the rails in gauge in the same manner as the transverse sleepers did in the common system.

(415.) *Method of piling down the rails.* — The structure of carpentry thus formed was not merely laid upon the road, but was held in its position by a novel contrivance. Piles of great length and magnitude were previously driven into the road by a proper engine, at regulated intervals, and the transverse timbers just mentioned, being laid over these piles, were bolted to them at the centre. The road structure was thus as it were bound down to the road by the piles gravel or other earth, called packing, was driven under the longitudinal beams supporting the rails, so as to prevent the transverse timbers from being broken or bent at the centre by the weight of the loads passing over them.

(416.) *Tested by experiments — fails and is abandoned.* — When the line thus constructed had been for some time in operation, it was found that this packing beneath the timbers required constant renewal, and labourers were kept incessantly employed for this purpose. Experience soon proved the inefficacy of this system; the piles, instead of affording a support to the road, prevented it from settling into its natural bed. Experiments were made on the road, under the superintendence of Mr. Nicholas Wood and myself, with a view to test the utility of such piles; the result of which proved that they impeded the consolidation of the road, and after some delay, they were finally abandoned. The cross timbers were detached from them, and the railway was permitted to be consolidated upon the foundation of the road in the usual way, by the action of the loads passing over it.

(417.) *Engines with ten-feet driving wheels tried and abandoned.* — One of the advantages proposed to be attained by the extraordinary width of gauge was, the power to use engines with driving wheels of more than ordinary diameter. It was considered, at that period, that one of the great sources of difficulty in the construction of locomotives engines was the extreme rapidity of the motion of the pistons and other reciprocating parts, which was necessary to produce the desired speed.

It will be remembered that for each revolution of the driving wheels, the pistons must move backwards and forwards once in each cylinder. It was therefore expected that by using driving wheels of great magnitude, and thereby producing a given progressive speed, with a slower reciprocation of the pistons, the engines would work to greater advantage. Engines were accordingly constructed on the Great Western line, with driving wheels having a diameter of ten feet. Each revolution of these would carry forward the train, therefore, nearly thirty-two feet of road, and consequently a given speed would be attained by one half the number of strokes which would have been necessary with five-feet wheels, which were then the common diameter. Subsequent experience, however, proved not only that the rapid reciprocation of the pistons was not attended with such injurious effects as were supposed, but that the ten-feet wheels were utterly unmanageable. The inertia of these prodigious revolving masses was such, that a great interval was necessary to get them into motion, and an equally great interval necessary to stop them.

This, independently of other difficulties, soon caused them to be laid aside, and the diameters of the driving wheels were subsequently limited to about seven feet.

(418.) *Gauge question.* — Although the legislature and the public, compelled to choose between the evils created by the construction of lines of railway in a certain small tract of the country with an exceptional gauge, have, as the lesser evil, acquiesced in the continuance of the anomaly presented by the Great Western railway and its tributaries and dependencies, we cannot totally omit all notice of a dispute so memorable as the "battle of the gauges."

(419.) *Practical inconvenience of break of gauge.*—As the extensive system of railways which had been projected, and sanctioned by parliament, came gradually into operation, it was evident that their ramifications must speedily come into contact, on the one side or on the other, with the system of the Great Western, the trunk which intersected the tract of country running westward from London towards Devonshire and Cornwall. In fine, this contact at length took place at more than one point, and the public began to feel and loudly complain of the nuisance of the *break of gauge.* At all the points where the branches of the wide gauge system terminated, and those of the narrow gauge commenced, the stream of traffic was found to be interrupted. A chasm, as it were, intervened and must be crossed. So far as related to the passengers, the inconvenience was limited to the transfer of persons with their luggage from one train of coaches to another. At the principal stations, the inconvenience of this would be mitigated by the provision of convenient covered ways to protect them from the weather. This, however, would not be the case with the secondary stations, where the traveller, in passing from one line to the other, would have to encounter all the vicissitudes of weather, at all hours, night and day, at which the arrivals and departures would occur.

But great as the inconvenience is of this interruption to passengers, it is evidently more serious for goods. A train of merchandize arriving, had to be unloaded and unpacked on one side, and reloaded and repacked on the other. The goods were thus liable to be damaged or lost, and their transport considerably delayed. Troops of porters were kept night and day relieving each other by relays always ready for this work, and all these must necessarily be maintained along the entire boundary line, extending a distance of some two or three hundred miles, which separates the wide from the narrow gauge system. These enormous evils were not long in arousing the complaints and remonstrances of the commercial interests, and petitions were sent to parliament in favour of a law compelling an uniformity of railway gauge.

(420.) *Parliamentary committee appointed to investigate the grievance.*—A commission was appointed accordingly, to investigate the question, consisting of Sir Frederick Smith, who had been formerly Inspector General of railways, Professor Barlow of Woolwich, and Mr. Airy, Astronomer Royal.

This commission called before it witnesses selected from all classes of persons having practical information with the construction, the working, and the use of railways, such as engineers, engine builders, directors of collieries, chairmen and directors of companies, contractors, and public carriers.

The evidence of about fifty witnesses of this description was collected, and published in a ponderous volume.

Experiments on a great scale were made, both on the wide and on the narrow gauge, with a view to test the capacity of the respective engines for power and speed, and the qualities of the lines themselves. Returns of accidents arising from defects either in the mechanism or in the rails, of the traffic on the several lines, of their cost of construction, maintenance, and operation, and, in general, all the statistical results which could have any bearing on the relative efficiency of the two systems, were diligently collected and published.

(421.) *Report of the committee.* — In fine, the commissioners reported in substance, that both gauges supplied all the requisite accommodation, convenience, and expedition that the public could desire, both as to transport of passengers and goods.

That in cases of speed so extreme as to be objectionable on the score of safety, there might be some advantage on the side of the wide gauge, but that for the transport of goods, the narrow gauge was more convenient, and better adapted, to the purposes of general traffic; that the broad gauge, without affording any economy either in the maintenance of the way, or the cost of working, involved a large additional outlay in its construction; and, in fine, the commissioners considered the narrow gauge to be that which for general convenience should be preferred if uniformity were attempted, more especially as, at the time of publishing the report, there were only 274 miles of the wide gauge constructed, while there were 1,901 miles of the narrow gauge. The commissioners therefore recommended a law to be passed, compelling all future railways, except those for which the Great Western Company had already obtained acts, to be constructed with the prevailing gauge of fifty-six inches and a half. The commissioners further recommended that some equitable means should be sought for producing a general uniformity of gauge through the country, by laying down upon the wide gauge line, narrow gauge rails.

(422.) *Bill passed omitting compulsory clause.* — A bill was accordingly passed in August, 1846, in this sense, parliament, however, declining to introduce a clause into it compelling the uniformity of gauge.

(423.) *Expedients for removing the evil suggested to the committee.* — In the course of the inquiry instituted by the commissioners, an infinite number of expedients were suggested for facilitating the transfer of goods from one line to the other, at the point where break of gauge occurred, such, for example, as that of loading the goods in loose boxes placed upon the railway trucks, and transferring these boxes bodily from the trunks on one line to the trucks on the other. None of these expedients, however, bore the test of examination, being all found subject to objections and difficulties even more serious than those attending the entire unloading and reloading by a sufficient force of porters.

(424.) *Means of producing uniformity suggested.* — The magnitude of the nuisance attending this difference of gauge being thus admitted on the one hand, and the utter impracticability of all expedients suggested for its abatement on the other, the only remedy remaining would be its removal, by producing a general uniformity of gauge. Several expedients were accordingly suggested for this purpose.

To appreciate these, it will be necessary, first, to state the respective lengths of railway with each gauge which were in actual operation.

There were in round numbers about 4,300 miles in operation constructed with the gauge of fifty-six inches and a half, and 306 miles constructed with the gauge of eighty-four inches in Great Britain. The former includes some few railways in England and Scotland, which, when first constructed, were laid down with a wider gauge; but the inconveniences encountered in consequence of a break of gauge were so great, that the proprietors resolved, though at a considerable cost, to change the gauge to the ordinary one of fifty-six inches and a half.

In Ireland the railways, with the exception of a short and isolated one between Dublin and Kingston, are laid down with a uniform gauge of sixty-three inches.

The expedients proposed for producing uniformity may be classed under three heads.

First, To lay down rails with the fifty-six inches and a half gauge on the 306 miles of wide gauge lines.

Secondly. To lay down rails with the gauge of eighty-four inches on the 4,300 miles of narrow gauge lines.

Thirdly. To adopt an intermediate gauge, say of sixty-six or seventy-two inches, and relay all the railways with such gauge.

If the first expedient were adopted, the present wide gauge rails might either remain or be removed. If they remained, the narrow gauge rails would be placed between them, and the engines, coaches, waggons, and trucks of the narrow gauge lines would run over the wide gauge lines, without excluding from them the larger engines, carriages, and waggons adapted to the wide gauge rails.

The chief objection brought against this system was, the confusion and danger which would arise from the multiplication and complexity of the points and switches, as they are called, by which the trains are enabled to pass from one line to another, or to pass into sidings at the intermediate stations.

As there would be in this case four lines of rails on the present wide gauge railway instead of two, the number of these switches, and their complexity, would be increased in a great proportion. This objection is rendered more grave by the consideration that a large proportion of the accidents which have occurred have arisen from neglect or mismanagement of this mechanism for enabling trains to pass from one line to another, or into sidings.

The second expedient, that of laying down rails of eighty-four inches gauge upon the 4,300 miles of narrow gauge railway now in operation would be totally inadmissible, inasmuch as it would require not only the enlargement of the width of the cuttings and embankments throughout the vast extent of lines ; but would also render necessary the enlargement of the span of the bridges, the width of the viaducts, and the calibre of the tunnels, and the consequent reconstruction of all these great works, which would of course be wholly out of the question.

The third expedient, proposed by Mr. William Cubitt, might, as he considered, be carried into effect without the alteration of all these great works. Mr. Cubitt proposed to widen the gauge of all the narrow gauge lines, and contract the gauge of the wide gauge lines, so that a uniform intermediate gauge might be obtained; and this might be accomplished without interrupting the traffic on the lines, and at an expence which would not be unattainable. He said that the cuttings, embankments, bridges, tunnels, and viaducts had already sufficient width to admit of a certain enlargement of gauge ; as a practical proof of which he stated, that some of the carriages which now pass upon the narrow gauge lines, and of course go through the tunnels, and under the bridges, are wide enough to allow of the wheels which bear them being separated to a greater distance from each other, without being outside the limits of the carriages. Thus he contended, that if the wheels, instead of being fifty-six and a half inches asunder, were seventy-two inches apart, they would still be within the carriages, and that consequently, when so constructed, they could run through the tunnels and bridges as they now do, as well as through the cuttings and over the embankments.

The only difference in the conditions of the line would be, that the outer rails of such line would be brought nearer to the side rails, and the inner rails nearer to each other. On the other hand, the outer rails of the wide gauge lines would be brought in further from the side rails, and the inner rails further from each other.

The uniform intermediate gauge proposed by Mr. Cubitt was seventy-two inches.

But it would be also necessary, after changing the gauge, to change in a corresponding manner the distance between the wheels of the engines, carriages, waggons, and trucks.

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## CHAPTER VII.

### RAILWAY CURVES.

(425.) *Railway carriages commonly move in a straight direction.*—A railway carriage, or engine, as commonly constructed, cannot move otherwise than in a straight line. If a common four-wheeled coach used on an ordinary stone road had no perch to the fore-wheels, and if the latter were, like the hind wheels, fixed square to the carriage, such a carriage, it is evident, could not be turned so as to change the direction of its motion, without scraping the wheels on the road and straining them. From its very construction, it could only move in a straight line, unless violence were opposed to it.

Such is the construction of all the carriages and engines commonly used on railways in Europe; but they are so much the more difficult to be turned from a straight direction, as the one pair of wheels is more distant from the other under the same carriage, than in carriages built for common roads. Not unfrequently, also, these carriages are supported on six wheels, the engine being now almost invariably so constructed.

(426.) *Direction of motion changed by curves.* — Since, however, no railway can hold a continuous rectilinear course, expedients must be provided for changing the direction of a railway carriage.

This is accomplished by *curves.*

The rails, instead of turning at an angle, as one road does from another, is so formed as to change its direction very gradually, by laying the rails according to the arc of a circle, having a greater or less radius. The engines and carriages having a constant tendency to move forwards in the straight line which forms a tangent to this curve, this tendency is resisted by the flanges of those wheels which are on the convex side of the curve. These flanges pressing against the rails, the reaction upon them continually presses the carriages round, so as to keep them upon the rails, and compel them to follow the flexure of the curve.

(427.) *Form of the flanges, and their action on the rails.* — If the tires of the wheels were cylindrical, having the flanges at right angles to them, the flanges would in that case continually rub against the rails, and produce a considerable resistance. To prevent this, the tires of the wheels are formed slightly conical, and their junction with the flanges is formed into a curve. The effect of this arrangement is, that the flanges act upon the rails without friction.

As the wheel presses upon the outer rail of the curve, there is a tendency of the tire to mount upon the rail, so that that portion of the wheel which actually rolls upon the rail has a little greater diameter. The opposite effect is produced upon the inner rail of the curve. The flange of the inner wheel recedes from the rail, and consequently the diameter of that part of the tire which rests upon the rail is diminished.

When a railway carriage, therefore, passes over a curve, the outer wheels become virtually greater than the inner, and in one revolution pass over a greater space of the rail.

As from the structure of railway carriages the wheels are keyed upon the axles with which they turn, both wheels must revolve simultaneously; and as those which rest on the outer rail must, from the nature of the curve, pass over a greater space than those which rest on the inner rail, the wheels adapt themselves to this by the circumstance just explained. Otherwise it is evident that one wheel or the other, in passing round a curve, must necessarily rub upon the rail more or less. If the inner wheel were to roll without rubbing, the outer wheel, being of the same magnitude, and going over a greater space in each revolution, must make up the difference by rubbing on the rail; and if the outer wheel roll without rubbing, then the inner wheel, being equal, and revolving in the same time, but passing over a less space, must slide as it were backwards on the rail through the difference. But, from the circumstance already explained, the carriage has a tendency so to mount on the outer rail, that the difference between the virtual diameter of the outer and inner wheels, produced by the conical form of the tires, will be such as to make the difference of their circumferences equal, or nearly so, to the difference between the lengths of the outer and inner rail of the curve over which they simultaneously pass.

In this manner the friction between the flange and the rail which would take place if the tire of the wheel were cylindrical, and the flange at right angles to it, is avoided, as is evident by observing the state of the flange of the wheels, which are never found to be polished by friction with the rails.

(428.) *Experiments showing that the effect of curves is much less than was apprehended.* — When the system of railways which now overspreads Great Britain was projected, great apprehensions were entertained, not only of the resistance which might be produced from curves, but of the danger of passing over them with considerable speed. Standing orders were adopted in parliament, which required that all curves having a less radius than a mile, should be the subject of special investigation.

In the course of experiments which I made in 1838, already adverted to, I had occasion incidentally to observe the effects of curves upon the resistance, and I found these effects to be infinitely less than had been previously suggested. Curves having a radius of three quarters, or even half a mile, did not produce the slightest augmentation of resistance at any speed which the trains attained; and from observations and experience which I have since obtained, especially on American railways, where curves of short radius are very common, I have no doubt that the effects ascribed to them, both as to resistance and danger, have been greatly exaggerated.

(429.) *Method of laying the rails on curves.*— It is usual, in the construction of curves upon railways, to lay down the outer rail at a greater elevation than the inner, the difference of elevation being regulated according to the radius of the curve. The effect of this is to make the carriage lean slightly inwards, so that its weight has a tendency to resist the centrifugal force attending the curvilinear motion. An animal spontaneously assumes such a position when moving in a circle; and it will be observed that the body in such motion will lean more and more inwards, according to the velocity of the motion, and the smallness of the circle. Every one is familar with this effect in witnessing the performances of horsemanship in a circus. When the horse walks slowly round the ring, his body and that of the rider remain nearly erect. When he trots round, both bodies lean towards the centre of the ring; and when he is made to go at a high speed, he counteracts the increased centrifugal force by leaning almost upon his side, a position in which the rider, whether standing or sitting, participates.

I do not know that engineers have hitherto adopted any principle in regulating the difference of elevation of the two rails forming a curve. Strictly speaking, the amount of this difference might be calculated when the radius of the curve is given, and the velocity of the train moving over it. If too great an elevation be given to the outer rail, the carriage will have an undue pressure on the inner rail; and if too little elevation be allowed, it will have an undue pressure on the outer rail.

As, however, the carriage cannot always be moved at the same velocity over the same curve, an exact adaptation cannot be effected. The difference of elevation might, however, be regulated by the average speed of the trains.

(430.) *Method of passing sharp curves on American railways.*— In America it is not uncommon, where railways are carried through the streets of a town, to turn corners at right angles by a very short radius. In this case it is usual so to form the outer rail that the outer wheels shall roll upon their flanges, having thus their virtual diameters considerably greater than those of the inner wheels, and thus facilitating the motion round the curves.

(431.) *Peculiar construction of the engines and coaches on American railways.* — The construction of the coaches and engines, however, on the United States railways* facilitates in another way their motion upon curves. The coaches, which are of considerable length, are supported at each end upon two-wheeled trucks, the fore and hind wheels of each of which are very close together; the end of the carriage rests on a pivot or perch in the centre of the truck, and the truck has a power of turning under the carriage in exactly the same manner as the fore-wheels do in a four-wheeled carriage constructed for a common road. Each of these trucks have their wheels so close together that they can move with great facility even in a curve of very short radius; and as, from the length of the carriages, the two trucks supporting the same coach are at a considerable distance asunder, they run in different parts of the curve, assuming different directions, so that the line joining their centres or pivots will form the chord of the arch of the curve which intervenes between them. In turning the corner of a street, it is not uncommon to see one of these trucks proceeding down one street before the other has left the street which is at right angles with it.

I am not aware that this expedient for facilitating the motion on curves has been adopted in any European railways.

The same expedient is adopted in the construction of the locomotive engine. The foremost end of the engine under the chimney rests upon a four-wheeled truck upon a pivot, as already described. The end next the fire-box is separated by the driving wheels.†

* See "Railway Economy," chap. xvi.

† For curves admitted on German railways, see "Railway Economy," p. 472.

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THE END.

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