

**Build This...****60-Shot Z-Fan Cake****Summary:**

Z-Fan cakes are a distinctive fan effect where many shots are fired one at a time in rapid succession, with the progression moving back and forth in a zig-zag fashion. These cakes have been appearing on both the commercial and consumer firework market in recent years, and a typical cake often exceeds 100 shots. Upon viewing one in action, one would think some kind of rapid burning visco had been invented to allow the fast yet precise timing of so many shots. However, as this article shows, these cakes are fused with nothing more than good old fashion black match!

Materials:

- ▶ (60) 5" long 3/4" I.D. PVC tubes
- ▶ (8) 4" long x 3/4" I.D. PVC tubes
- ▶ (60) 1/2" long x 3/4" O.D. wood plugs
- ▶ (4) 4" wide x 22-1/2" long x 1/8" thick PVC sheets
- ▶ (2) 2" wide x 22-1/2" long x 1/8" thick PVC sheets
- ▶ (8) 4" long x 5/8" O.D. wood dowel rods
- ▶ (1) 25" long x 7" wide x 3/4" thick board
- ▶ (60) 3/4" long tacks

Unmeasured Materials:

PVC cement, Foil tape, 1/8" cross match, 2Fg lift, 5/8" stars or comets, 3/8" I.D. match pipe

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Technique:

[Making KP Burst Charge](#)

Gallery:

[1st American Maltese Show](#)

Tool Tip:

[Making End Disks](#)

Autopsy:

[Peanut Shells](#)

Tools:

- ▶ Belt sander or sand paper
- ▶ Hack saw or cutoff saw
- ▶ Small electric drill
- ▶ Deburring tool
- ▶ 1/8" drill bit
- ▶ 3/4" drill bit
- ▶ Bar clamps
- ▶ Hammer
- ▶ Hot glue gun





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Figure 1: 60 tubes and end plugs ready for assembly.



Figure 2: Using a belt sander to trim down wood plugs that are too large.



Figure 3: Bracing the tube while tacking the wood plugs in place.

Introduction

Last month we looked at a simple way to build fan cakes where all shots in a row fire at once. This month's project features a different kind of fan cake known as a Z-fan, which is a type of fan cake where all the shots in each row fire one at a time from left to right, then right to left, then left to right etc. This back and forth motion requires very rapid firing of adjacent shots in order to achieve the ideal wave-like motion.

The first time I saw a commercial Z-fan cake in action, I couldn't figure out what they were using to fuse the shots that would allow such a rapid progression. The shot rate is far faster than any type of visco fuse would allow, but slower than quickmatch would produce. As it turns out, the fusing is sort of a half-breed between quick match and raw match. Raw black match is in fact used to make the fuse connections between shots, but it is only partially piped. This loose confinement results in less pressure to drive the flame front forward as the fuse burns. There are a few other tricks used to control the timing, as discussed in the section on loading the cake.

The timing is so fast yet precise on the cake shown here that it was mistaken by some onlookers as a 10ms computer firing demo that was scheduled for the FPAG fall festival last month. The cake was actually fired as part of the multi-tube repeater competition, where it took 1st place.

Building the Cake

As you might guess, the majority of the work in building this cake is making all the tubes and building them into properly angled racks. For this reason I have opted once again to go with a re-usable PVC type design that can be washed out with water. However, the exact same procedure could be used to produce the same cake using paper tubes plugged with clay and connecting them together with sheets of corrugated cardboard. The paper cake carcass is actually faster to produce, but it can't be re-used as easily as the PVC type.

This cake features four rows that contain 15 shots each. It is best to use an odd number of shots in each row so that the center tube will point straight up and serve as a mid-point when building the cake. The number of rows is arbitrary and can be as many as you have the patience to build. Sixty tubes was enough for me, thank you!

The cake shown here is designed to fire 5/8" stars or inserts, thus a pipe having an I.D. of 3/4" was used. The PVC shown here has a 1/16" thick wall, which will actually play a role in how fast the shots are timed. The cake actually fired a little too fast for my liking and if I



Figure 4: Using a wood alignment fence and an framing angle to mark the center tube.



Figure 5: Using small 1/2" spacer blocks to set tube angles.



Figure 6: All 15 tubes glued into place on one of four plates.

were to build this again I would use thicker pipe to slow the shot propagation down. Paper tubes are usually at least 1/8" thick anyway so they will not be a problem if you go that route. Note that going with thicker tubes will change the length of the rows and you will have to alter the dimensions given in this article. It is best to cut all your tubes first and then test align them in place on your divider material to see how long the rows need to be.

The tubes and plugs are cut and trimmed as shown in last month's [article](#). If you haven't been able to justify buying a cut-off band saw yet, this project will certainly add incentive. I was able to build and assemble the entire cake rack in only 4 hours using the cut-off saw. Cutting all the tubes and dowels by hand would probably double this time. The sideways mounted belt sander shown in Figure 2 also helps speed up the trimming of burrs from the outside edges of the pipes and plugs. Depending on the thickness of your dowel, you may also need to use the sander to reduce the plug diameters very slightly so that they fit into the pipes. Wooden dowels tend to have inconsistent outer diameters, so if you test fit them into your pipe before leaving the hardware store you may find one that fits without the need for sanding.

Figure 1 shows all the 5" long pipes and 3/4" long plugs ready to be inserted. Since these small shot tubes are not subjected to much force, I just use a single 3/4" tack to hold them in place. Figure 3 shows a pair of wood strips used to brace the tube while tacking the plugs in place.

Once all your shot tubes are complete, they are ready to be assembled onto the divider plates. The fuse holes for the tubes will not be drilled until the row assembly is complete, rather than worry about trying to correctly align pre-drilled tubes when gluing everything together.

If making the cake from PVC, you will need to acquire some 1/8" thick PVC sheets. These will be cut into 4 strips that are 4" wide and 4 strips that are 2" wide. This material is often used for making signs, so you could check with a local sign manufacturer as a potential source. If making a paper cake, then sheets of corrugated cardboard can be used in place of the PVC. If you are using different tubes than the ones shown here, then you will need to lay them out onto an oversized length of backing material to determine the correct row length, as shown in Figure 6. The angles are set by using small wooden blocks that are about 3/8" wide to control the spacing between the tops of each tube, rather than actually measuring the angles. The backing material should extend at least 1-1/2" beyond the edge of the last tube on both ends.

Once you have cut all your backing material to length, you are ready to glue all the tubes in place. If using cardboard, then hot glue can be used to quickly assemble the cake. The PVC cake is glued together with PVC cement, which sets fast enough to allow very rapid assembly of the tubes.

The assembly process needs to be done against an alignment block so that the tubes butt up against a common ground for alignment, as seen in Figure 4. Start by marking a center line with a framing angle,



Figure 7: Attaching the guide tubes at each end.

which is where you will glue the first tube. Figure 5 shows how the spacer blocks are used to align and glue the next two tubes. This process is repeated, making sure the bottoms of all tubes contact each other, until all 15 tubes have been glued in place as seen in Figure 6.

Next you will need to glue a 4" long guide tube at each end of the fan plate, as seen in Figure 7. Use a block of wood held up against the end of the backing sheet to make sure each tube is aligned at the same distance from each end, and is also parallel to the edge of the backing plate. These tubes have no end plugs and do not fire anything, they will actually slide over wooden guide posts to hold all the mini-racks in position.

If you haven't passed out from PVC fumes yet, it is time to glue the 2" top plate across the tops of all the tubes. Regardless of whether you are using PVC or hot glue, you will have to apply the glue to all the contact points very rapidly so that you can set the top plate before any glue dries. The roll of foil tape shown in Figure 8 is just there as a spacer gauge, since foil tape will be laid across all the exposed tubes during the loading process.

Figure 9 shows one completed fan row ready for drilling. You still have three more to make, so get to work!

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Figure 8: Gluing the front PVC strip across all tubes to finish the plate.



Figure 9: One of four fanned rows is completed.



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Figure 10: Drilled out 1/8" passfire holes.

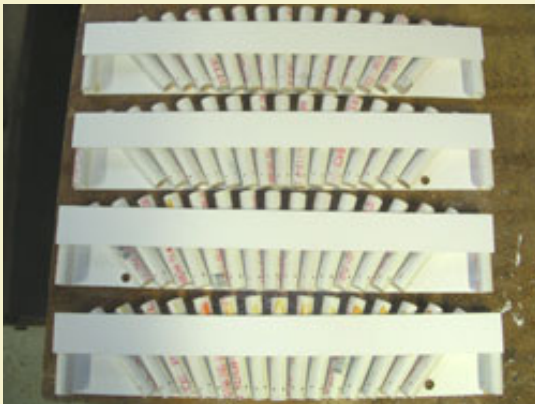


Figure 11: All four fanned rows completed.



Figure 12: Gluing wood pins onto the holding fixture.

The next step in completing each fan row is to drill out all the passfire holes in each shot tube. A small hand drill such as a variable speed Dremel tool makes this job much easier. Make sure the black match you intend to use will fit into the holes you are drilling. I use a 1/8" hole, which works well when fusing with the thin type of cross match described [here](#). It is important that the holes not be drilled so that they are too close together, otherwise the timing will be faster than desired. A 45 degree angle is just about right, as seen in Figure 10. The outer holes on the two outside tubes should be drilled directly into the side of the tube instead of at a 45 degree angle, otherwise the piped match connecting the rows to each other will be subjected to excessive bending.

Care must be taken not to drill your fuse holes into the wood plugs, which is an easy mistake to make when drilling the more angled tubes at the ends. The closer you get to each end of the rack, the more diagonal the adjacent fuse holes will be to each other.

Lastly you will need to drill 3/4" diameter holes at each end of the fan rack so that the piped match can be passed through the backing material. Figure 11 shows the minimum number of holes required for the Z-fan configuration, but it is a good idea to drill the passfire holes on both sides just in case you need it. Note that the back row does not need any holes, only the first three rows.

Once all your mini fan-racks are completed, you will need to make a holding fixture to keep them all in place. The simple fixture shown in Figure 12 and 13 is designed to allow easy assembly and disassembly of the racks when reloading the cake. The tubes on the end of each fan rack simply slips over the wooden pins, holding it upright and insuring that it does not tip over. The four pins on each side are spaced 1-5/8" from each other, measured from the center point of each pin. The spacing for each pair should be measured by placing the fan rack directly on the board and marking the center point of the left and right guide tubes.

Figure 14 shows the completed cake with all four rows loaded onto the holding fixture. At this point the hard part is done and the cake is ready for loading!

Well, I've said everything I can possibly think of to fill this column with text, yet there are still two images hanging down on the left margin. I don't want to get into the next logical section because the associated pictures are all on the next page, yet I can't stand it when the copy falls short of the image column. It just makes it look like I forgot to finish the article or got lazy and went to bed early or something. So



Figure 13: Shot rows slide onto support pins.

please bare with me while I ramble on about nothing at all in order to fill this space for the higher purpose of visual design aesthetics. OK, close enough. Thanks for your patience and now back to our regularly scheduled Build This column...

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Figure 14: Completed cake ready for loading.





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Figure 15: Fusing shots together with segments thin blackmatch.



Figure 16: Painting prime slurry over holes that receive fire.



Figure 17: Making sure all air gaps under

Loading the Cake:

Once you have the cake mortar racks completed, it only takes less than an hour to load it. Begin by removing all the racks from the support base and linking each set of holes with a length of thin black match. The quality of the match used here is very important, because it will get bent in several places, which will cause the outer coating to chip off. If your match is not internally saturated with black powder, then you will be left with dead spots in the fuse chain that risk causing the cake to stop short of firing all the shots. Good match should not reveal any white threads when bent or cut in half, otherwise you are going to have ignition problems. The match used for this project was made as described [here](#).

Using segments of black match that are about 1-1/4" long, connect each pair of adjacent shot holes in all four racks, as shown in Figure 15. You are going to have to bend the match at right angles in a few places to do this. Sometimes the match sticks will get too mangled to insert and you have to toss it, so be sure to cut a dozen more pieces than you actually need.

The next step is the key to prevent a rapid fire chain reaction. Using a black powder prime slurry and a small cue-tip or paint brush, paint prime over each fuse hole that will be on the receiving end of the fuse fire. In Figure 16, the shots will be igniting from left to right, so the right side of each passfire link gets the prime protection. This step prevents the gas and fire from blowing out one shot hole straight into the next shot hole, thus bypassing the fuse and eliminating the short delay element. Thus it is important to make sure the prime fully seals off around the fuse so that no gaps are left open. The prime can also be used to patch up any areas of excessive powder loss on the black match itself if you are worried about dead spots. Due to the confinement around the fuse connections, the entire black match connection tends to take fire all at once, so you can actually get away with some pretty beat up fusing.

Applying the prime to both input and output holes may be one way to slow the cake progression down when using the thin wall tubes shown here, although I have not tried it at the time of this writing. It seemed to me that just the one prime block would add enough delay, but in reality it burns through in just a fraction of a second.

Once all the priming is done, set the racks aside to dry for a day (or half a day in a drying box). When the prime is dry and solid, the next step is to cover all the match connections with one continuous strip of foil tape. The tape not only serves to protect the match from side igniting out of order, it also adds some confinement to increase the

tape are sealed off to prevent gas from skipping ahead.



Figure 18: Piped match segments for connecting the rows together.



Figure 19: Using hot glue to connect piped match segments.



Figure 20: Piped match connecting the rows together.

fire transfer rate. Even though the black match links are not completely enclosed in a pipe the way quickmatch is, there is still enough enclosure around it to semi-trap the gas and fire. This results in a burn rate that is slower than quick match yet considerably faster than if the 1/2" fuses just burned end to end in open air.

When applying the foil, be sure to iron out any wrinkles or gaps under the tape where it contacts the shot tubes, as seen in Figure 17. There will still be enough gas pressure when the fire is transferring between shots to shoot under any gaps in the tape, thus short circuiting the desired shot and causing two or more shots to fire at once. This is a common problem that can be seen even in the commercial Z-fan cakes. The commercial cakes use gummed paper instead of foil tape for this purpose, and I think air gaps are harder to prevent with that method. I also prefer the foil tape for its ease of use, superior fire resistance and ability to stick to plastic.

At this point the four racks are ready to be chained together in the correct firing sequence. This will require that you make three piped match segments as seen in Figure 18. The pipes shown here are 3/8" I.D. and measure 3-1/2" long. The ends of each pipe are clipped at about 45 degrees to account for the angled tubes they will be connecting to. A single strand of high quality match measuring 4-1/4" long is passed through each tube.

Begin by fusing the last row first, which is laid flat on a table foil side up. You will only be making one connection on this row, either on the left or right side depending on the firing sequence you want. It is important that you keep track of the designated firing direction as dictated by the holes you protected with prime. If you get it backwards and start from the wrong end, then the cake will rapid fire and ruin the effect. Peek under the tape and make sure that the tube you are fusing into does not have the prime slurry on it. If you primed both input and output holes with the slurry then you don't have to worry about this issue and you can pick an arbitrary side to fuse into.

The fuse pipes are connected to the side of the shot tube with hot glue, as seen in Figure 19. Make sure the glue fully seals the air gap as much as you can, otherwise fire could sneak in there and set things off out of order.

The connection you just made was an "input" connection, so next you will be connecting the other end to the output of the 3rd row. Place the 3rd row on top of the 4th row and feed the piped match through the hole you drilled for this purpose. If you foiled over any of the fuse holes you should open them all up with an awl or pencil tip at this point. Be careful not to rough up the black match when pushing it through the hole, since the tip can become too damaged to fit into the hole and that would force you to redo the previous connection in order to replace the match.

Continue the same fusing process, starting on the opposite end of the 3rd row and fusing up to the 2nd row. The fusing will snake back and forth as seen in Figure 20, stacking the rows on top of each other as you go. Once all four rows are fused together, carefully pick up the stack and invert it onto the support base. You will have to set one row at a time and pull the others out like an accordion until all the



Figure 21: 1/4" teaspoon of 2Fg into each tube.



Figure 22: Inserting a 5/8" round star.

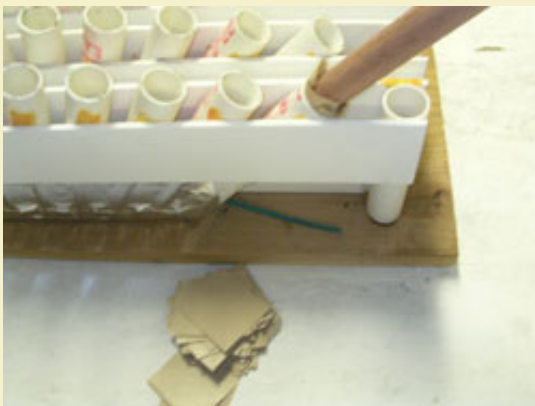


Figure 23: Pushing in 1-1/2" square paper sheets to plug each tube after loading.

rows are seated over the pins, then push them all down to the base at once.

Finishing the loading process from this point on is a piece of cake, no pun intended (OK, the pun was obviously intended but tradition requires me to deny it). Each tube gets 1/4 teaspoon of 2Fg lift, followed by a star, followed by a compression plug. It is actually faster to add the lift to all tubes first, then the stars to all tubes etc rather than completing each tube one at a time. However, care must be taken to keep track of the last tube loaded, otherwise it is easy to accidentally add a lift charge or star to the same tube twice! I like to keep one finger pointed at the next tube to be loaded while my other hand does the actual loading.

The paper plug being pushed into each tube in Figure 23 serves to protect from accidental ignition from above, and also keeps the lift from migrating above the star during transportation if the cake was ever accidentally tipped on it's side or upside down. These are made from 1-1/2" sheets of 30 lb virgin kraft and pushed in with a 5/8" dowel rod.

As one final precaution it is a good idea to foil over the tops of each row with strips of aluminum foil, as seen in Figure 24. This is done to prevent sparks from falling between the tubes during firing, which has the risk of igniting the exposed segments of black match and start the cake firing out of order. Keep in mind Murphy's rule of cake malfunction: "anything that can take fire, will." Skimping on precautions such as this can result in a lot of wasted effort in the end, so don't give in to temptation!

The star used in this cake was a 5/16" flitter core with tiger tail rolled up to a final 5/8" O.D. The effect is a thick gold streamer that releases a burst of silver at the top, making an attractive snowfall effect that follows behind the streamer progression. The most visually pleasing Z-fan effects are those where all shots are the same and some event occurs at the zenith of each shot, such as a salute, crossette, color change etc. This creates the appearance of a secondary effect that lags behind the motion of the swaying comets, as if chasing them from behind. 🔥



Figure 24: Finished cake ready for firing.