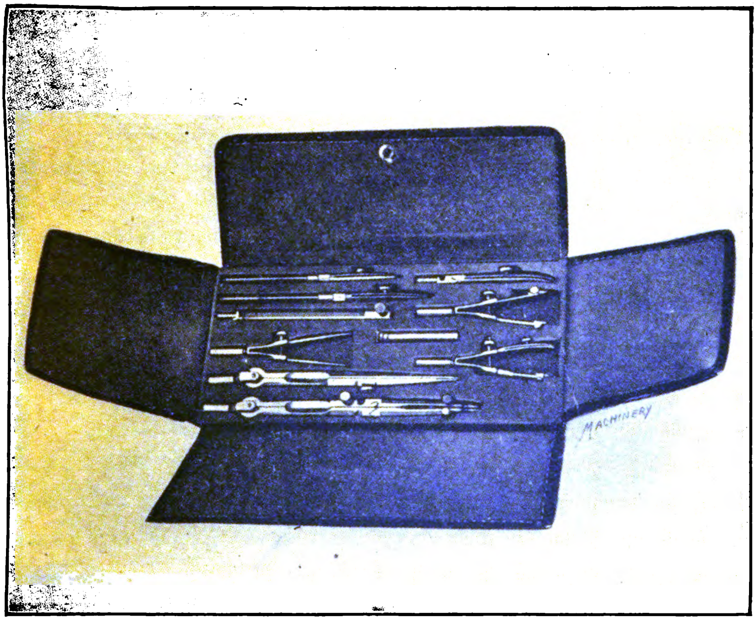
25 CENTS

MECHANICAL DRAWING

BY OSCAR E. PERRIGO

PART III—MACHINE DETAILS



MACHINERY'S REFERENCE BOOK NO. 87
PUBLISHED BY MACHINERY, NEW YORK

MACHINERY'S REFERENCE BOOKS

This treatise is one unit in a comprehensive Series of Reference books originated by MACHINERY, and including an indefinite number of compact units, each covering one subject thoroughly. The whole series comprises a complete working library of mechanical literature in which the Mechanical Engineer, the Master Mechanic, the Designer, the Machinist and Tool-maker will find the special information he wishes to secure, selected, carefully revised and condensed for him. The books are sold singly or in complete sets, as may be desired. The price of each book is 25 cents (one shilling) delivered anywhere in the world.

LIST OF REFERENCE BOOKS

No. 1. Worm Gearing.—Calculating Dimensions for Worm Gearing; Hobs for Worm Gears; Location of Pitch Circle; Self-Locking Worm Gearing, etc.

No. 2. Drafting-Room Practice.—Drafting-Room System; Tracing, Lettering and Mounting; Card Index Systems.

No. 3. Drill Jigs.—Elementary Principles of Drill Jigs; Drilling Jig Plates; Examples of Drill Jigs; Jig Bushings; Using Jigs to Best Advantage.

No. 4. Milling Fixtures.—Elementary Principles of Milling Fixtures; Collection of Examples of Milling Fixture Design, from practice.

No. 5. First Principles of Theoretical Mechanics.

No. 6. Punch and Die Work.—Principles of Punch and Die Work; Suggestions for the Making and Use of Dies; Examples of Die and Punch Design.

No. 7. Lathe and Planer Tools.—Cutting Tools for Planer and Lathe; Boring Tools; Shape of Standard Shop Tools; Forming Tools.

No. 8. Working Drawings and Drafting-Room Kinks.

No. 9. Designing and Cutting Cams.—Drafting of Cams; Cam Curves; Cam Design and Cam Cutting; Suggestions in Cam Making.

No. 10. Examples of Machine Shop Practice.—Cutting Bevel Gears with Rotary Cutters; Making a Worm-Gear; Spindle Construction.

No. 11. Bearings.—Design of Bearings; Causes of Hot Bearings; Alloys for Bearings; Friction and Lubrication; Friction of Roller Bearings.

No. 12. Mathematics of Machine Design.—Compiled with special reference to shafting and efficiency of hoisting machinery.

No. 13. Blanking Dies.—Making Blanking Dies; Blanking and Piercing Dies; Construction of Split Dies; Novel Ideas in Die Making.

No. 14. Details of Machine Tool Design.—Cone Pulleys and Belts; Strength of Countershafts; Tumbler Gear Design; Faults of Iron Castings.

No. 15. Spur Gearing.—Dimensions; Design; Strength; Durability.

No. 16. Machine Tool Drives.—Speeds and Feeds of Machine Tools; Geared or Single Pulley Drives; Drives for High Speed Cutting Tools.

No. 17. Strength of Cylinders—Formulas, Charts, and Diagrams.

No. 18. Shop Arithmetic for the Machinist.—Tapers; Change Gears; Cutting Speeds; Feeds; Indexing; Gearing for Cutting Spirals; Angles.

No. 19. Use of Formulas in Mechanics.—With numerous applications.

No. 20. Spiral Gearing.—Rules, Formulas, and Diagrams, etc.

No. 21. Measuring Tools.—History and Development of Standard Measurements; Special Calipers; Compasses; Micrometer Tools; Protractors, etc.

No. 22. Calculation of Elements of Machine Design.—Factor of Safety; Strength of Bolts; Riveted Joints; Keys and Keyways; Toggle-joints.

No. 23. Theory of Crane Design.—Jib Cranes; Calculation of Shaft, Gears, and Bearings; Force Required to Move Crane Trolleys; Pillar Cranes.

No. 24. Examples of Calculating Designs.—Charts in Designing; Punch and Riveter Frames; Shear Frames; Billet and Bar Passes; etc.

No. 25. Deep Hole Drilling.—Methods of Drilling; Construction of Drills.

No. 26. Modern Punch and Die Construction.—Construction and Use of Subpress Dies; Modern Blanking Die Construction; Drawing and Forming Dies.

No. 27. Locomotive Design, Part I.—Boilers, Cylinders, Pipes and Pistons.

No. 28. Locomotive Design, Part II.—Stephenson Valve Motion; Theory, Calculation and Design of Valve Motion; The Walschaerts Valve Motion.

No. 29. Locomotive Design, Part III.—Smokebox; Exhaust Pipe; Frames; Cross-heads; Guide Bars; Connecting-rods; Crank-pins; Axles; Driving-wheels.

No. 30. Locomotive Design, Part IV.—Springs, Trucks, Cab and Tender.

No. 31. Screw Thread Tools and Gages.

No. 32. Screw Thread Cutting.—Lathe Change Gears; Thread Tools; Kinks.

No. 33. Systems and Practice of the Drafting-Room.

No. 34. Care and Repair of Dynamos and Motors.

No. 35. Tables and Formulas for Shop and Drafting-Room.—The Use of Formulas; Solution of Triangles; Strength of Materials; Gearing; Screw Threads; Tap Drills; Drill Sizes; Tapers; Keys; Jig Bushings, etc.

No. 36. Iron and Steel.—Principles of Manufacture and Treatment.

No. 37. Bevel Gearing.—Rules and Formulas; Examples of Calculation; Tooth Outlines; Strength and Durability; Design; Methods of Cutting Teeth.

No. 38. Grinding and Grinding Machines.

(See inside back cover for additional titles)

MACHINERY'S REFERENCE SERIES

EACH NUMBER IS A UNIT IN A SERIES ON ELECTRICAL AND STEAM ENGINEERING DRAWING AND MACHINE DESIGN AND SHOP PRACTICE

NUMBER 87

MECHANICAL DRAWING

By OSCAR E. PERRIGO

SECOND EDITION

PART III

MACHINE DETAILS

CONTENTS

CHAPTER I

THE DRAWING OF SCREWS AND BOLTS

It is not an unusual occurrence to see an otherwise well laid out mechanical drawing that is to a very great extent a practical failure, because sufficient attention has not been given to the mechanical details of the parts represented. The artistic work may be well executed, lines and circles cleanly made and nicely joined, centers exactly indicated by the intersecting lines, spacing and measurements even and accurate, dimensions given from practical working points, and the terminals of dimension lines carefully indicated, figures plain and unmistakable, and the general features of the design well and cleanly represented; but many of the minor details are incomplete or lacking altogether, and there are no notes or other directions which supply the information which the absence of these details renders necessary.

It has been truly said that "a mechanical drawing is valuable just in so far as it gives practical information to the workmen in the shop who build the device which it represents." What are frequently considered as minor details, are frequently of the utmost importance, and we would fail in our work as draftsmen and designers if we neglected to give proper and careful attention to the bolts, nuts, screws, etc., with which the parts are fastened together.

In the drawing of screw threads, it is not usual to show the exact form of each individual thread unless there is some special reason for doing so, as this would be a waste of time for which there would be no valid excuse. If the exact form of the particular thread is required to be represented, as for instance, where a special tool is needed in forming it, the contour of the thread must be very carefully laid out. If it is to have a flat bottom and inclined sides, the width of the flat at the bottom and the inclination of the sides should be given, the latter expressed in degrees.

Let it now first be required to represent a square thread of 1¾-inch pitch, cut for a distance of 9 inches on a bolt 5½ inches in diameter. Fig. 1 shows the completed drawing.

First draw the center line, and then the two lines representing the diameter of the piece. Then draw the two lines representing the depth of the thread, which in this case is equal to one-half the pitch, or ⅞ inch. Then space off the thickness of the threads and the spaces between them, ⅞ inch each, and through each alternate point draw vertical lines for the right-hand sides of the threads on the top and the left-hand sides at the bottom. Draw the inclined lines across the piece, representing the top edges of the thread. From the intersection of these lines with the center line, draw the inclined lines representing the bottom of the threads. The upper end of the thread, as at *A*, is usually made on the center line, and shows the location for the withdrawal of the thread-cutting tool. The necessary dimension lines are then drawn as shown. In some cases the sides of the thread are not exactly at right angles to the surface, but are inclined from 2 to 5 degrees, and still the thread is frequently called a square thread. In such a case the pitch, the angle, and the depth of the thread must be given.

It is required to draw a regular V-thread (sometimes called "a sharp V-thread") of ⅜-inch pitch, on a 2½-inch bolt, and cut to 3⅝ inches from the end.

A regular V-thread is shown in Fig. 2. This thread is always of 60-degree angle (30 on each side), unless otherwise specified. If the top and bottom of the thread is to be flat instead of a sharp angle, the width of this flat space should be specified, unless it conforms to that of the United States Standard (U. S. S.) thread, in which it is one-eighth of the pitch, or the distance from thread to thread.* To draw a bolt with sharp V-thread, first, lay out the center line and the parallel lines above and below it showing the diameter of the bolt. Space off the pitch, ⅜ inch, upon the top line, and one-half of one of these spaces from the end at the right (as at *B*) on the bottom line. This will determine the angle of the thread as the line *AB*. Through the spaced points along the top line, draw lines parallel to the line *AB*. These lines represent the top edges of the thread. From the points of the intersection of these lines with the top and bottom lines, and by the aid of the 60-degree angle, draw the V-form of the threads at the top and bottom lines. From the intersection of these lines at the bottom of the thread, draw the inclined lines representing the bottom of the thread. These lines will not be quite parallel to those representing the tops of the thread. The upper end of the thread is usually drawn as at *C*.

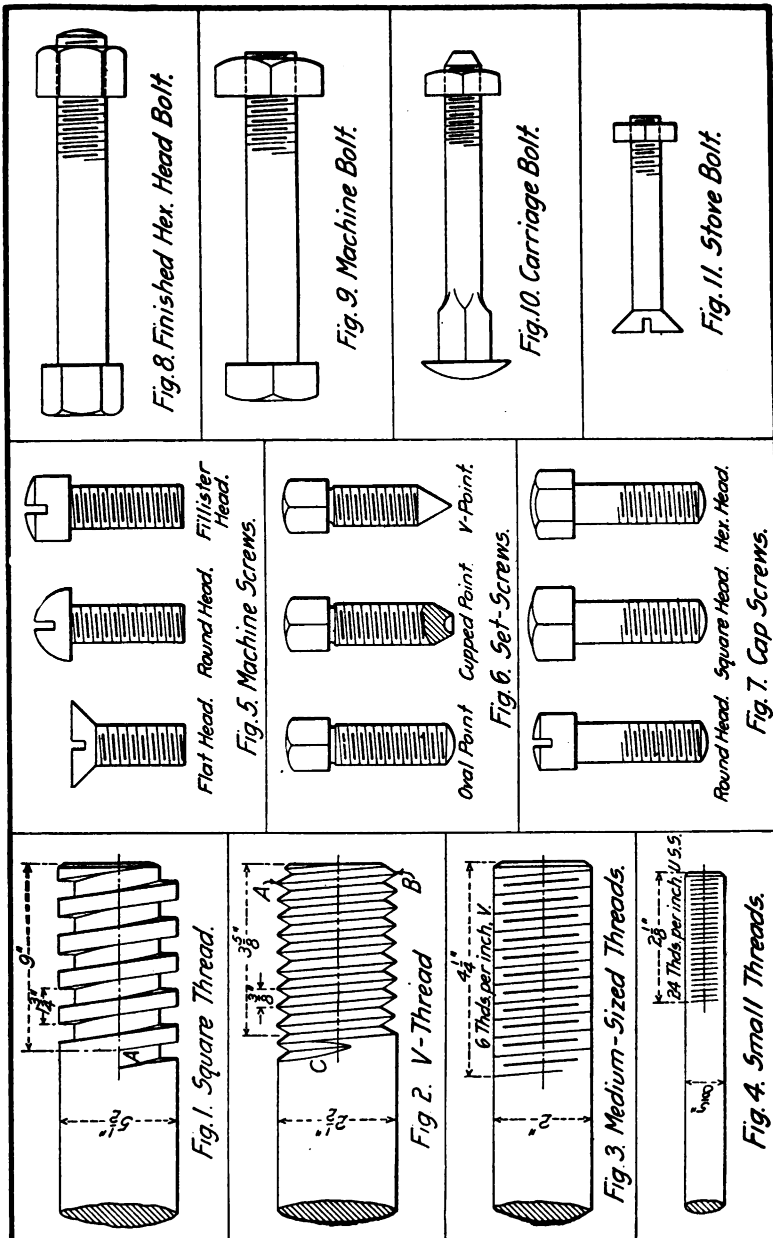
Fig. 3 shows the usual method of representing screw threads in comparatively large details. The fine lines are supposed to represent the top edges, and the pitch and angle of the thread. The heavy lines represent the bottoms of the thread. The number of threads to the inch and the form of the thread should also always be specified. The form at the present time in the United States is usually understood to be the United States Standard when no other form is specified. The length along the bar to be threaded should also be given.

Fig. 4 shows the method of representing threads on small rods, screws, bolts, etc., or upon such as are drawn to a small scale. The lines are supposed to represent the pitch and angle of the thread, and may be drawn entirely across the piece or they may terminate a short distance inside the outside lines, as shown. The same dimensions should be given as are specified for Fig. 3.

Machine Screws

The term "machine screw" is to most persons, and often to machinists and draftsmen, a rather indefinite designation. They frequently

*For a more thorough treatise on screw thread systems, see MACHINERY'S Reference Series No. 31, "Screw Thread Tools and Gages."



Figs. 1 to 11. Screw Threads, S

have rather vague ideas in reference to what is meant by machine screws, cap screws, set screws, etc., and the distinguishing difference between these various forms. The draftsman should, however, be able to state on his drawing exactly what may be had in the open market, so that money may not be spent in making special sizes when the regular sizes carried in stock or easily procured will answer the purpose quite as well, and frequently better, and at much less cost.

Machine screws are shown in Fig. 5. They are made of both iron and brass and divided into three classes according to the form of the head: flat head, round head and fillister head. The thread is cut close up to the head except in the comparatively long sizes. The diameters are not given in fractions of an inch, but by certain arbitrary numbers, corresponding to the "screw gage." These arbitrary numbers, the number of threads per inch, and the diameter expressed in the nearest common fraction of an inch are as follows:*

TABLE OF DIMENSIONS OF MACHINE SCREWS

A. S. M. E. Standard

Machine Screw Number	Threads per Inch	Approximate Diameter
10	30	3/16
12	28	7/32
14	24	1/4
16	22	17/64
18	20	19/64
20	20	5/16
24	16	3/8

In giving the length of machine screws, they should be measured "over-all" for flat heads, and from under the head to the point for round and fillister heads. Many mistakes occur on drawings, and in the correct reading of drawings, in regard to dimensions of machine screws by disregard of, or lack of information on, this point. It should be noticed that the heads of all machine screws are circular, and all are slotted for the use of a screw driver. The threads of machine screws are usually drawn in a manner similar to that shown in Figs. 3 and 4. The head of the flat-head type is about twice the diameter of the body. The angle under the head is usually about 45 degrees. The slot extends about one-half the depth of the head. The round head is a trifle less than twice the diameter of the body, and the thickness or height is 0.7 of the diameter. The diameter of the fillister head is a trifle more than one and one-half times the diameter of the body. Its height, exclusive of the rounded top, is equal to 0.66 times the diameter of the body. The radius of the arc of the top of the head is equal to the diameter of the head. The slots are one-half the depth of the head. The width of the slot is about one-fifth to one-fourth the diameter of the body.†

The object in using machine screws and cap screws—which latter will be presently described—is to secure one piece to another, much in

* For more complete data, see MACHINERY'S Data Sheet Series, No. 1, "Screw Threads," pages 22 and 23, or MACHINERY'S Reference Series No. 35, "Tables and Formulas for Shop and Drafting-room," page 30.

† For more complete data, see MACHINERY'S Data Sheet Series, No. 2, "Screws, Bolts and Nuts," pages 14 and 15.

the same way that bolts are used. Therefore, the head is very important, whatever may be its form, or whether it is adapted for the use of a wrench or a screw driver. Set-screws are intended for an opposite purpose, that is, to screw through one member or part and to force the next member away from it. Hence, the form of the head is only a matter of convenience in handling it, while the form of the point is important. Set-screws, shown in Fig. 6, are usually of machine steel and case-hardened. They are always specified and classified by the form of their points, as oval points, cupped points and V-points. Sometimes the V-points have a short portion turned straight between the point and the beginning of the thread, and are then called gib screws.

When the square head is omitted, and in place of it a slot for a screw driver is used, it is called headless, and must be so specified in addition to the specification regarding the form of the point. The diameters to which set-screws are made are given in common fractions of an inch. The following table shows the diameters and threads per inch for the usual sizes:

TABLE OF DIMENSIONS OF SET-SCREWS

Diameter	Threads per Inch	Diameter	Threads per Inch
1/4	20	1/2	13
5/16	18	9/16	12
3/8	16	5/8	11
7/16	14	3/4	10

Unless otherwise specified, all set-screws have square heads. They are made from square rods of machine steel just large enough to permit of finishing the body to the size required. Consequently, the heads, "across flats", are slightly larger than the diameter of the body. "Across corners", as usually shown on a side elevation, the head is practically one and one-half times the diameter of the body. The height of the head is the same as the diameter of the body. The radius of the arc at the crown of the head is one and one-half times the diameter of the body. The radius of the arcs at the top of the two faces of the head, as shown in Fig. 6, is one-half the diameter of the body. The heads are partially finished by grinding on an emery wheel.

The body is "nicked" under the head with a round groove about the width of the pitch of the thread. The radius of a round point is three-fourths the diameter of the body. The diameter of a cupped point is one-half the diameter of the body, and the sides form an angle of 60 degrees. The "cup" is a semi-circle. A V-point screw has an included angle of 60 degrees. Cap screws are used for similar purposes as machine screws, but where greater holding power is needed. They are shown in Fig. 7, and are classified by the form of the head as round head, square head and hexagon head screws.

It will be noticed that the same head which is called a fillister head in machine screws is called a round head in cap screws, while the round head of a machine screw is of hemi-spherical form. Ordinarily, cap screws should have the thread cut for about two-thirds of the length of their bodies, although the shorter sizes are cut all the way up to the heads. The diameter of the head of a round head cap screw is one and one-half times the diameter of the body. The thickness of the head of all cap screws is equal to the diameter of the body. The radius of the arc at the crown is one and one-half times the diameter of the body. The slot is of the same proportion as that in machine screws. The head of the square head cap screw "across flats" is 1.2 times the diameter of the body. "Across corners", as it is generally shown on a drawing, it is nearly 1.7 the diameter of the body. The radius of the arc at the top of the side faces, as shown, is equal to the height of the head. The height of the hexagon head is equal to the diameter of the body. The width across the corners is practically 1.4 times the diameter of the body. The width across flats is 1.25 times the diameter of the body. The radius of the arc at the crown of the head is twice the diameter of the body. The center for the arc of the center face is at the base line of the head. The radius of the arcs for the side faces is equal to half the width of the center face. If the head is drawn in a view at right angles to the view here shown, the radius of the arc at the crown of the head will be one and one-half times the diameter of the body, and the arcs for the tops of the two faces will be drawn from a center at the base line of the head.

In considering the subjects of bolts, nuts and screws we should not forget that cap screws are frequently called bolts. In former years they were called "tap bolts." In reality, a bolt is distinguished by the fact that it must have a nut to make it complete. In machine shop work a bolt with the body turned accurately to size and the head and nut finished, is usually called a finished bolt. This is shown in Fig. 8. It will be noticed that the diameter of the head is smaller than that of the nut, and also that the head and nut are each equal in thickness to the diameter of the bolt. These bolts have hexagonal heads and nuts. Fig. 9 shows the ordinary, rough machine bolt. It has a square head and nut, each slightly thinner than the diameter of the bolt, and has no machine finish but that on the thread. The hole for it is always drilled somewhat larger than the nominal diameter of the bolt, to allow for the roughness of the unfinished body.

Fig. 10 shows what is known as a carriage bolt. The head is quite flat, and for a short distance under it the body is square to prevent it from turning when driven through wood. It is a rough bolt, slightly finished on the head, and has a peculiar form of deep, square thread, and a rather thin, square nut. Fig. 11 shows what is known as a stove bolt. This may have either the flat (countersunk) head shown, or a round head as shown for machine screws. Stove bolts are made in machine screw sizes with threads cut only a short distance from the point, and are provided with a quite thin, square nut. While originally designed for fastening the parts of stoves, they are frequently found very convenient for many other kinds of ordinary unfinished work.

The different forms of bolts are drawn in a similar manner to that described for drawing machine, cap and set-screws. In practice it will be found that there is a considerable variation in bolts made by different manufacturers, so that it is difficult to fix any exact rules for their representation on drawings, although the proportions shown in Figs. 8, 9, 10 and 11 are accurate enough for all practical purposes. In addition to drawing the proper form of bolt, it is well to mark upon the drawing the dimensions of the bolts, as "½" by 3" machine bolt." It should not be forgotten that in giving the lengths of bolts, allowance must be made for the thickness of the nut, since bolts are measured from under the head to the point, regardless of the nut.*

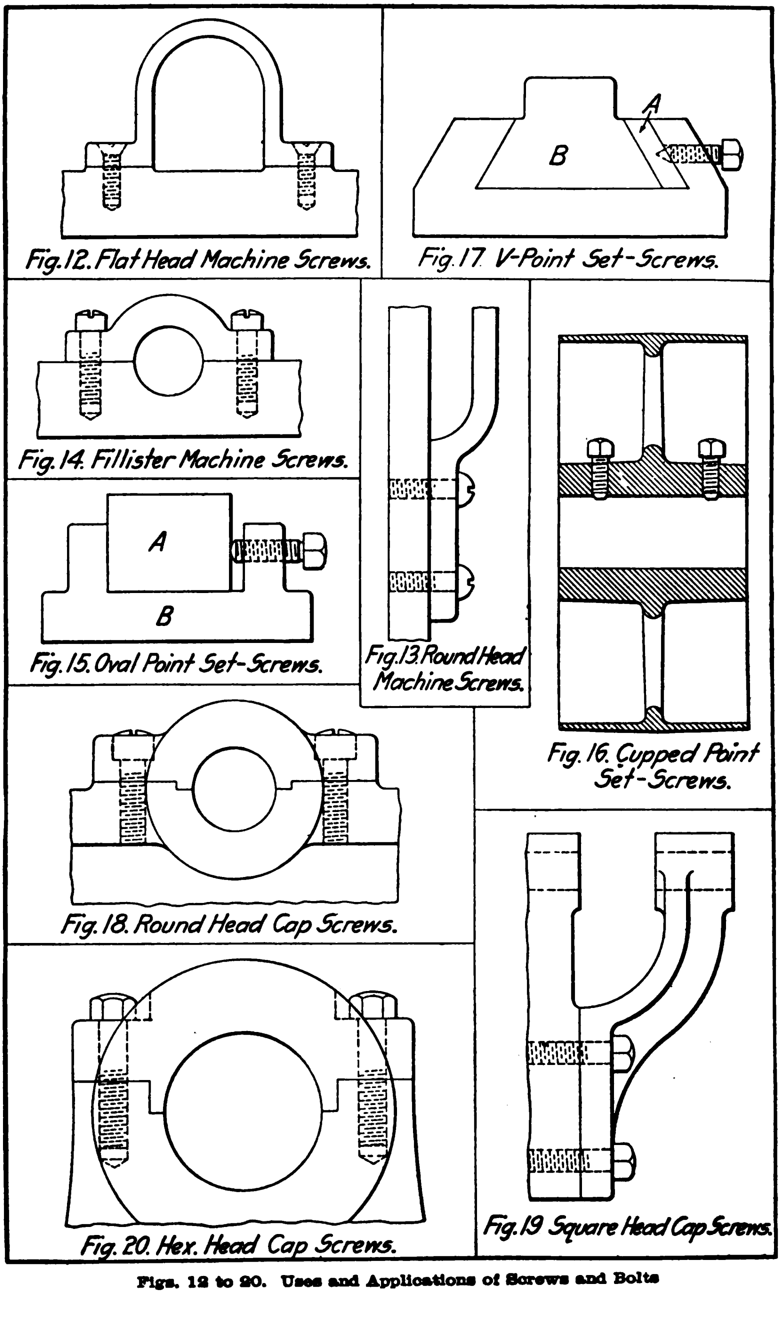
Application of Screws and Bolts

The large number of errors found in shop drawings in showing the screws and bolts, very clearly indicate either a rather vague idea of the proper class of fastenings to use, or a good deal of carelessness in their correct use. There is no excuse for carelessness in this respect, since each different form of screw or bolt has been developed for some special use, to which it is better adapted than for any other purpose. To make the uses of the various screws and bolts just shown and described more plain and conveniently remembered, small portions of drawings are presented in the following, in which the screws and bolts are used in connection with the proper machine parts to which they are best adapted.

Fig. 12 shows one of the ordinary uses of flat head machine screws. They are used for fastening comparatively small and simple pieces, and in cases where projecting heads would be in the way, or objectionable for other reasons. Fig. 13 shows a somewhat similar use for round head machine screws. In this case they are used for fastening a small bracket, in a place where the projecting head is not objectionable, but rather adds to the appearance of the device. Fig. 14 shows a common use of fillister head machine screws. In this case they are used for securing the caps of a bearing for a small rod or shaft. There are some limitations to the use of machine screws on account of the manner in which they are usually made. They fit rather loosely in the tapped hole, and therefore cannot be depended upon to stay in place unless screwed down very tightly. The heads of the fillister head machine screws are seldom fitted into a counter-bored hole as they are liable to vary too much in diameter to insure a good fit.

Fig. 15 shows the most simple use of the oval point set-screw. This is a simple planing or milling fixture, and the use of the set-screw is to clamp a piece of work *A* in the fixture *B*. Many similar uses for this form of set-screw will be found in practice. Fig. 16 shows one of the most common uses of the cupped point set-screw, that of securing a pulley upon a shaft. This method is frequently used for pulleys, gears, collars and similar pieces, as the sharp edges of the cupped point cut slightly into the shaft and hold the part firmly. Where considerable holding power is required, recourse should be had to a key-

*For dimensions of screws and nuts according to the standard of a leading machine tool building concern, see MACHINERY'S Data Sheet Series No. 2, "Screws, Bolts and Nuts," pages 4, 5 and 6.



Figs. 12 to 20. Uses and Applications of Screws and Bolts

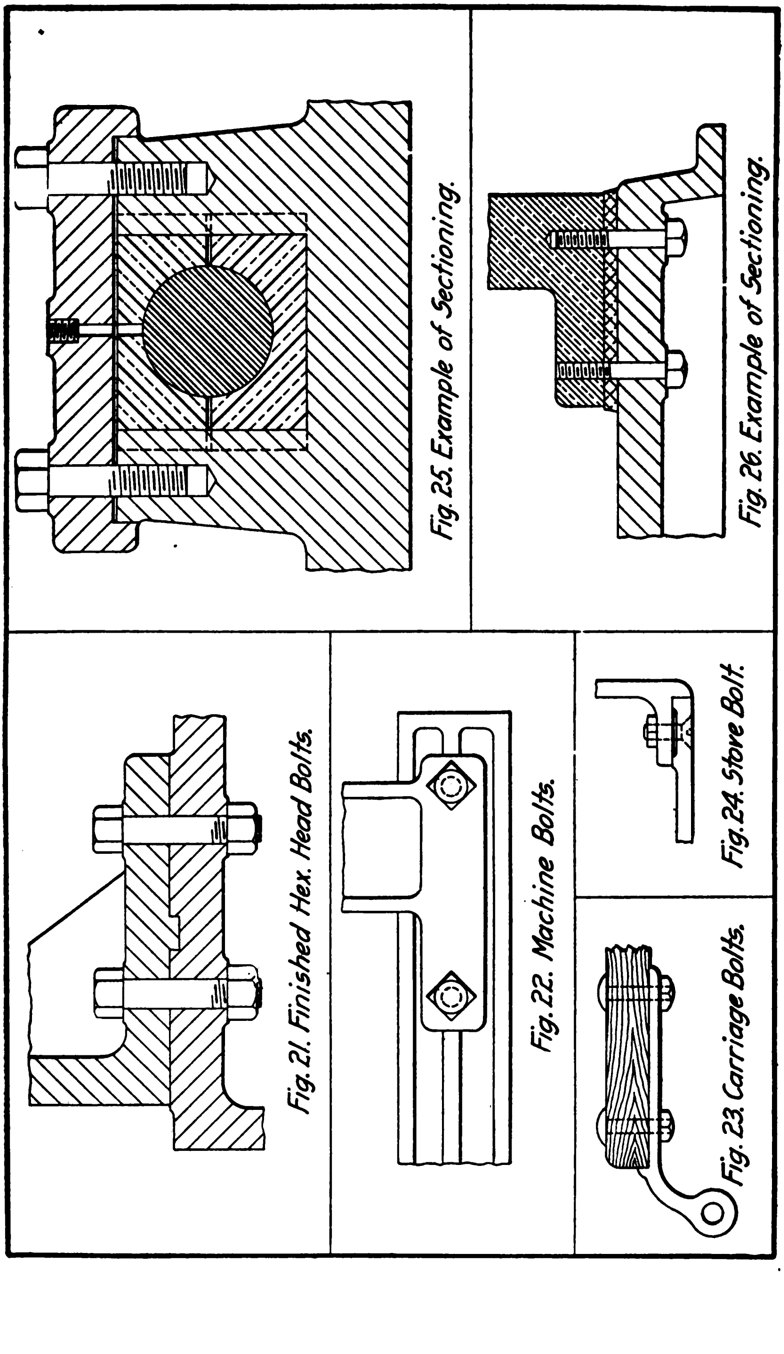
way and key. In addition to this means, set-screws are sometimes used, either on top of the key to prevent it from becoming loosened, or at points 120 degrees each way from the key, to provide for additional resistance.

Fig. 17 shows the ordinary use of V-point set-screws. These are generally used in cases where the point must bear against angular or inclined surfaces, as in the present case, where a gib *A* is pressed against a moving inclined surface *B*. It is necessary to keep the gib *A* from sliding back and forth with the moving part *B*. Sometimes screws used for this purpose have the point turned to about half the diameter of the body of the screw, for a short distance, the end being beveled or made of V-form, and fitted to a shallow hole in the gib. As already mentioned, such a screw is generally called a gib screw. Set-screws are often provided with thin nuts called check nuts, screwed nearly up under the head before the screw is put in place. When the set-screw is screwed down sufficiently, the check nut is screwed tightly against the surface of the piece, and thus prevents the set-screw from becoming loosened.

Fig. 18 shows the most common form and use of round head cap screws, that of holding down the caps over small shaft journals. Cap screws are usually uniform in the diameter of the head and body, and the form and diameter of the thread. Hence, they can be accurately fitted, both as to the head and the body. The round head screw is generally used to a much greater extent than the other forms of cap screws, although the fact that it must be handled by a screw driver rather than a wrench restricts its use in cases where a great amount of holding power is required. Fig. 19 shows the ordinary use of square head cap screws. In this case they are used for holding in place a cast iron bracket, forming an outer bearing for a shaft. While hexagon head cap screws might be used in a similar place, the square head screws seem to be preferred by many mechanics.

Fig. 20 shows the use of hexagon head cap screws, which are the most reliable of all fastenings, with the exception of a bolt and nut supplemented by a check nut, or a stud threaded on both ends, the lower end being screwed into the main casting and the upper end coming up through the cap or upper piece and provided with a nut and check nut. Used as shown in the engraving, these cap screws should be accurate as to the diameter of the body and the form and diameter of the thread, so as to fit closely in all drilled and tapped holes. The surface around the hole must be faced off so as to give a fair bearing for the under side of the head.

Fig. 21 shows one of the ordinary uses of the finished hexagon head bolt. This bolt should be well fitted to the hole, and the surfaces upon which the head and nut rest should be faced so as to give them a fair bearing. This bolt is used in the best classes of machine work. Fig. 22 shows the use of the rough machine bolt, which is ordinarily used for fastening together the rough cast parts of common machine frames, but is never used on first-class machine work. It is, however, much used for fastening frames of wood together, and for fastening



Figs. 21 to 26. Applications of Bolts, and Examples of Sectioning iron parts to wood frames. When used on wood work, thin iron or steel washers are placed under such heads and nuts as would otherwise come in contact with the wood.

Fig. 23 shows a familiar use of carriage bolts, showing them used to fasten the joint-iron to the shaft of a carriage. They are useful in many cases where light forgings or sheet metal parts are to be fastened to wood parts. The flattened head and the thin nut increase the usefulness of this bolt for most of the purposes for which it is used. Fig. 24 shows one of the most common uses of the stove bolt, that of fastening two thin castings together. A stove bolt is really only a machine screw to which a thin square nut has been added.

CHAPTER II

DRAWING OF MACHINE PARTS

By the terms "section" and "sectioning" on a mechanical drawing we understand the representation of related or connected parts as they would appear if cut through on a certain line, usually specified, as, for instance, "Vertical section on line *A-A*." The purpose of showing parts in section is to indicate the design and construction, and the form of the parts, in a more graphic manner than by the usual plans, elevations, etc. Another advantage in thus showing the parts is that it permits the use of certain conventional methods of distinguishing the materials of which the parts are made. It is to this latter feature that attention is now directed.

On some kinds of drawings, as, for instance, those for exhibition purposes, or those used as exhibits in courts, the sections of the various parts are usually indicated by appropriate water colors, representing different materials. In making tracings upon tracing cloth it is sometimes customary to indicate the different materials by the use of a soft pencil on the back or dull side of the cloth. But the more general, and by far the better, method is by the use of various conventional forms of section lining on the face of the tracing cloth, or the drawing, when it is "inked in."

Fig. 27 shows a system of representing the different materials by means of combinations of diagonal, parallel lines; lines and dots; and two series of such lines drawn at right angles to each other.*

* There is no universally adopted standard for cross-sectioning for the purpose of indicating different materials. The chart shown does not agree fully with the charts given in any of a number of other text-books on mechanical drawing, but as these at the same time do not agree with one another, it has been assumed that the chart above represents as good practice as those in other text-books. A chart, similar to this, but differing in a few instances, and more extensive, was given in MACHINERY'S Data Sheet No. 15, December, 1902. Another chart is given in MACHINERY'S Reference Series No. 2, "Drafting-Room Practice." There being no recognized standard, however, cross-sectioning alone should never be depended upon for indicating materials to be used. Written directions should also be given, or a small chart placed in a corner of the drawing, indicating the conventions used in designating the various materials.

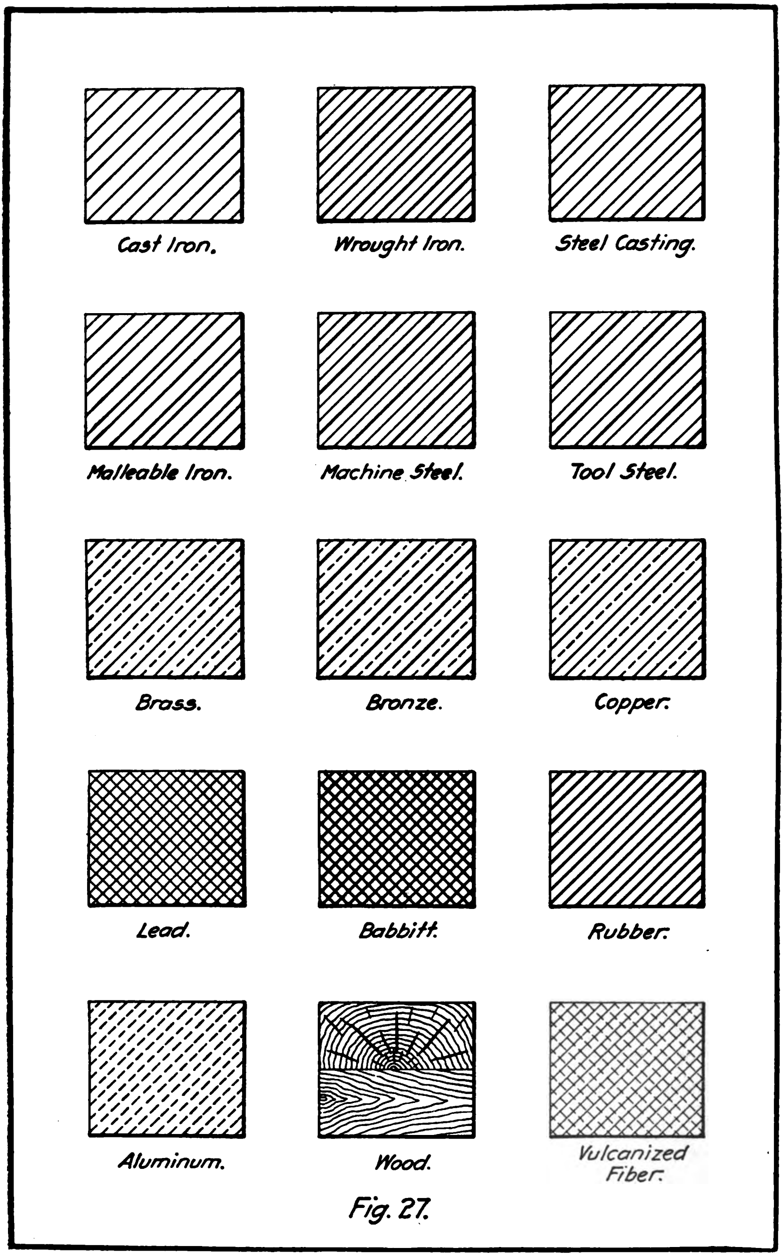


Fig. 27. System of Cross-sectioning to Indicate Materials

Figs. 25 and 26 give typical examples of sectioning, showing the usual manner of applying the methods shown in Fig. 25. It will be noticed that all section lines are drawn at an angle of 45 degrees with the horizontal and vertical lines. This is for the purpose of showing them in contrast to the other lines and thus emphasizing their purpose. The section lines of the most prominent piece are usually drawn from the lower left-hand corner to the upper right-hand corner. Those for adjacent parts are, as far as possible, drawn at right angles to these, and so on, changing the direction of the lines so as to make the several pieces as distinct, one from the other, as possible. These examples should be carefully studied.

Free-hand Sketching

Free-hand sketching is here introduced as it is necessary to be able to sketch various parts of machines, to take sufficient measurements, and to write in these dimensions on the sketch, and thus make a record of sufficient data from which a working drawing may be made. The ability to make a rapid, even though rough, sketch which, with the dimensions given, will show to the mechanic just what is wanted, should be acquired by every draftsman.

Fig. 28 shows a sketch of this kind, to be sent to the forge shop. From it the blacksmith may get as clear an idea as to what is wanted as from the most finished drawing. The same may be said of the sketch for a pattern shown in Fig. 29, when sent to the pattern-maker. For a temporary pattern it is all that is necessary. Frequently, a forging for a brace, or a similar piece of forging, is required. Fig. 30 shows how it should be sketched, including detached views at the ends, the relative position of the bolt holes, etc. Fig. 31 shows two views of a special wrench. All necessary dimensions are given to enable the blacksmith to do the job without waiting for a drawing made to scale. Fig. 32 is an example of a sketch made to locate the bored holes in a portion of a machine frame that has already been made, and the distances on which are required for laying out a subsequent drawing. With either one of the three holes determined on a drawing, the others can be readily located from the dimensions given.

Machine Drawing

In the following pages the drawing of minor machine parts is illustrated and discussed as the next progressive steps in the practice of machine drawing, some more or less complicated parts having been chosen as examples. In most cases either an elevation and a section are given, so as to show interior construction lines, or two elevations are shown, one or the other method being used according to which may seem best adapted for showing the construction in the most graphic manner. All of these examples should first be carefully studied for the purpose of learning why each part is represented as it is, and then, carefully laid out. Draw them first in light pencil lines, and then ink in all lines that are to appear in the finished drawing.

Shade lines are to be drawn on the lower and right-hand side of all raised portions, and on the upper and left-hand side of all depressed

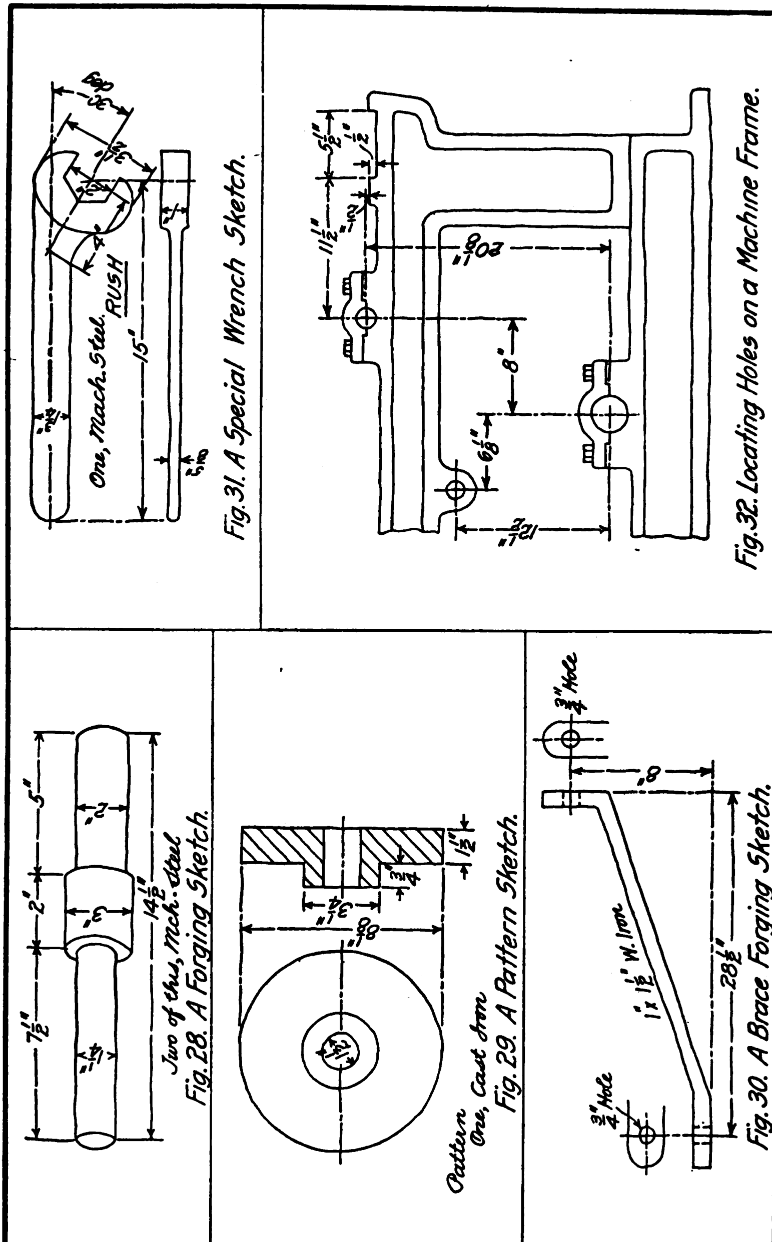


Fig. 31. A Special Wrench Sketch.

Fig. 32. Locating Holes on a Machine Frame.

Fig. 28. A Forging Sketch.

Fig. 29. A Pattern Sketch.

Fig. 30. A Brace Forging Sketch.

Figs. 28 to 32. Examples of Free-hand Sketching of Machine Details surfaces, in the manner shown in the illustrations. In doing this work, the drawings of Figs. 33, 34, 35, and 36 may be drawn to the same scale as shown. All the others should be drawn on a scale of from one and one-half to two times the size of the illustrations.

Dimensions have been purposely omitted on the plates, so as to give the student an opportunity of working out this important feature of the work himself. Dimension lines should, however, be drawn, and figures written in, by taking the necessary measurements by a scale on the drawing. General directions for the drawing work will be given for each sheet or plate; these directions should be carefully studied before commencing the drawing.

A cast-iron flange is shown in Figs. 33 and 34. This is a very simple drawing and ought to be very easily laid out. First draw the vertical center line, and then the horizontal center line in Fig. 33. Draw the circles representing the diameters of the hole, the hub and the outside, and also the circles showing the six bolt holes. The location of two of the bolt holes is on the horizontal center line. Locate the other four by the use of the 60-degree angle, drawing lines from the center of the flange. Lay out the keyway at *A*. The width of this is usually from one-fifth to one-fourth the diameter of the hole. The depth should be one-half the width. Draw the section shown in Fig. 34, projecting horizontal lines across from Fig. 33 where possible. Draw the dimension lines, determine the dimensions by a scale, and write the proper figures as plainly as possible, and in the manner shown previously in this treatise. (See Part II, Chapter II). Draw the diagonal section lines; in doing this, use the 45-degree angle and draw the lines all of even width and with as regular spacing as possible. Irregularity in this respect is a serious defect in the appearance of a drawing.

A flange coupling for connecting shafts is shown in Figs. 35 and 36. This drawing is quite similar to that shown in Figs. 33 and 34, but is somewhat more complicated and shows several parts assembled in a complete group. Proceed to lay out the work as in the former example, so far as the directions there given will apply. In drawing the hexagonal nuts, first draw circles equal to the distance across the flat sides, and around these circles draw the hexagons by the use of the T-square and the 60-degree angle. Project lines from the corners of the hexagonal nuts at *A* in Fig. 35, to obtain the sides of the nuts and bolt heads in Fig. 36. Be very careful to draw the arcs representing the top of the bolt head and chamfer of the nuts exactly as represented, so as to give a neat, finished and correct appearance. To effect this, the radius of the arcs must be drawn as directed in the previous chapter. Notice that the ends of the two shafts connected by this coupling meet in the center of Fig. 36; also note that the two parts of the couplings are held central with relation to each other by a circular recess turned in one of them and a corresponding projection turned on the other. Draw dimension lines, and after carefully measuring the various parts, write in the dimensions as before.

A crank for a steam engine is represented in Figs. 37 and 38. This

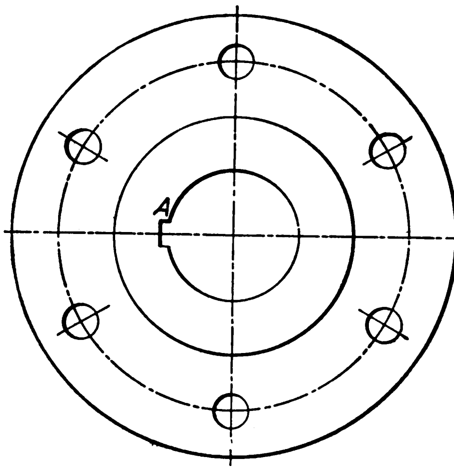


Fig. 33. Plan.

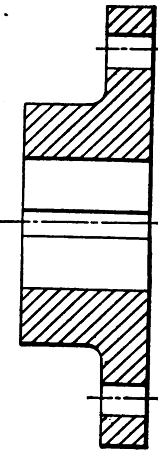


Fig. 34. Cross Section.

Cast Iron Flange.

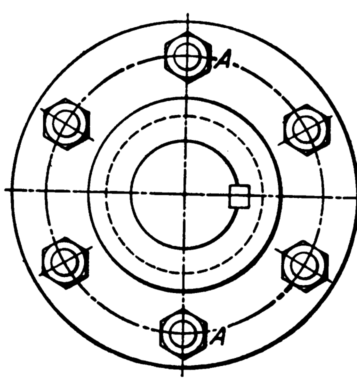


Fig. 35. Elevation.

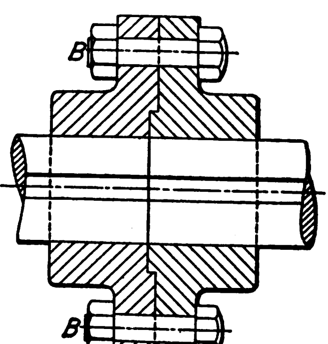
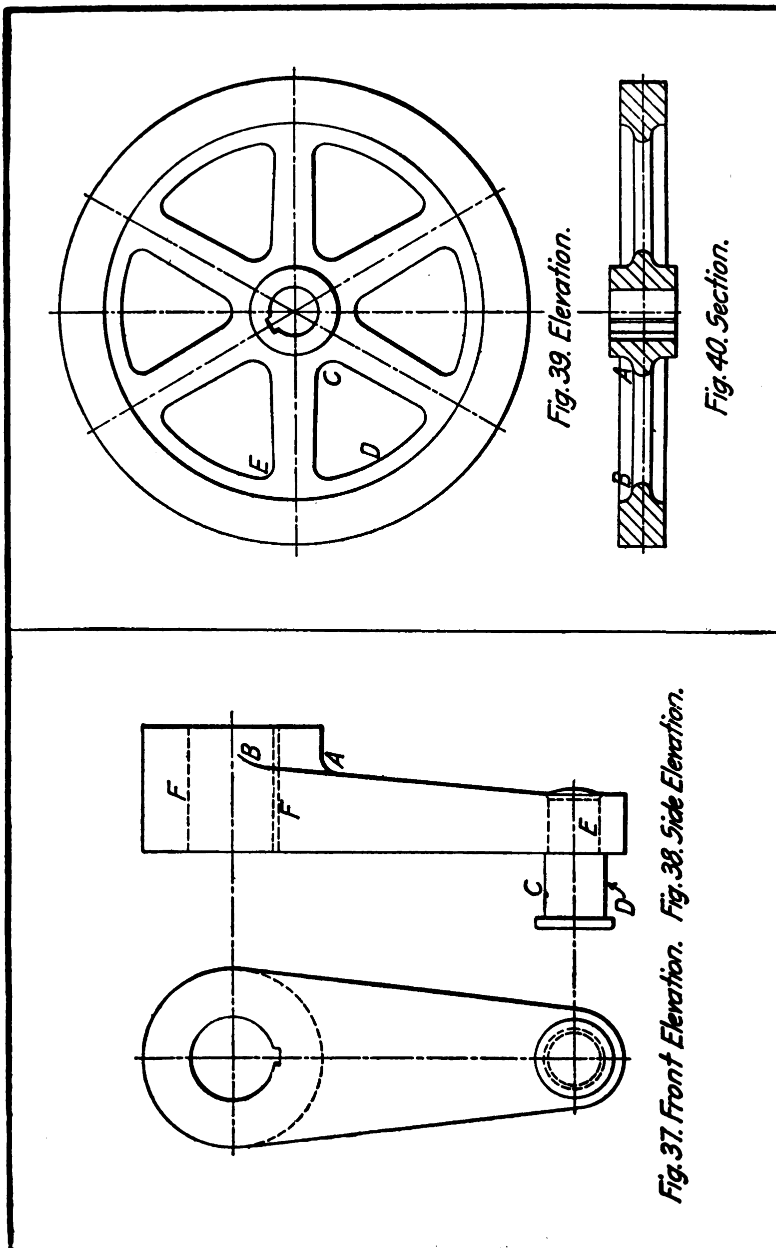


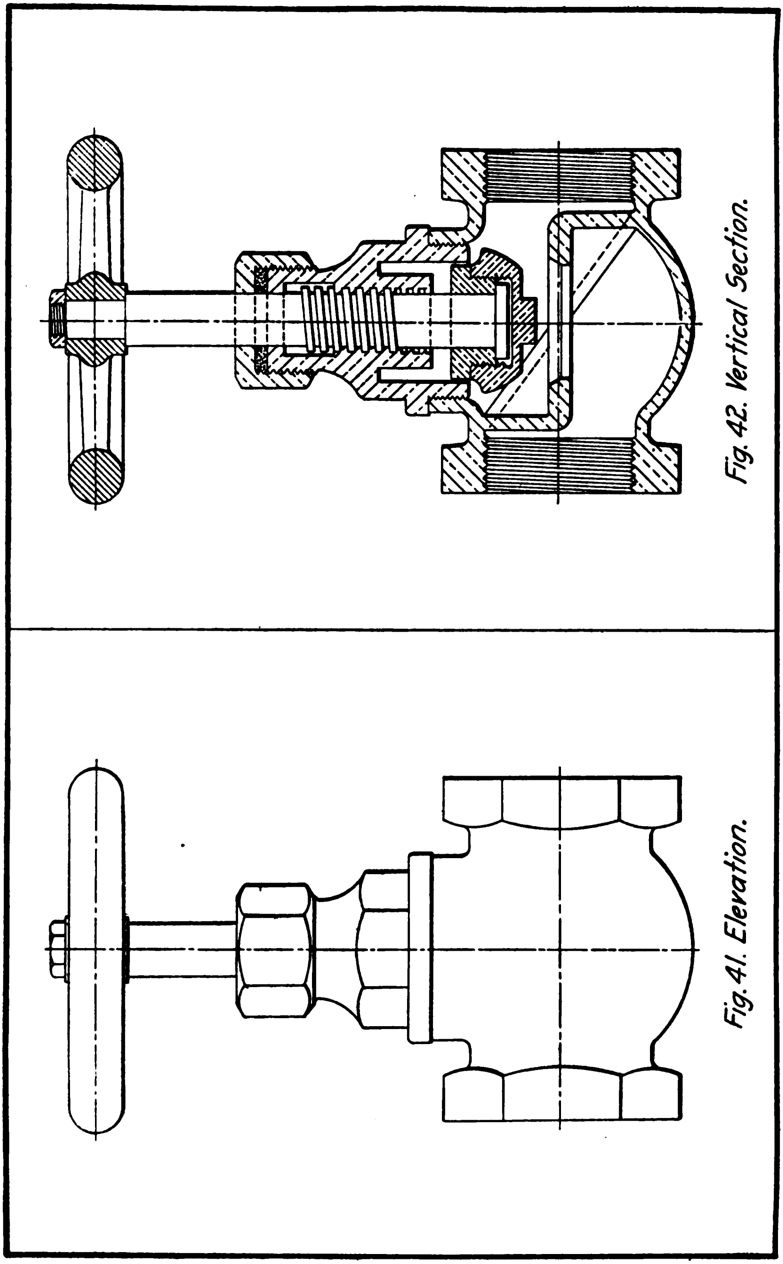
Fig. 36. Section.

Cast Iron Flange Coupling.

Figs. 33 to 36. Flange and Flange Coupling



Figs. 37 to 40. Crank and Fly-wheel



Figs. 41 and 42. Globe Valve

should be drawn one and one-half times the size here shown. First draw the center lines, and then the circles in Fig. 37. Add the inclined side lines, and lay out the keyway. Represent by dotted circles the parts that are not seen. Project from Fig. 37 all the lines possible for obtaining Fig. 38. Lay out the other lines by careful measurements. Notice the fillet at *A* and the slight curve at *B* in Fig. 38. The first is for the purpose of strengthening the connection between the hub and the arm; the latter curve is due to the inclined side in Fig. 37, joining the cylindrical part of the hub. Notice also that the crank-pin *C* is driven tightly through the lower end of the crank and riveted, the rear end of the hole in the crank being slightly countersunk for that purpose.

In Fig. 37 the circle representing the bearing *D* of the crank-pin *C* and its shank *E*, passing through the crank, is represented by dotted circles as these parts are hidden. The shank, and the lines representing the shaft hole *F*, Fig. 38, are shown by dotted lines for the same reason. Complete the drawing by adding the proper and necessary dimension lines and figures, as in the previous examples.

A fly-wheel is shown in Figs. 39 and 40. These two views are to be drawn at least twice the size shown, so that there may be ample space in which to draw the smaller arcs at the hub and rim in both views. Draw first vertical and horizontal center lines, and then the circles for the hole and hub, and for the inside and the outside of the rim. Draw center lines for the arms, using the 60-degree angle. Carefully space off on each side of these the width of the arms, observing that they are wider at the hub than at the rim. Draw the sectional view in Fig. 40, showing the thickness of the arms, and also the strengthening webs *A* at the hub and *B* inside the rim. With the dividers transfer the required measurements relating to these webs from Fig. 40 to Fig. 39, so as to locate the curve at *C* and the circle *D*. Draw the small arcs at *C* and *E* for all the arms. Then lay out the keyway and project lines from it to the hole in Fig. 40 as shown. Draw the cross-section lines in Fig. 40. Draw dimension lines where necessary, and write in the figures after careful measuring.

A globe valve is represented in Figs. 41 and 42. It should be drawn at least twice the size shown. Proceed as before, drawing the center lines first and making careful measurements, preferably with the dividers, of all points necessary for an accurate drawing. Complete Fig. 41 in all its details before commencing to draw Fig. 42, as there are many points which may be easily transferred from Fig. 41 to Fig. 42. Much care is required in laying out Fig. 42, as the thickness of metal must be maintained, and the distances on each side of the center line very accurately laid out.

In laying out threads, draw a line for the top and another for the bottom of the thread. Then lay out the form of the thread, as on the valve stem. Then draw the parallel lines representing the thread, making them at such an angle that their inclination will be exactly one-half the pitch of the thread. Remember that all threads are right-

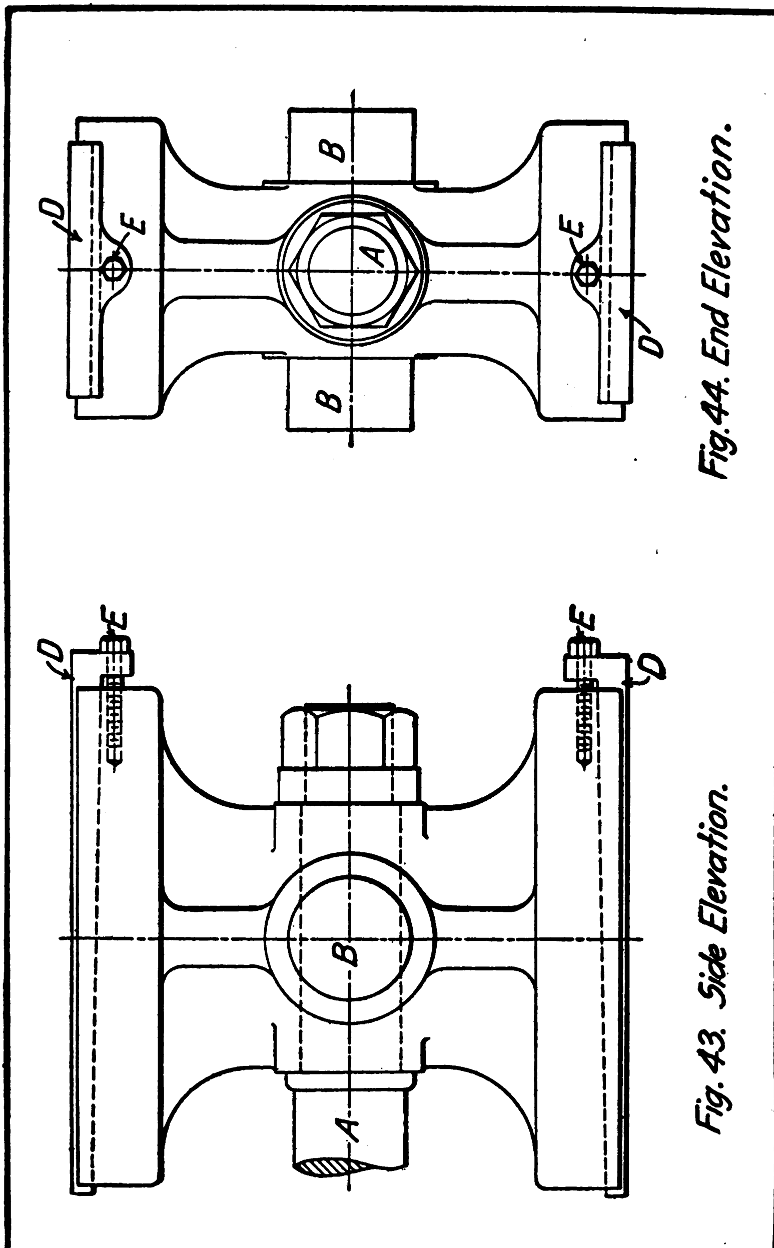


Fig. 43. Side Elevation.

Fig. 44. End Elevation.

Figs. 43 to 44. Steam Engine Cross-head

hand unless specified left-hand, and that a thread upon a cylinder, or a bolt, will show right-hand, while an internal thread, as in a nut, if shown in section will be inclined in the opposite direction, although both are right-hand threads. Carefully draw all section lining, noting that while the body of the valve and its interior parts are of brass, the hand-wheel is of cast iron. Lastly add dimensions and figures wherever they may be necessary.

A cross-head for a steam engine is shown in Figs. 43 and 44. This drawing should be made at least twice the size shown. Both of these views are elevations, or exterior views. Fig. 43 represents the side elevation, or the front of the cross-head, as we face the front side of the engine. *A* is the piston-rod and *B*, *B*, are the trunnions upon which one end of the forked connecting rod is journaled, while the opposite end fits upon the crank-pin *C*, Fig. 38. The upper and lower surfaces of the cross-head are fitted to and slide upon the guiding surfaces attached to the main frame of the engine and guide the cross-head in a straight line. *D*, *D*, are bronze wearing pieces of wedge-like form, held in place and adjusted to position by the hexagon head cap screws *E*.

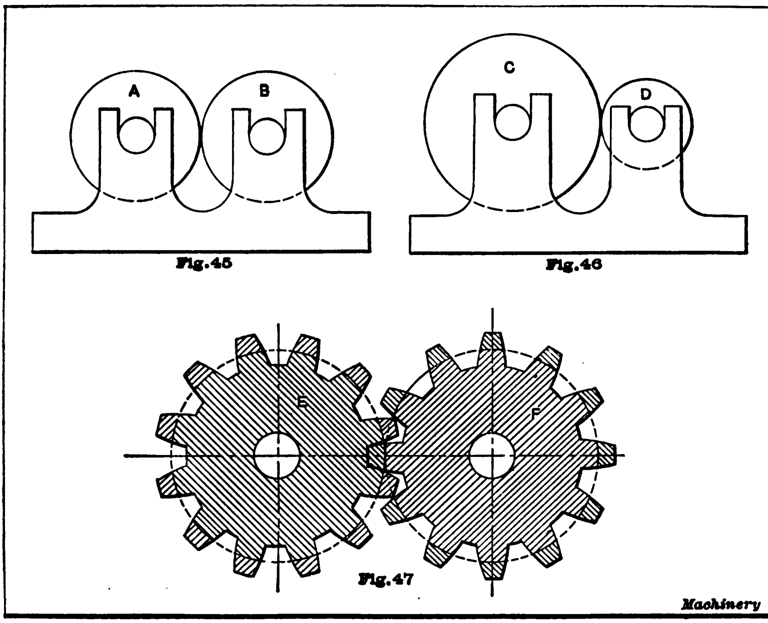
In drawing these two views, we first draw center lines, and then the principal circles in both views, working alternately on one view or the other as is most convenient, and always projecting points and lines from one view to the other when possible, as this is quite as accurate and may be more quickly done than by taking measurements. Be very careful in setting off distances with the dividers, so as to have them the same on each side of the center line.

There are two important objects which the student should have in view when drawing the examples given. First, he should train himself to draw machine details on an arbitrary scale different from that shown, and, second, he should measure and write in all dimensions, and calculate such other dimensions as are necessary, by the adding of several detail dimensions to find a dimension "over-all." This will necessitate very thorough and careful work, as there must be sufficient dimensions to enable a machinist to accurately make the piece, when a single piece is concerned, or to fit the parts together and assemble them, when a group of parts are represented.

CHAPTER III

THE DRAWING OF SPUR GEARS AND RACKS

The principles of toothed gearing must be fully understood before any attempt is made to represent gears in a drawing. Toothed gearing was doubtless originally suggested by, and developed from, two cylinders rolling in contact with each other, and in the endeavor to prevent any slipping between the two. This condition is graphically shown in Fig. 45. It is readily seen that if both cylinders are of the same diameter, as shown at *A* and *B*, they will revolve with equal speed,



Figs. 45 to 47. Principles of Toothed Gearing

that is, if *A* is revolved through one complete revolution, the cylinder *B* will make one complete revolution also. But, if one cylinder is twice the diameter of the other, as at *C* and *D*, Fig. 46, the smaller cylinder must make two revolutions while the larger makes but one. Simple cylinders would, however, transmit but little power, owing to their liability to slip when in contact with each other, and to avoid this difficulty, they are provided with teeth, those of one cylinder meshing with those of the other.

We cannot form the teeth entirely by cutting grooves in the cylinders, because we should then have to move the cylinders nearer

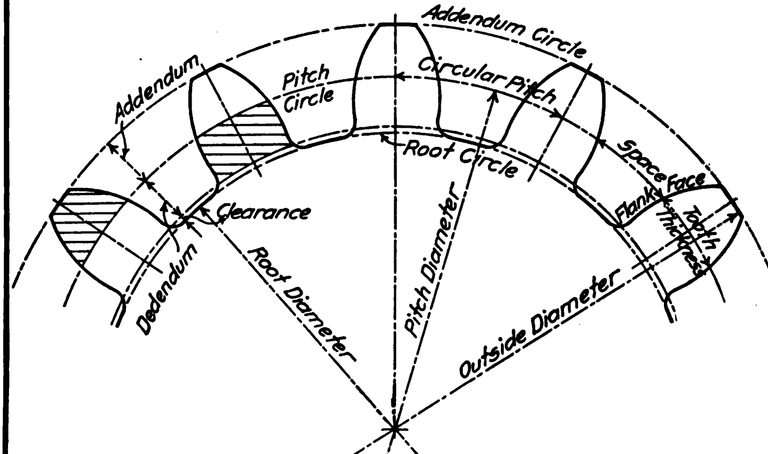


Fig. 48. Diagram of Tooth Parts.

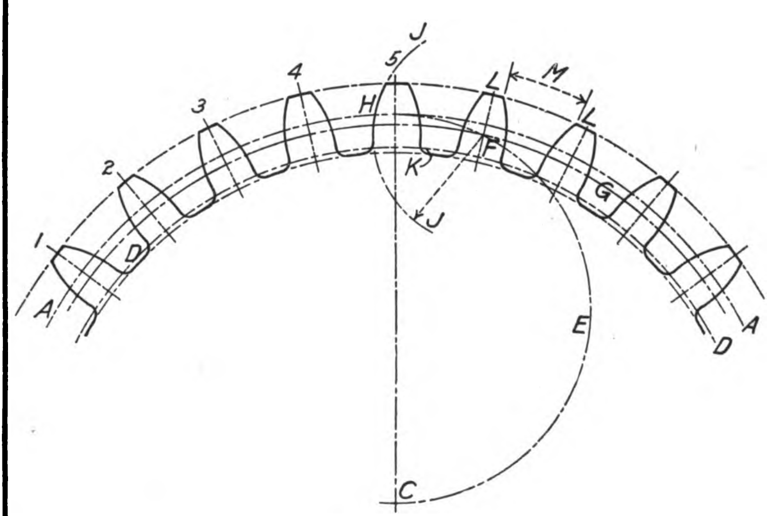


Fig. 49. The Involute Form of Gear Teeth. For Gears of 30 Teeth or Over.

Figs. 48 and 49. Laying out Gear Teeth

together in order that the teeth may properly mesh or interlock; and this would have the effect of changing the diameters of the cylinders and hence their relation to each other, when one is larger than the other. Neither can we form teeth by attaching strips to the cylinders for the reason that this also would change their relative diameters, causing them to be moved further apart. Therefore, we must adopt a plan midway between these two, which will retain the cylinders in their original positions. We cut grooves one-half as deep as the teeth are to be, and add strips to represent the other half, as shown at *E* and *F*, Fig. 47. By this means the centers of the cylinders remain in their original position, and their relative diameters are unchanged, the added parts of one cylinder entering into the grooves of the other.

We will now consider the method for determining the number of teeth. The peripheries of the cylinders forming the rolling contact are the basis upon which all calculations of speed and the number and dimensions of the teeth are made. The circles representing these cylinders are called the pitch circles. The other terms relating to gear teeth are given in the diagram, Fig. 48. These terms should be thoroughly memorized. It will be seen that the addendum circle is the same as the outside diameter, that is, the diameter over the ends of the teeth. The circular pitch is the distance from the center of one tooth to the center of the next, when measured along the pitch circle. The pitch diameter is the diameter of the pitch circle, and the root diameter is the diameter of the root circle, or the diameter at the bottom of the teeth. The face of a tooth is that portion of the curve of the tooth outside of the pitch circle, and the flank is that portion within the pitch circle. The width of the tooth is called the thickness and the portion between the teeth is called the space.

In the past, all gears were designed with reference to the circular pitch of the teeth. This distance multiplied by the number of teeth, gives the circumference, which in turn, divided by 3.1416, gives the pitch diameter. This method of calculation of the various parts of the teeth proved very tedious, and in consequence some more simple system was sought for; thus the diametral pitch system was finally developed. In this system the diametral pitch, which indicates the ratio between the number of teeth in the gear and the diameter of the pitch circle in inches, is made the basis of the system. The number expressing the diametral pitch gives the number of teeth in the gear for each inch of the diameter of the pitch circle. Consequently if a gear is 8 diametral pitch and 10 inches in diameter, it will have 80 teeth, and if 5 inches in diameter, it will have 40 teeth, and so on.

We may, therefore, deduce three very simple rules for designing gears, obtaining the proper number of teeth, determining the diameter of the pitch circle, etc. These should be committed to memory:

1. Multiply the pitch diameter by the diametral pitch to obtain the number of teeth.

2. Divide the number of teeth by the pitch diameter to obtain the diametral pitch.

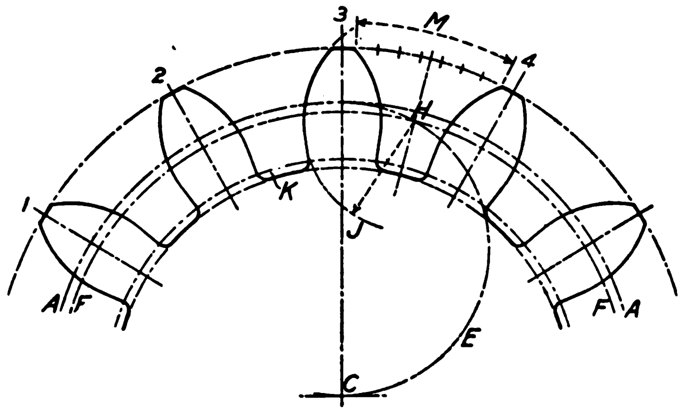


Fig. 50. Involute Teeth. For 12 to 18 Teeth.

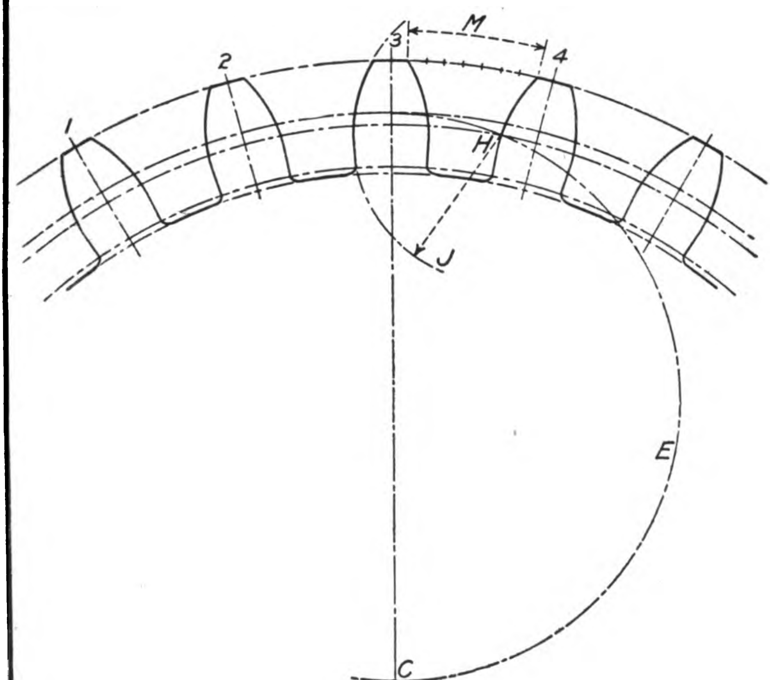


Fig. 51. Involute Teeth. For 19 to 29 Teeth.

Figs. 50 and 51. Laying out Involute Gear Teeth

3. Divide the number of teeth by the diametral pitch to obtain the pitch diameter.

The proportions of the parts of the teeth are based upon equally simple rules. The addendum, in inches, is equal to one divided by the diametral pitch. Therefore, on a gear of 8 diametral pitch, the addendum is ⅛-inch. The dedendum equals the addendum. The clearance at the bottom of the teeth is equal to one-tenth the thickness of the tooth at the pitch line. The relation between the thickness of the tooth at the pitch circle and the width of the space at the same point varies with the dimensions of the tooth. In accurately cut gears this clearance amounts to from 0.02 to 0.03 of the circular pitch, and is intended to be only sufficient to permit the teeth to roll freely into the spaces.

The development of gear tooth curves is a matter requiring much careful attention. Formerly the epicycloidal curve was considered proper for the teeth of gears, since it is a curve traced by a point in one circle rolling upon another. But the curves for the teeth of two wheels of dissimilar diameters would so vary in form that neither would run properly with other gears of a much different diameter. This condition led to such a great variety of patterns when teeth were cast, and of cutters when teeth were cut from the solid, that the method was very troublesome and expensive.

The involute curve was tried and it was found to possess several important advantages over the epicycloidal. There is no undercutting of the flank of the tooth. Gears with any number of teeth will run with other gears of the same pitch and of any number of teeth. This last is the most important advantage.

Cutters properly shaped for involute teeth may be used for several different numbers of teeth, consequently the numbers of cutters of each pitch is much reduced, as will be seen from the following table, which shows the number of teeth cut for each different arbitrary number of cutters:

No. 1 will cut from 135 teeth to a rack.
No. 2 will cut from 55 teeth to 134 teeth.
No. 3 will cut from 35 teeth to 54 teeth.
No. 4 will cut from 26 teeth to 34 teeth.
No. 5 will cut from 21 teeth to 25 teeth.
No. 6 will cut from 17 teeth to 20 teeth.
No. 7 will cut from 14 teeth to 16 teeth.
No. 8 will cut from 12 teeth to 13 teeth.

The involute curve is one that may be traced mechanically by a point at the end of a cord as it unwinds from the surface of a cylinder, as has been previously explained in Part I of this treatise. In drafting practice, a single arc very nearly approaching the true involute is used for the curve of the tooth, including the face and the flank. This method of drawing is illustrated in Fig. 49, in which *A* is the pitch circle, *C* the center of the gear, and *D* the working depth of the tooth. To obtain the curve necessary for the sides of the teeth, we lay off on the pitch circle the spaces 1, 2, 3, 4, 5, equal to the circular pitch, and draw radial lines through them from the center *C*. Then draw the semi-circle *E*, equal in diameter to the radius of the pitch circle *A*. Through the point *F* where the circle *E* intersects the radial lines through the center of the tooth, draw the base circle *G*. From the radial lines *L*, indicating the centers of the teeth, space off on each side, upon the pitch circle, one-half the thickness of the tooth. With a radius equal to the distance from the point *F* to the point *H*, and with *F* as center, draw the curve *JJ* which will be the curve of the tooth. With the other points where the base circle intersects the radial lines as centers, draw the remaining curves of the sides of the teeth. Then draw another circle inside of the dedendum circle *D*, this circle to be sufficiently smaller to provide for the bottom clearance, and make the radius of arc *K* equal to one-seventh of the distance of the space *M*. This method of laying out the curves is satisfactory for all gears of 30 teeth or more. Gears of less than 30 teeth must be treated differently, as explained below:

Gears having less than 30 teeth are divided into two classes, *viz.:*

1. Those having from 12 to 18 teeth, inclusive.
2. Those having 19 to 29 teeth, inclusive.

In both cases the semi-circle *E* is determined in the same manner as in Fig. 49; that is, its diameter is equal to the radius of the pitch circle *A*.

Then, for the first class of gears, instead of using for the center the intersection with the radial line passing through the center of the tooth as in Fig. 49, we use in this case the intersection with the radial line passing through the center of the space as in Fig. 50. The point *H*, where this line intersects the semi-circle *E*, determines the radius of the base circle *F*, and also determines the radius *HJ* of the curve for the sides of the teeth. This curve is continued below the base circle a distance equal to the distance from the base circle to the pitch circle. From here it is continued by a short straight radial line which joins the arc *K* for the bottom clearance. The radius of this arc is equal to one-seventh of the distance between the points of the teeth, this distance being divided as at *M*. It is sometimes the practice to omit the straight radial line altogether, and to continue the curve of the sides of the teeth all the way to the clearance arc *K*.

The second class of gears, having from 19 to 29 teeth, inclusive, have the center of the curve forming the faces of the teeth located at an intermediate position between the two locations shown in Figs. 49 and 50. In this case the radial line intersecting the semi-circle *E* is located at the side of the tooth, as shown at *H* in Fig. 51, and the radius *HJ* describes the proper curve for the tooth. In this case the flank of the tooth, from the arc of the face of the tooth to the clearance arc, may be a radial line. As before, the radius of the clearance arc is one-seventh of the distance between the points of the teeth, as shown divided at *M*.

These three methods of drawing the forms of involute gear teeth by describing arcs of circles and using, where necessary, short, straight lines, will be found sufficient for all practical purposes. However, it is frequently very convenient to have a table of the various parts of standard gear teeth. Such a table is given below.

In Fig. 52 is shown a spur gear and pinion drawn in accordance with the foregoing methods. The lay-outs in this chapter should be drawn several times and on different scales, so as to give ample practice. For a more thorough treatise of the calculation and design of spur gears, see MACHINERY'S Reference Book No. 15, "Spur Gearing."

The Drawing of Racks and Internal Gears

Usually there is not enough attention given to the form of the teeth of racks. Therefore, particular attention is called to the two quite

TABLE OF GEAR TEETH DIMENSIONS

Diametrical Pitch	Circular Pitch	Thickness of Tooth	Addendum	Working Depth	Whole Depth
1	3.1416	1.5708	1.0000	2.0000	2.1571
1½	2.0944	1.0472	0.6666	1.3333	1.4381
2	1.5708	0.7854	0.5000	1.0000	1.0785
2½	1.2566	0.6283	0.4000	0.8000	0.8628
3	1.0472	0.5236	0.3333	0.6666	0.7190
4	0.7854	0.3927	0.2500	0.5000	0.5393
5	0.6283	0.3142	0.2000	0.4000	0.4314
6	0.5236	0.2618	0.1666	0.3333	0.3594
7	0.4488	0.2244	0.1429	0.2857	0.3080
8	0.3927	0.1963	0.1250	0.2500	0.2696
9	0.3491	0.1745	0.1111	0.2222	0.2396
10	0.3142	0.1571	0.1000	0.2000	0.2157
12	0.2618	0.1309	0.0833	0.1666	0.1796
14	0.2244	0.1122	0.0714	0.1429	0.1540
16	0.1963	0.0981	0.0625	0.1250	0.1348
18	0.1745	0.0871	0.0555	0.1111	0.1198
20	0.1571	0.0785	0.0500	0.1000	0.1078
24	0.1309	0.0654	0.0417	0.0833	0.0898

simple but proper methods of drawing them. The first of these is shown in Fig. 53, in which *A* is the pitch line, *B* the addendum line, *D* the dedendum line, and *E* the clearance line at the bottom of the space. In this case the pitch is divided into two equal parts for the thickness of the tooth and the width of the space. The sides of the teeth are straight lines inclined 14½ degrees from a perpendicular to the pitch line, or 75½ degrees to the pitch line itself. The root of the tooth below the dedendum line is formed by an arc whose radius is one-seventh of the distance *F*, as in the former examples. The ends of the teeth may be slightly rounded or not, as may be desired. This form of rack tooth is used to mesh with spur gears and pinions having involute teeth.

Another form of rack teeth, to mesh with gears having epicycloidal teeth, is shown in Fig. 54, in which curves are used for the sides of the teeth. *A* is the pitch line; *B*, the top of the teeth; *C*, the line determining the working depth of the teeth; and *D*, the bottom of

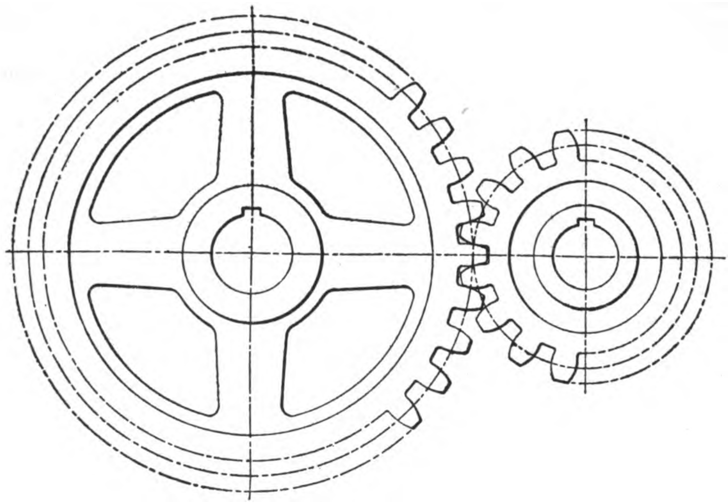


Fig. 52.

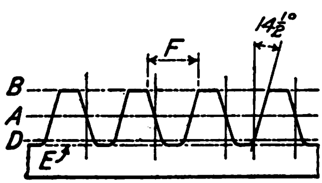


Fig. 53.

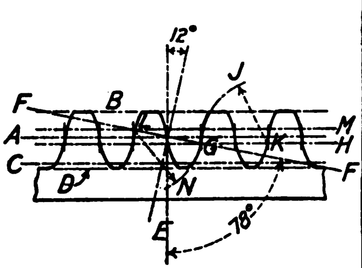


Fig. 54.

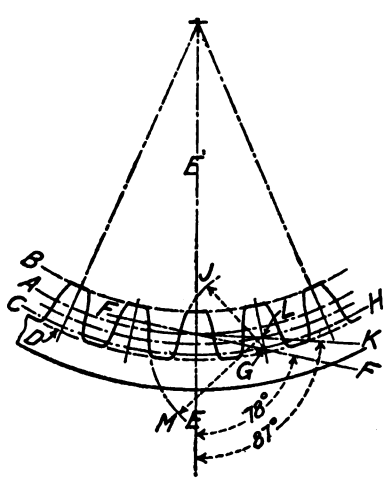


Fig. 55.

Figs. 52 to 55. The Drawing of Spur Gears and Racks

the teeth. The pitch and thickness of the teeth are laid off as before, and at the side of one of the teeth is erected the perpendicular *E*. Through the point of intersection of this line with the pitch line *A*, is drawn the line *FF*, at an angle of 78 degrees to the perpendicular *E*. Through the intersection *G* of the inclined line *FF* with the nearest side of the next tooth, draw the base line *H*, which will furnish the centers for the arcs describing the face of the teeth with the radius *JK*. The inclined line *FF*, being continued through the side of the tooth at *L*, gives the location of the base line *M*, upon which is located the center *L* for the arcs for the flanks of the teeth, drawn with a radius *LN*. The general inclination of the sides of the teeth is 12 degrees, or a perpendicular to the inclined line *FF*. The arc at the clearance line at *CD* is drawn as in the former examples.

Internal gears are drawn in a manner similar to that described in the preceding chapter for spur gears. There are, however, some differences which should be properly understood. Heretofore the gears discussed have been those whose teeth have been upon the outer surfaces of the cylinders representing the pitch circles. It often happens, however, that the smaller gear, or pinion, engaging with the larger gear cannot be located outside of the pitch circle, but for various reasons must be located within it. In these cases the teeth project inwardly from the pitch circle instead of outwardly, and we have an example of an internal gear.

In our spur gear examples we considered two cylinders rolling against each other. In the case of the rack to be used in connection with a gear or pinion, we have the condition of a cylinder rolling upon a straight line. When we consider the internal gear, as shown in Fig. 55, we have a smaller circle rolling within a larger circle. The tooth form may properly be modified so as to be represented by arcs with easily determined radii. The method of laying out the teeth is as follows:

Draw the pitch circle *A*, the addendum circle *B*, the dedendum circle *C*, and the clearance circle *D*, as before. Lay off the pitch and divide it for the thickness of the teeth and the width of the spaces as in former examples. Through the perpendicular or radial line *EE*, at the point of its intersection with the pitch circle *A*, draw the inclined line *FF*, at an angle of 78 degrees to the line *EE*, and through the point of intersection with the center line of the next tooth, as at *G*, draw the base circle *H*, which by its intersection with the center lines of the teeth furnishes the centers for the arcs describing the faces of the teeth with the radius *GJ*. Again, through the point of intersection of the line *EE*, with the pitch circle *A*, draw a second inclined line to *K*, at an angle of 87 degrees to the line *EE*, which by its intersections with the center line of the teeth furnishes centers for the arcs representing the flanks of the teeth in the manner shown, the radius being *LM*. The arc at the clearance line *D* is the same as in former examples.*

*For additional information on internal spur gears, see MACHINERY'S Reference Series No. 15, "Spur Gearing," second and following editions, Chapter III.

CHAPTER IV

THE DRAWING OF BEVEL GEARS

The proper design and construction of bevel gears will be considered in this chapter. In this case, instead of the gears being mounted upon parallel shafts, they are placed upon shafts set at an angle with each other, usually at a right angle. Instead of the gears being represented by two cylinders, they are represented by two cones rolling upon each other. This form is shown in Fig. 56, where the two cones *A* and *B* rolling in contact produce the same effect as the two cylinders shown in the chapter on spur gears. Their relative diameters govern their ratio of speed the same as in spur gears.

A pair of bevel gears is shown in Fig. 57. These gears are of the same relative proportions as the cones in Fig. 56, the triangle *ABC* representing the cone *A*, Fig. 56, and the triangle *BCD* representing the cone *B*. The calculations for the number of teeth are made from the outer ends, at *A*, *B*, and *D*, and are the same as the calculations for spur gears. The distances *AB* and *BD* are the pitch diameters. The tops and the bottoms of the teeth, as shown at *G* and *H*, are radial lines from the apex *C*, which is also the point of intersection of the center lines *CF* and *CE*.

The two shafts may be at any desired angle, but must always be in the same plane, if motion is to be transmitted by normal bevel gears, that is, by gears whose teeth are radial, or formed along lines drawn from the apex of the fundamental cone. When the teeth are not so placed, as in case of shafts not in the same plane, but passing each other on either side of the apex of the cone, the gears are said to be skew bevel gears. Such construction should always be avoided, if possible.

There are several calculations in bevel gearing not found in spur gearing. These calculations consist in accurately determining the angle of the pitch cones *ABC* and *BCD*, Fig. 57, the angle of the face of the teeth, and the angle of the bottom of the teeth, or cutting angle. From an accurate drawing these angles may be measured with a protractor. In general, however, they should be calculated as explained in MACHINERY's Reference Series No. 37, "Bevel Gearing." When the angles are written on a drawing they should be so expressed that a bevel protractor may be set against the hub of the gear, and its arm against the face angle, when turning the face. It is not convenient for the machinist to have the angles calculated from the axis of the shaft.

The portion of the spur gear tooth called the addendum is sometimes called the increment of a bevel gear, while the dedendum of the spur gear is called the decrement in bevel gears. However, these terms need not necessarily be used in describing the teeth of gears or

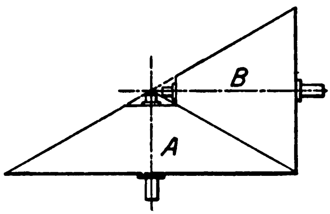


Fig. 56.

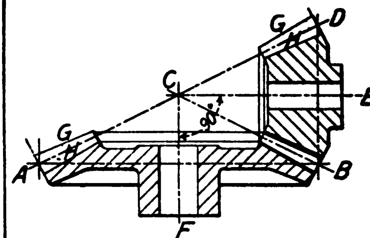


Fig. 57.

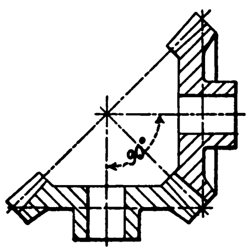


Fig. 58.

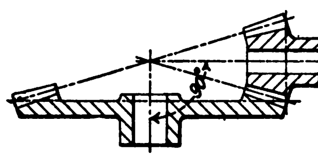


Fig. 59.

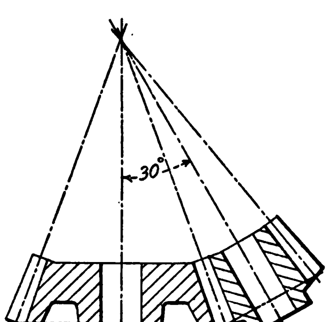


Fig. 60.

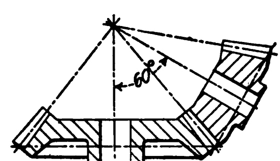


Fig. 61.

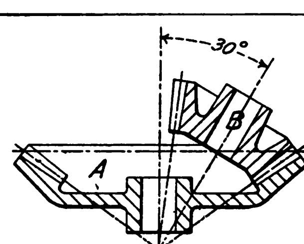


Fig. 62

Figs. 56 to 62. Bevel Gears

their parts, as the terms addendum and dedendum sufficiently describe what is meant.

In drawing a pair of bevel gears, we first draw the center lines of the shafts, that is the lines *CF* and *CE*, Fig. 57. Having determined the respective pitch diameters of the two gears, we set off the diameter of the large gear on each side of the center line *CF*, as to *A* and *B*, and draw the vertical line *BD*. On each side of the center line *CE* we set off the diameter of the smaller gear, as to *B* and *D*, and draw the line *AB*. Draw the lines *AD* and *BC*, representing the surfaces of the fundamental cones upon which the gears are constructed. The lines for the outer and inner ends of the teeth are always at right angles to these lines. At *A*, *B* and *D* set off the addendum and dedendum (above and below the pitch line), and from the points thus determined draw radial lines to the common center *C*. These lines will be the top and bottom of the teeth. Determine the width or face of the gears, remembering that it should in no case be over five times the thickness of the teeth.

Lay out the diameters of the two shafts, bearing in mind that their diameters should bear a proper relation to the diameters of the two gears. Thus, if one gear is twice the diameter of the other, the areas of the cross-sections of the shafts (not their diameters) should theoretically, bear the same proportion. The length of the bearing on the shaft should be from one to two times the diameter of the shaft. The longer this bearing is, the more rigid the gears will be, and hence the better they will run. The remaining outline of the section of the gears will depend very much upon the purpose and use of the gears, the location in which they are placed, and their relation to other parts surrounding them or connected with them.

Fig. 58 shows the outlines of a pair of bevel gears of equal diameters. These are usually called "miter gears." The included angle of the pitch cones is 90 degrees. Fig. 59 shows the most common form of bevel gears, usually called bevel gear and pinion. Fig. 60 shows the outlines of a pair of bevel gears located on shafts at an angle of 30 degrees. The method of drawing them is apparent from the illustration. Fig. 61 shows a similar pair of gears whose shafts are at an angle of 60 degrees. Fig. 62 shows a section of an internal bevel gear meshing with a pinion. In this case the gear *A* must be cut on the inside, while the pinion *B* is constructed in the usual manner. The construction lines given in the engraving show clearly the method of laying out the gears. The tooth parts are calculated from the large ends of the teeth as before.

CHAPTER V

WORM AND SPIRAL GEARS

There has been a great deal of discussion as to the methods of calculating and drawing worm-gears, and many elaborate formulas have been devised and used for this purpose. In this chapter it is proposed to illustrate and describe a method which is simple and easy to remember, and one that has been tested by years of practical work under the most severe conditions.

As a general term, worm gearing includes that class of gearing in which a gear similar in construction to a spur gear is driven by a worm, *i. e.* a cylinder, upon whose surface is formed a thread adapted to engage the teeth of the gear. A single-thread worm will move the worm-gear a distance of one tooth for each revolution of the worm. With a worm having a double thread, the worm-gear is moved two teeth for each revolution of the worm, and so on. The shafts of the worm-gear and worm are nearly always, but not necessarily, at right angles to each other.

In Fig. 63 is shown a side elevation and in Fig. 64 a front elevation of a simple form of worm and worm-gear. The worm *A* is cut with a single thread, the sides of which are of 14½-degree inclination. The worm-wheel has a similar form of teeth, the pitch line being located the same as in a spur gear; but, inasmuch as we have the thread at an angle, the teeth of the worm-gear must be cut at an angle also, as shown at *C*. The diameter of the pitch circle is calculated the same as in a spur gear. The number of teeth multiplied by the circular pitch gives the circumference, which, divided by 3.1416, gives the diameter of the pitch circle.*

The special point of simplicity in this instance is the unusually large diameter of the worm in proportion to the thickness, or width across the face, of the worm-wheel, the contact being on an arc of only 28 degrees. With this proportion the pitch line of the teeth of the worm-wheel may be straight, and still conform, approximately, to the curvature of the worm. This, however, will be found to be an exceptional case, and this construction is never used when a considerable amount of power is to be transmitted, as the contact surface between the thread of the worm and the sides of the worm-gear teeth will be of too small an area to operate without undue friction.

The design more often employed is that shown in Fig. 65, where, instead of the angle of 14 degrees on each side of the center line, or 28 degrees in total for the two sides, we have 40 degrees on each side, or an included angle of 80 degrees, which gives ample area of bearing surface. Here, however, a new problem is presented. As we formerly

*For a thorough treatise on the calculation of worm-gear dimensions, see MACHINERY'S Reference Series No. 1, "Worm Gearing."

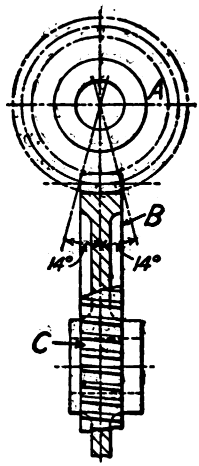


Fig. 63.

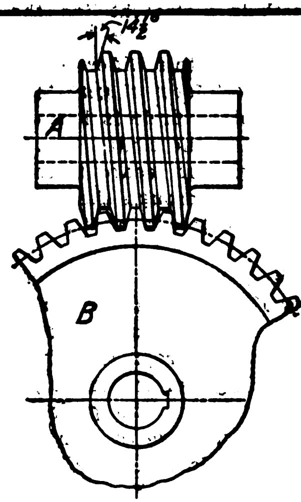


Fig. 64.

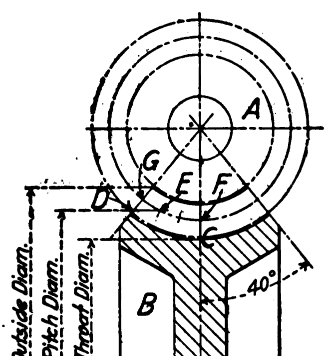


Fig. 65.

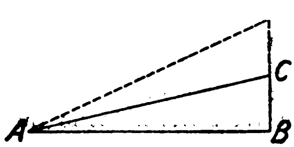


Fig. 66.

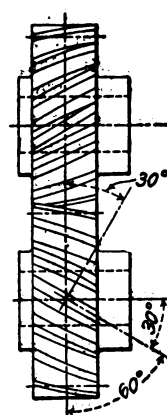


Fig. 67.

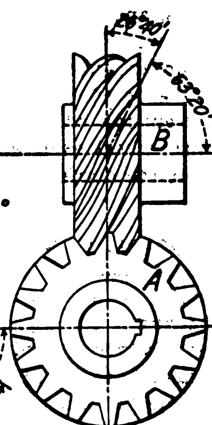


Fig. 68.

Figs. 63 to 68. Worm and Spiral Gearing

cut the teeth in a straight line, the pitch circle could be measured as in a spur gear. Now we have a considerable curvature, and it is readily seen that this different condition must be provided for. In practice, the best form of gear teeth for wearing qualities will be the result if the pitch circle is located as follows: Divide the pitch line curve from *F* on the center line, to *G* on the angular line, into three equal parts, without regard to the number of degrees comprising the enclosing angle; through the second division point *E*, thus obtained, draw the line determining the diameter of the pitch circle, as indicated.*

Fig. 66 is a diagram showing the relation of the angle of a thread to the axis of revolution. Let the base *AB* of the right-angled triangle *ABC* represent the circumference of the pitch circle of the worm, and the height *BC* represent the pitch. The hypothenuse *AC* forms with *AB* the angle of the thread, which may be found in degrees and minutes by dividing the pitch in inches by the circumference in inches, which will give the tangent of the angle. We then obtain the angle from a table of natural tangents.† If the worm has a double thread, the height of the right-angled triangle will be twice that for a single thread, as shown by the dotted lines; if it has a triple thread, three times; and for a quadruple thread, four times, and so on.

With these principles understood it is not difficult to lay out worm gearing. In cutting a worm-gear, a milling cutter of the proper form and of practically the same diameter as the worm, is set at the proper angle, and is gradually sunk into the gear, cutting the spaces between the teeth. This operation will not form the teeth with the necessary accuracy, and hence a cutter called a "hob" is used for finishing. The hob is, in effect, a worm with longitudinal grooves cut in it, thus forming cutting edges or teeth. The hob is revolved in contact with the worm-wheel exactly in the same manner as the worm, and gradually gives the correct form to the teeth.

Spiral Gears

The subject of spiral gears is not very well understood by the average mechanic. The teeth of a spur gear are cut in a straight line parallel to the axis. When the teeth are cut at an angle to the axis, the angle being produced by a gradual rotation of the blank, as the cut advances, a spiral gear is the result. If the face of the blank is of sufficient width, the tooth finally makes a complete turn, and the completed gear resembles a screw. The distance from the point of the beginning of the cut until one complete revolution has been made, measured on a line parallel to the axis of the gear, is the *lead of the spiral.* The angle of this spiral is found by dividing the circumference of the cylinder or blank upon which the spiral is cut by the lead of the spiral; the quotient is the tangent of the angle of the spiral.

If the angle of the spiral and the circumference are known, the

*This method is not universally employed. For a discussion of various methods used, see MACHINERY'S Reference Series No. 1, "Worm Gearing," Chapter IV.

†See MACHINERY'S Reference Series No. 52, "Advanced Shop Arithmetic for the Machinist," Chapter XI.

lead may be found by dividing the circumference by the tangent of the angle, the quotient being the lead.

If the angle of the spiral and the lead are given, the circumference may be determined by multiplying the tangent of the angle by the lead, the product being the circumference.

It should be remembered that in making calculations for spiral gears as for spur gears, the circumference used in the calculations is always that of the pitch circle and not that of the addendum circle, or the outside circumference of the blank.*

If the shafts on which spiral gears are mounted are parallel, the gears will have their teeth cut at the same angle. (See Fig. 67). If two spiral gears are in mesh and both have right-hand spiral teeth, the angles of the two shafts will be equal to the sum of the two spiral angles. When two spiral gears are in mesh, one having a right-hand and the other a left-hand spiral, subtract the spiral angle of the one from the spiral angle of the other, to obtain the angle between shafts. When two spiral gears, the teeth of which are in mesh, each have teeth cut at an angle of 45 degrees, and have the same number of teeth, the lead of their spirals and their pitch diameters will be the same.

All angles of the teeth of gears must be considered at the pitch line, since it will be readily understood that if the pitch is comparatively large in proportion to the diameter of the pitch circle, the angle will be considerably greater at the points of the teeth, *i. e.* at the outside diameter.

Fig. 67 shows an ordinary pair of spiral gears in mesh, the angles of the teeth being equal and 30 degrees with the axis. The only requirement in this case is that the angles in both gears shall be alike, but the angles should not be too acute; they ought not to be over 45 degrees. While the two gears here shown have the same number of teeth, this is not essential, as the number of teeth may be according to the speed ratio desired, the same as in spur gears.

In Fig. 68 is shown a pair of spiral gears with their shafts at right angles, the gear *A* having 16 teeth and the gear *B* 8 teeth, from which it necessarily follows that the speed of gear *B* will be twice that of *A*. It is essential, from the angles of the two gears, that *B* must be the driver and *A* the driven gear, otherwise they will not operate. Spiral gears are frequently and properly called "helical," because of the fact that the tooth is wound around the gear in the form of a helix. It will be noticed that the gears shown in Fig. 68 are similar, in action, to worm-gearing, to which all spiral gears are, by their construction, closely allied.

In designing spiral gears we may take the following as an example: Suppose the two gears are to be 8 and 2 inches in pitch diameter. The larger one will have 48 inches lead, and the smaller one a lead of 12 inches. Then $8 \times 3.1416 = 25.1328 =$ circumference, which, divided by the lead (48) gives 0.5236. Hence, it will be found from a table of tangents, that the angle is 27 degrees 40 minutes. The angle of the

*For a thorough treatise on the calculation of spiral gears, see MACHINERY'S Reference Series No. 20, "Spiral Gearing."

smaller gear will be 90 degrees minus 27 degrees 40 minutes or 62 degrees 20 minutes.

The angles added together must be equal to 90 degrees so long as the shafts are at right angles.

It must always be remembered that when the shafts are at other than right angles, this fact will very materially change the angles of the teeth of spiral gears, and when the pitch diameters are alike and the number of teeth different, the angles will be different.

Racks may be used in connection with spiral gears, of comparatively short lead. The teeth of the rack may be at right angles to the line of movement, or at any angle from 90 degrees to 45 degrees. The shaft of the spiral gear engaging them may be parallel with them, or at any angle up to 45 degrees. Better results will usually be obtained if this angle is less than 35 degrees. The teeth of the rack may be made concave as in a worm-gear, if desired, but they are usually cut straight.

No. 39. Fans, Ventilation and Heating.—Fans; Heaters; Shop Heating.

No. 40. Fly-Wheels.—Their Purpose, Calculation and Design.

No. 41. Jigs and Fixtures, Part I.—Principles of Jig and Fixture Design; Drill and Boring Jig Bushings; Locating Points; Clamping Devices.

No. 42. Jigs and Fixtures, Part II.—Open and Closed Drill Jigs.

No. 43. Jigs and Fixtures, Part III.—Boring and Milling Fixtures.

No. 44. Machine Blacksmithing.—Systems, Tools and Machines used.

No. 45. Drop Forging.—Lay-out of Plant; Methods of Drop Forging; Dies.

No. 46. Hardening and Tempering.—Hardening Plants; Treating High-Speed Steel; Hardening Gages.

No. 47. Electric Overhead Cranes.—Design and Calculation.

No. 48. Files and Filing.—Types of Files; Using and Making Files.

No. 49. Girders for Electric Overhead Cranes.

No. 50. Principles and Practice of Assembling Machine Tools, Part I.

No. 51. Principles and Practice of Assembling Machine Tools, Part II.

No. 52. Advanced Shop Arithmetic for the Machinist.

No. 53. Use of Logarithms and Logarithmic Tables.

No. 54. Solution of Triangles, Part I.—Methods, Rules and Examples.

No. 55. Solution of Triangles, Part II.—Tables of Natural Functions.

No. 56. Ball Bearings.—Principles of Design and Construction.

No. 57. Metal Spinning.—Machines, Tools and Methods Used.

No. 58. Helical and Elliptic Springs.—Calculation and Design.

No. 59. Machines, Tools and Methods of Automobile Manufacture.

No. 60. Construction and Manufacture of Automobiles.

No. 61. Blacksmith Shop Practice.—Model Blacksmith Shop; Welding; Forging of Hooks and Chains: Miscellaneous Appliances and Methods.

No. 62. Hardness and Durability Testing of Metals.

No. 63. Heat Treatment of Steel.—Hardening, Tempering, Case-Hardening.

No. 64. Gage Making and Lapping.

No. 65. Formulas and Constants for Gas Engine Design.

No. 66. Heating and Ventilation of Shops and Offices.

No. 67. Boilers.

No. 68. Boiler Furnaces and Chimneys.

No. 69. Feed Water Appliances.

No. 70. Steam Engines.

No. 71 Steam Turbines.

No. 72 Pumps, Condensers, Steam and Water Piping.

No. 73. Principles and Applications of Electricity, Part I.—Static Electricity; Electrical Measurements; Batteries.

No. 74. Principles and Applications of Electricity, Part II.—Magnetism; Electro-Magnetism; Electro-Plating.

No. 75. Principles and Applications of Electricity, Part III.—Dynamos; Motors; Electric Railways.

No. 76. Principles and Applications of Electricity, Part IV.—Electric Lighting.

No. 77. Principles and Applications of Electricity, Part V.—Telegraph and Telephone.

No. 78. Principles and Applications of Electricity, Part VI.—Transmission of Power.

No. 79. Locomotive Building, Part I.—Main and Side Rods.

No. 80. Locomotive Building, Part II.—Wheels; Axles; Driving Boxes.

No. 81. Locomotive Building, Part III.—Cylinders and Frames.

No. 82. Locomotive Building, Part IV.—Valve Motion.

No. 83. Locomotive Building, Part V.—Boiler Shop Practice.

No. 84. Locomotive Building, Part VI.—Erecting.

No. 85. Mechanical Drawing, Part I.—Instruments; Materials; Geometrical Problems.

No. 86. Mechanical Drawing, Part II.—Projection.

No. 87. Mechanical Drawing, Part III.—Machine Details.

No. 88. Mechanical Drawing, Part IV.—Machine Details.

No. 89. The Theory of Shrinkage and Forced Fits.

No. 90. Railway Repair Shop Practice

ADDITIONAL TITLES WILL BE ANNOUNCED IN MACHINERY FROM TIME TO TIME

MACHINERY'S DATA SHEET SERIES

MACHINERY'S Data Sheet Books include the well-known series of Data Sheets originated by MACHINERY, and issued monthly as supplements to the publication; of these Data Sheets over 500 have been published, and 6,000,000 copies sold. Revised and greatly amplified, they are now presented in book form, kindred subjects being grouped together. The purchaser may secure either the books on those subjects in which he is specially interested, or, if he pleases, the whole set at one time. The price of each book is 25 cents (one shilling) delivered anywhere in the world.

TITLES AND CONTENTS ON BACK COVER

CONTENTS OF DATA SHEET BOOKS