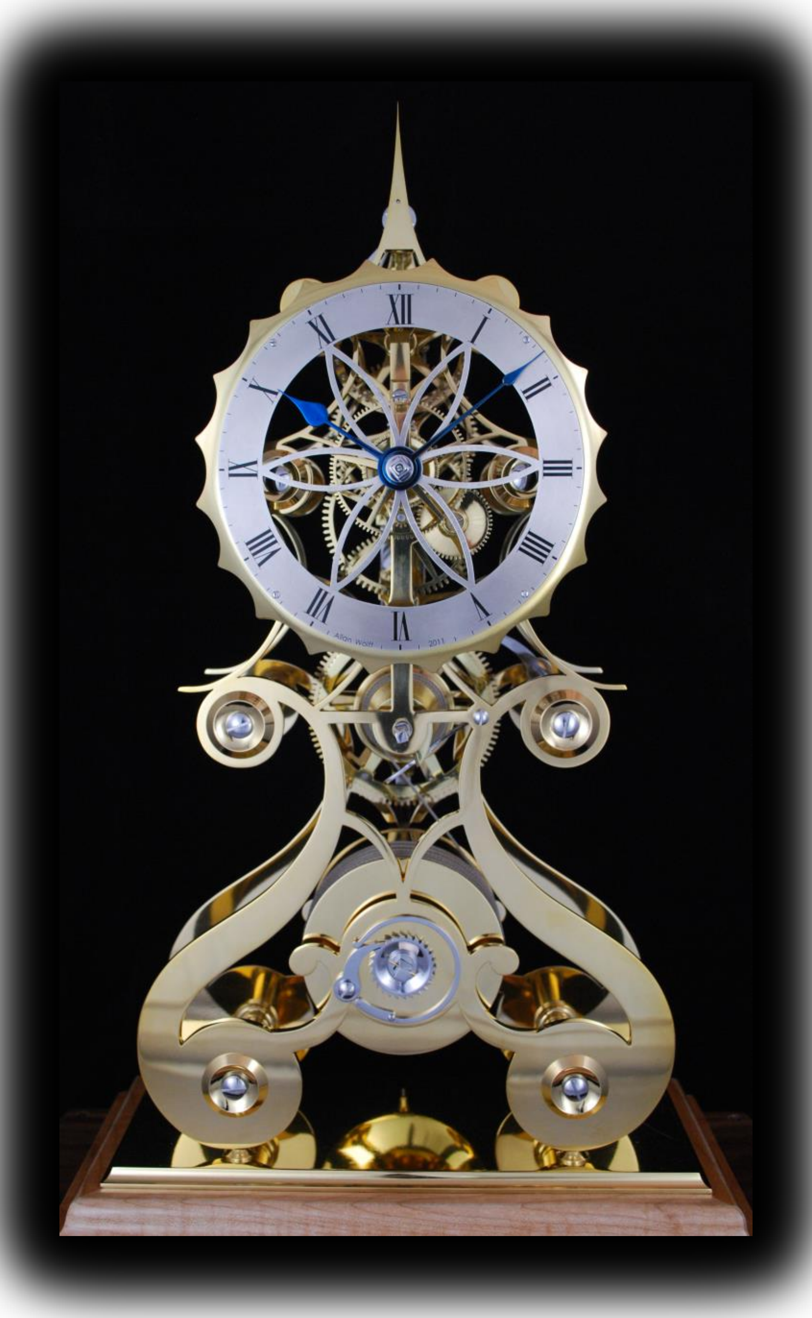
Building a Pinwheel Skeleton Clock



by
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Material List

Note: This is material list provides dimensions to minimize machining and waste. If material is being ordered, it may be more economical to "round up" some materials so fewer individual pieces need to be purchased. For example, instead of ordering 2 inches of 1/16" mild steel rod, 2 inches of 3/32", 1 inch of 3/16" and 2 inches of ¼"; a single 7-inch piece of ¼" rod could be ordered.

Material	Dimensions	Item
O-1 ground flat stock	1/16" X 3" X 1"	Pallet arms, barrel click spring
O-1 Drill rod	1/8" dia. X 1" long	Fusee stud
O-1 Drill Rod	5/16" X 4.25" long	Fusee arbor
O-1 drill rod	1/2" X 6" long	Pinions
Mild steel rod	1/16" X 2"	Fusee iron pin, taper pin
Mild Steel rod	3/32" X 2"	Rating rod, rating weight stud
Mild Steel rod	3/16" X 1"	Crutch shoulder nut
Mild steel rod	¼" X 3"	Fusee iron mount screw, suspension bracket screw, motion works bridge screw, intermediate pinion
Mild steel rod	3/8" X 10" long	Minute pipe-lower, intermediate arbor, plate screws (Qty 12)
Mild steel rod	1" X 4" long	Barrel arbor
Mild steel plate	1/32" X 6" X 1"	Hour & minute hands
Mild steel plate	1/16" X 6 ½" X 1"	Fusee iron, pendulum center sections (2)
Mild Steel Plate	1/8" 2" X 6"	Barrel ratchet and click, maintaining pawl, pendulum upper & lower sections
Mild steel plate	3/32"X 1" X 1"	Fusee click
356 brass sheet	1/16" X 12" X 12"	Escape wheel, 72-tooth wheels (3), fusee stop, motion works hour wheel & intermediate wheels, dial pan
356 brass sheet	1/8" X 3" X 9"	Maintaining wheel, pendulum connector caps (2), key head
356 brass sheet	3/16" X 12" X 24"	Great wheel, barrel flanges (2), plates, pendulum connectors (2), pendulum rating weight
356 brass plate	¼" X 4.5" X 9.5"	Base plate
260 brass sheet	.015" X 1" X ½"	Motion works clutch spring
260 brass sheet	1/32" X 6" X 10"	Fusee click spring, suspension spring block, bob, crutch arms, dial
260 brass sheet	1/16" X 3" X 1"	Crutch
360 brass rod	3/16" X 6"	Crutch posts, washers, dial pan mounting posts (3)

Material	Dimensions	Item
360 brass rod	¼″ X 1″	Motion works washer
360 brass rod	3/8″ X 5″	Fusee iron mount, bridge pipe, minute pipe-upper, drive pinion, rating nut, hand washer
360 brass rod	½″ X 15″	Pallet collet, escape wheel collet, pallet spacer, second, third & fourth wheel collets, hour pipe, rating weight stud, feet, key stem
360 brass rod	5/8″ X 6″	Upper pillars (2)
360 brass rod	¾″ X 12″	Center & lower pillars (4)
360 brass rod	7/8″ X 4″	Fusee ratchet, small plate washers (4)
360 brass rod	1″ X 3″	Large plate washers (8), great wheel slip washer
360 Brass rod	1.875″ X 2″	Fusee
360 brass bar	½″ square X 3″	Bridge
Brass tube	3″ X .125″ WT X 3″ long	Mainspring barrel
Music wire	.015″ X ¾″	Fusee iron spring
Music wire	.055″ X 20″	Escape wheel pins, minute pipe pivot, intermediate shaft
Music wire	.062″ X 3″	Pendulum lock clip
Music wire	#36 (.106″) X 12″ long	Pallet arbor, escape arbor, third arbor, fourth arbor
Music wire	1/8″ X 6″ long	Maintaining pawl arbor, second arbor
Blue Spring Steel	0.020″ X 1.5″ X 120″	Mainspring
Blue spring steel	.003″ X .2″ X 1.25″	Suspension spring
Flat Head Machine Screw	#10-32 X ½″	Mainspring hooks (2)
Flat head Machine screw	#2-56 X 3/8″ long	Fusee ratchet fastener (3)
Flat Head Machine Screws	#2–56 X 1″ long	Dial pan mounting screws (3)
Flat Head Machine Screws	#0–80 X 3/8″ long	Barrel flange screw (6)
Pan Head Machine Screws	#0-80 X ¼″ long	Various (32)
Pan head machine screws	#6-32 X 1.5″ long	Base mounting screws (4) (length may vary depending on base thickness)
7 X 19 stainless steel wire rope	3/64″ dia. X 10′ long	Fusee cable
Hardwood	½″ X ½″ X 1″	Pendulum lock
Heat shrink tubing	1/8″ dia. X 3″ long	Pendulum lock clip cover

Forward

This book is a result of my desire to construct a skeleton clock from the ground up, not based on somebody else's plans. I did not intend to write a book; it just seemed like the next logical step. After designing a component, I made a list of machining steps I thought would provide an efficient process. Photos were also taken as each part was built. It seemed only natural to combine all of this information into one package.

The order of construction documented here follows the same order I used to build my clock. Although some additional work is needed to build "throw-away" parts such as the test frame, the cost is minor compared with the flexibility and knowledge gained through experimentation.

I would consider this an advanced clock project. Although the tools used are relatively simple, a substantial time investment is required. I did not keep a detailed record of the time involved, but I estimate approximately 1000 hours were required from start to finish. Some of this time was spend designing and documenting, but there were many more hours of tedious sanding and polishing. As you toil away with sore arms and numb fingers, remember that the greater the effort, the greater the reward.

A Pinwheel Skeleton Clock

1 - Introduction

Figure 1: *Design of the pinwheel clock is based on this spring pallet regulator, maker unknown, circa 1830's.*

The design of this clock is based on photos of an English tabletop regulator. Its symmetry and graceful curves are visually appealing and present a number of new clock building challenges. Silvering the dial and forming the scalloped dial ring and base will provide new learning opportunities. This will also be my first clock constructed without the aid of a "how-to" book. All dimensions will be estimated from photos or obtained through the design process utilizing CAD drawings and test builds.

Most clock construction books follow a similar sequence of construction. The frame is usually constructed first and then the mechanism is built progressing up the train from the mainspring to the escapement. Although this is most convenient in terms of construction, it is doubtful that the original clock was built in that order. This documentation will follow the order of original construction, starting with the escapement.

The original clock used a unique spring pallet escapement whereas this clock will use a pinwheel arrangement. A prototype escapement will prove the design actually works and provide an indication as to the amount of power needed to drive the clock. From this the mainspring size and fusee dimensions can be derived.

The Escapement

Typical pinwheel arrangements place all of the pins on the same side of the wheel and stagger the pallets using different length arms to obtain the necessary clearance and drop. On this design, the pins are located on alternating sides of the wheel allowing the pallet arms to be equal in length. Although uncommon today, some of the first pinwheel escapements used this staggered arrangement of the pins.

The Train

Several factors influence the train design. A tabletop size requires the use of a half-seconds pendulum resulting in a beat rate of

120 beats per minute; or 7200 beats per hour. Additionally, the clock should run for 8 days on a single wind. Finally, pinions with 12 or more leaves are desirable to reduce power loss. Experience with previous clock construction and repair projects showed that any imperfections with low (typically 8) leaf pinions causes a tremendous loss of power as the pinion and wheel mesh on a single point at a time. 12 leaf or higher pinions result in two points of contact and thus smoother operation. A spreadsheet was used to quickly develop several gear combinations. None of the combinations could achieve the required runtime with a three-arbor system without using high tooth count wheels. The four-arbor combination selected used the following wheels and pinions.

	Wheel	**Pinion**	**RPD**	**RPH**
Escape	50	12	3456	144
Fourth	72	12	576	24
Third	72	12	96	4
Center	72	12	16	.67
Main	96		2	

An appealing characteristic of this train is all of the pinions and three of the wheels are the same size allowing common parts to be machined together. This is especially convenient since the pinions will be cut from a single setup rather than individually constructed as lantern style pinions. A 0.8 module wheel and pinion size results in a time train that fits nicely within the allowable space of the frame.

A Computer Aided Design (CAD) application was used to create a side and front view of the time train. Dimensions are obtained from this scale drawing to ensure the train will fit within the frame. On the front view, simple circles represent wheels and pinions with red for the pitch circle diameter (PCD) and black for the wheel blank, or tooth tip diameter. Green represents the motion works that is mounted on the outside of the front plate. On the side view, rectangles represent the wheels, pinions and arbors. This view is convenient for verifying the wheels will clear the arbors and also assists with general layout of the wheels and pinions on their respective arbors. A few important dimensions are called out on the drawing such as the distance from the winding arbor to dial center and overall time train length. The distance of the pallet arbor from the escape arbor is determined geometrically and will be discussed in the escapement section.

The reader may have noted that a key requirement for all clock designs has not yet been addressed; the minute hand must rotate once per hour and preferably in a clockwise direction. Typically, the minute hand is driven directly by one of the arbors. For this design, the third arbor will extend through the front plate and hold a 13-leaf pinion. The pinion will drive one of the 52-tooth motion works wheels and divide the third arbor's 4 revolutions per hour (RPH) to the necessary 1 RPH. This appears to be similar to the design of the original spring pallet regulator.

The motion works utilizes the traditional English design that achieves the 12:1 ratio through a 96-tooth wheel driven by an 8-leaf pinion. Since the pinion drives the wheel, power loss is minimal and is not a concern like it is in the time train where the wheel drives the pinion. A .5 module gear size keeps the dimensions of the motion works wheels and pinions to a manageable level.

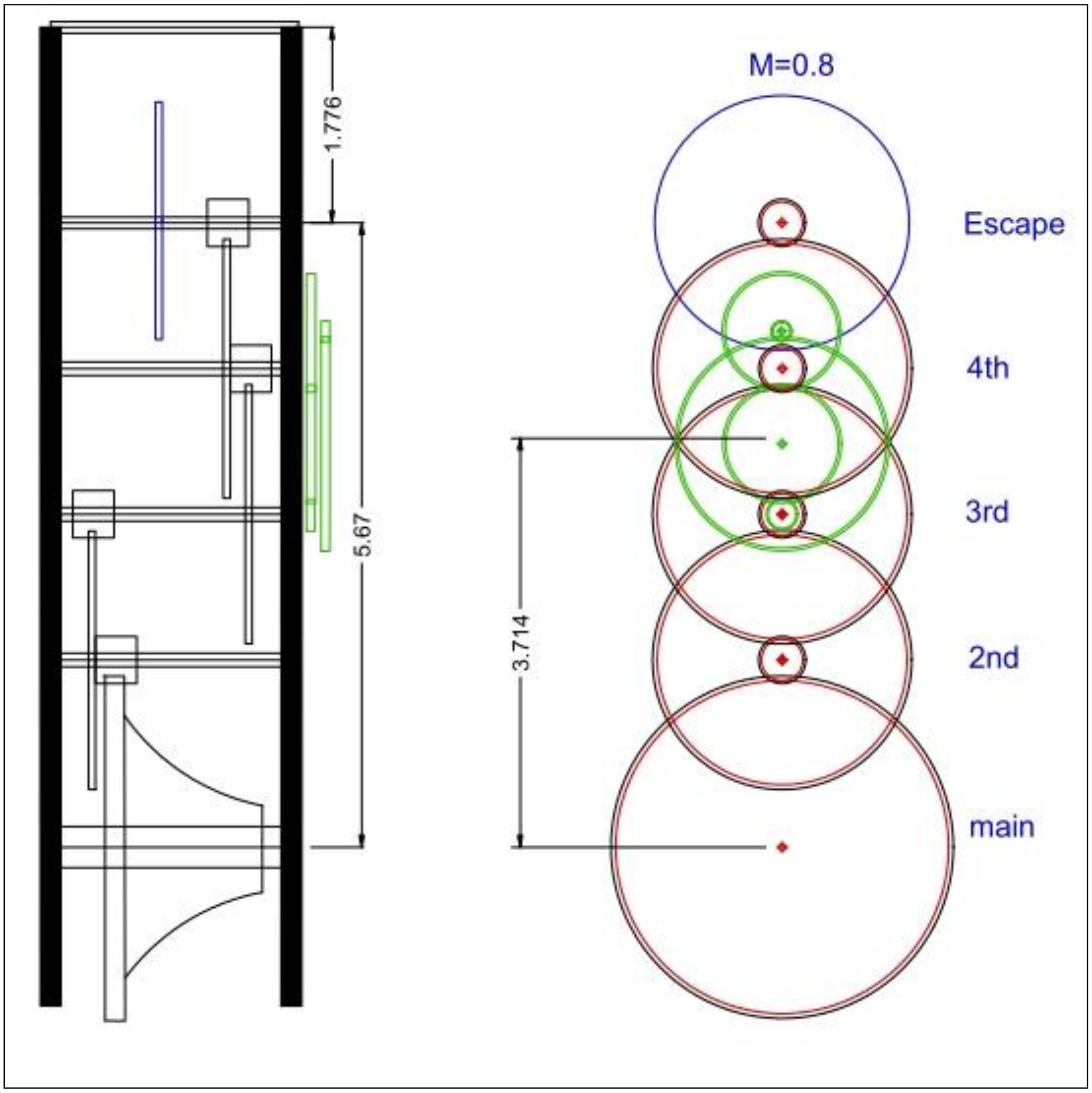


Figure 2: *CAD sketch used to determine wheel spacing and placement. This drawing is used to look for interference between parts and to provide preliminary dimensions. The circles on the right represent the wheels with black circles for the tips of the teeth, red circles for pitch diameter and green for the motion works. Black circles overlap (representing teeth meshing) and red circles touch at a single point.*

Tools and Construction Methods

No exotic or expensive equipment is used to construct this clock. All machine work is done with only a grinder, drill press and Taig lathe. The lathe is equipped with a second head for milling, but does not have CNC or threading capability. The dividing plates and cutters used for machining wheels and ratchets are all homemade. The remainder of the work is done by hand.

Standard materials will be used to construct the clock, primarily brass and steel. Every attempt will be made to make all of the required parts within reason. Plate screws and other pieces that are obviously visible will be constructed, but there is no reason to spend countless hours making 0-80 screws or a fusee chain that are simply impractical to make in the home shop. I applaud any purists that wish to pursue this level of detail.

A Pinwheel Skeleton Clock

2 - The Escapement

Escapement Description

The escapement is a pinwheel of an unusual architecture in that the pallet arms are equal in length and the pins are placed on alternate sides of the escape wheel. By making the pallet arms the same length, the impulse on each pallet is equal. Pinwheel escapements with unequal pallet arms technically have an imbalanced impulse, although the imbalance is not likely to affect the operation or accuracy of the clock. Alternating the pins on each side of the escape wheel does provide a substantial improvement in the amount of drop available and reduces the need for extremely tight tolerances when making the escapement.

Pallets

The pallet arms are cut from 1/16″ O-1 oil hardening ground flat stock. Layout two identical parts according to the dimensions indicated in Figure 4. Cut each part slightly oversize with a jeweler's saw and file to shape. The flag portion indicated in red will be bent at 90 degrees later in the process. The rounded portion can be filed by eye, but better results are obtained by using filing buttons.

A set of filing buttons is easily made and can be used over and over. Chuck a short piece of ½″ drill rod in the lathe and face the end. Center drill and then step drill to a final size of #36 (.106″) to a depth of 3/8″. Part off two washers approximately 1/8″ thick, remove any burrs and harden to bright orange with a propane torch. The buttons should be left "glass hard" so a file skates across the surface. Do not temper.

Figure 3*: Use of filing buttons to shape the round ends of the pallet arms. A 1/8" drill bit keeps the parts aligned.*

Drill and ream the center of the rounded end of the pallet arms to .106″. Reamers of this size are often made from the same stock used to make the arbor. A homemade reamer is shown in Figure 18. The mounting holes are drilled to #52 (.0635″) for clearance of 0-80 screws. Sand or file off any burrs raised by the drill. Sandwich both arms between the filing buttons using a #36 drill bit as an alignment pin as shown in Figure 4. The parts can be super glued together, but clamping the unglued parts with the alignment pin in place in a bench vise works just fine. File the rounded end of the pallet arms until the file contacts the buttons all around.

Smooth all faces and edges of the pallet arms by draw filing and then using progressively finer grades of sandpaper to a 600-grit finish. Some touch up may be needed to remove marks from the tab bending operation, but it is easier to prepare the surface as much as possible while the part is flat and easy to hold.

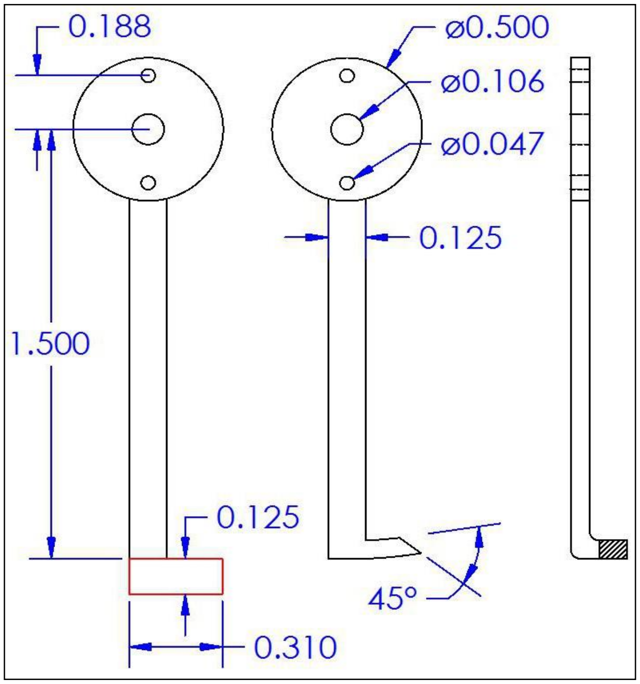


Figure 4: *Pallet arm construction drawing. Material is 1/16" O-1 flat stock. The front view on the left shows the arm before the tab (shown in red), is bent 90 degrees, the front view in the center shows the arm after the tab is bent.*

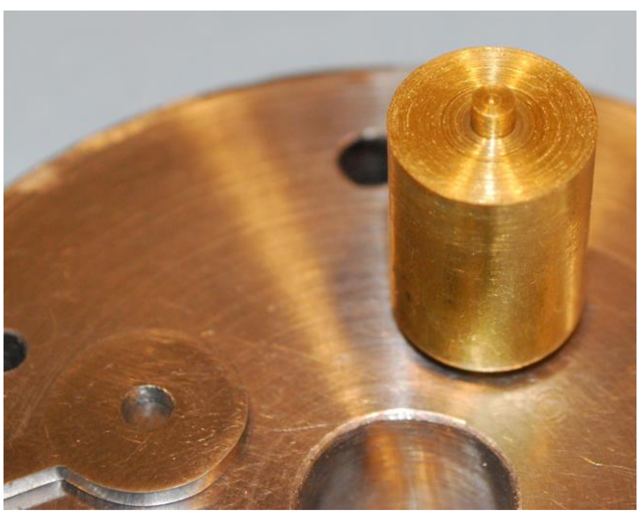


Figure 5: *Centering adapter.*

The tabs of each pallet arm are now bent to form the pallet surfaces. This is accomplished by using a 3″ round bench block as a bending form. The bench block is from a piece of 1″ thick steel, 3″ in diameter with flat faces and various diameter holes drilled in it. The center hole is not drilled through, providing a flat surface on one side and a ½″ hole on the other. If the reader does not have such a bench block, it is easy enough to make and serves a multitude of tasks in the clockmaker's shop.

An adapter shown in Figure 5 is made that fits the center hole and cut to length such that the end sits 1/16″ above the bench block surface. A pip 1/16″ high is then machined to a diameter that fits snugly into the .106″ center hole of the pallet arm. The adapter should fit somewhat loosely into the bench block hole. The tab on the pallet arm must be heated before bending due to the sharp radius bend required. To prevent the bench block from absorbing heat away from the pallet arm, place a spacer between the pallet arm and bench block as shown in Figure 6.

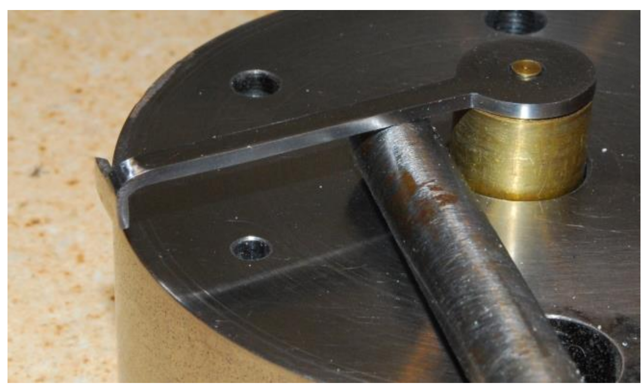


Figure 6: *A ¼" rod holds the pallet arm away from the bench block during heating. These photos were taken after the pallet was completed to recreate the process.*

The following sequence must be done quickly because the pallet arm will cool rapidly. It may be advisable to rehearse a few times before performing the actual operation.

Heat the tab and lower end of the arm to a dull red with a propane torch. Set down the torch, remove the spacer and push the pallet arm against the bench block with a block of wood. Hammer the tab over the edge of the bench block with a rawhide mallet. Continue hammering the tab so it conforms to the round contour of the edge of the bench block. It may be necessary to reheat the tab or arm to complete the shaping process. Bend the tab on the other arm in exactly the same way. Carefully inspect the bend area. It will be necessary to remake the part if any cracks are found.

Figure 7: *Hold the pallet arm against the bench block with a piece of wood while hammering to keep it straight and force the bend to be as sharp as possible. Firebrick under the bench block prevents the torch flame from burning the bench. The wood block will smoke, but it absorbs less heat from the pallet than a metal block. A rawhide mallet is used because a steel hammer would dent the soft hot metal and a plastic or rubber mallet would melt.*

The 45° impulse face can now be cut. It is necessary to compensate for the additional angle from the curved tab. This is calculated by measuring the width of pallet arm (.114″ in my case vs .125″ called for in the drawing. Too much filing!) Subtract half the arm width from the measured length of the tab (.305″) to obtain the distance from the centerline of the pallet arm to the tip of the tab (.248″). Next measure the distance from the tip of the tab to the center of the arbor hole (1.53″). The angle is then calculated by $\sin^{-1}(.25/1.53) = 9.4°$, or approximately 9°. The reference angle from the Y-axis can now be found as 45° + 9° = 54°.

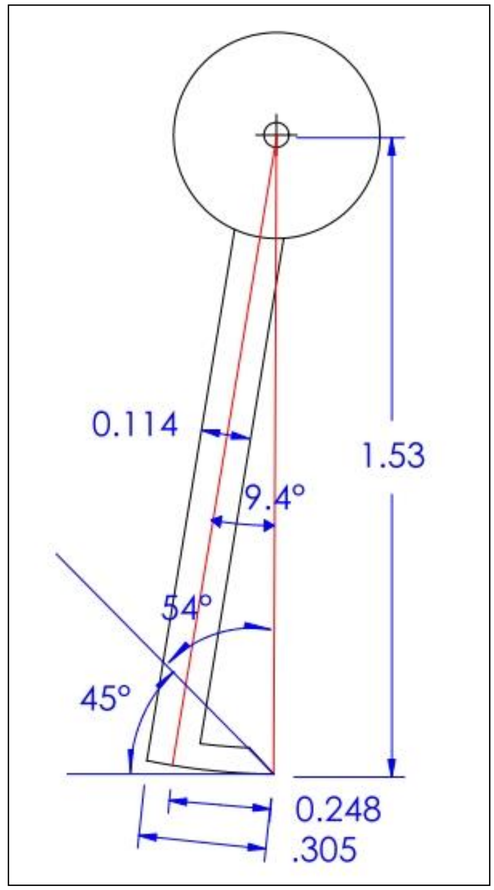


Figure 8: *Determining the grinding angle of the impulse face.*

A jig held in the lathe tool post holder is set so the pallet arm is 54° offset from the side of a grinding wheel. Cover the lathe bed to protect it from grinding dust. Move the pallet into contact with the grinding wheel using the carriage and grind approximately ¾ of the impulse face. Check the face to make sure it is being cut straight. Adjust the pallet as necessary and continue grinding and checking until a sharp edge is obtained. Repeat the grinding operation for second pallet.

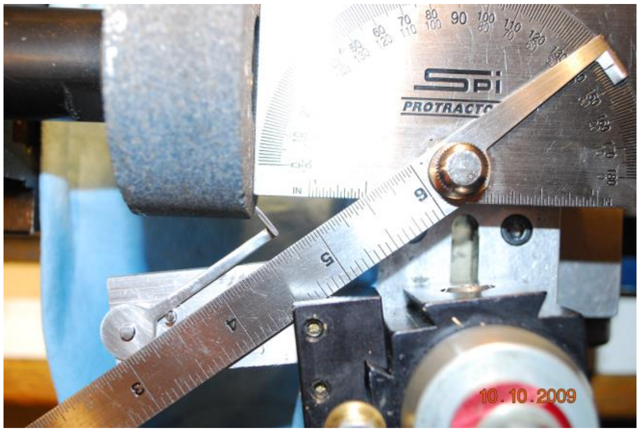


Figure 9: *Use a protractor to set the jig to the correct angle for grinding the impulse face. Since the side of the protractor is being used, the angle is set to 144° (90° + 54°). The jig consists of a piece of aluminum with two pins. One pin fits through the pallet arm center hole and acts as a pivot. The other pin stops the arm from rotating clockwise.*

After grinding the impulse face angle, polish the impulse face with progressively finer grades of sandpaper to 600-grit. If the paper is mounted to a round disk spun in the lathe, 600-grit will leave a mirror finish on the impulse face. Polish the curved top of the pallet by holding sandpaper against the side of the bench block and rubbing the pallet back and forth against the sandpaper with the round end centered by the adapter. Sanding in this method retains the correct radius on the top of the pallet.

Harden the pallet by heating to bright orange and quenching in oil. Immediately temper at 350° F. for one hour in a kitchen oven. The pallet can now be sanded all over to 600-grit. If desired, all parts will be polished to a mirror finish after the clock is completely assembled.

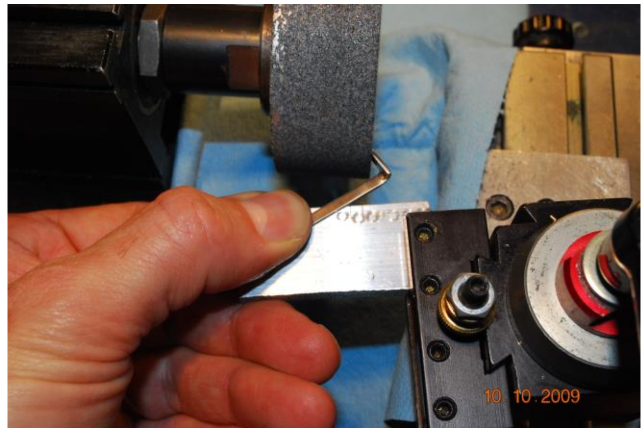


Figure 10: *Hold the pallet in position while moving the impulse face into the wheel with the carriage.*

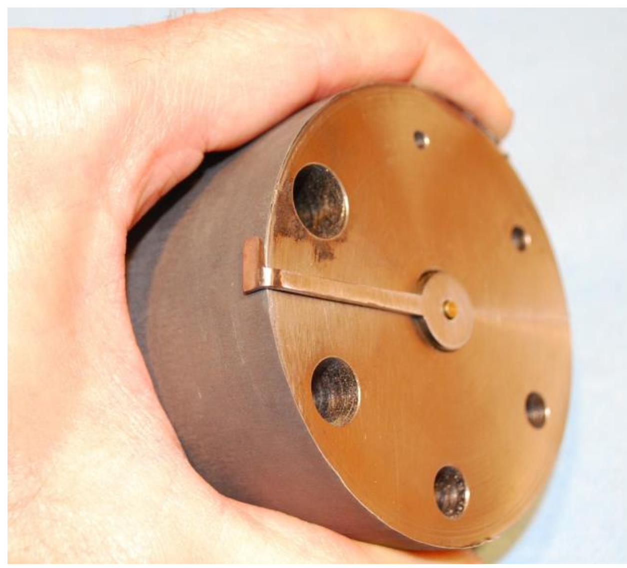


Figure 11: *Wrap sandpaper around the bench block to polish the top of the pallet while maintaining the correct radius necessary for deadbeat action.*

To prevent rust or fingerprints, apply automobile wax to the entire pallet arm except the top of the pallet and impulse face, which should receive a light coat of clock oil.

Escape Wheel

The escape wheel is fairly simple to construct. Proper care should be used to ensure the outside edge and holes for the pins are concentric with the center hole. Turn a disk of 1/16" brass to a diameter of 2.156".

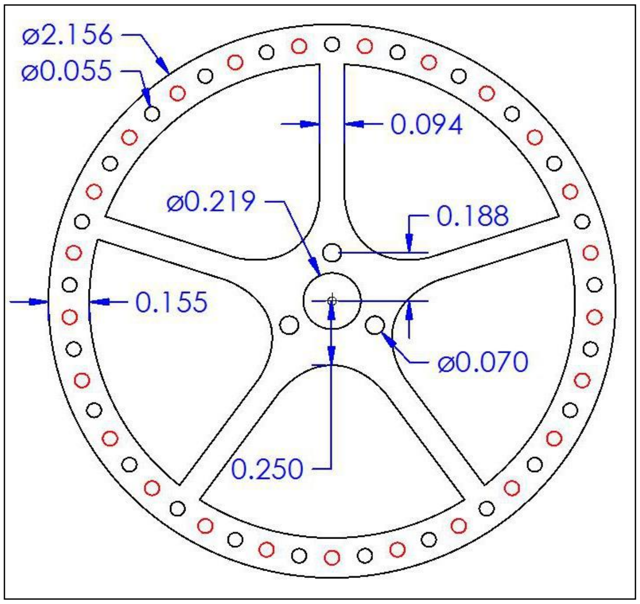


Figure 12: Escape wheel construction drawing. The Red holes indicate the wire is located on the back of the wheel and the Black holes indicate the wire is located on the front.

Mount a milling spindle on the cross slide similar to Figure 32. Offset it 1" from the center of the wheel. With an index plate mounted to the lathe headstock, spot drill 50 holes around the disk with a small center drill bit. Then drill each hole through with a #54 bit. This bit should make a .055" diameter hole for a press fit of the music wire pins. Consider drilling a test hole in a piece of scrap brass to verify a tight fit. Reset the milling spindle for a 3/16" (.188") offset and spot 3 holes to attach the collet. Remove the wheel and drill the 3 holes through with a #50 drill bit.

The wheels spokes are cross out in the typical manner. 5 spokes were used here, but any number can be used. Sanding and polishing the wheel will be very difficult once the pins are installed, so the builder may wish to perform these steps and lacquer the wheel before inserting the pins. Care will be required when handling the finished wheel from this point forward to prevent damaging the lacquer.

A length of music wire is prepared by sanding with 600 and 1200-grit paper followed by Simichrome polishing paste. A Dremel cutoff wheel is mounted and the tool is placed in the bench vise with the wheel .220" from the vise.

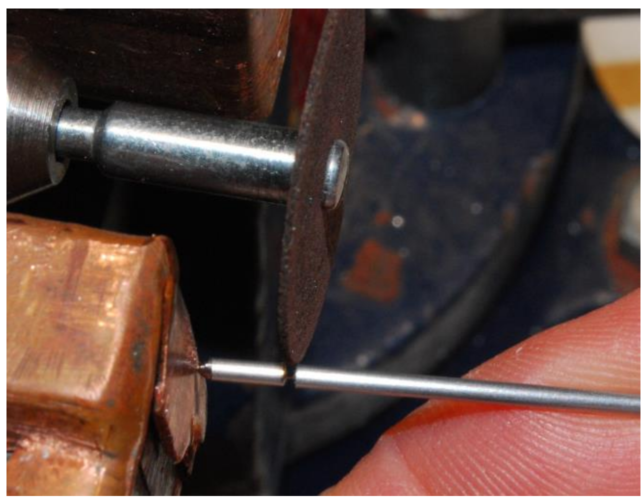


Figure 13: The end of the wire against the vise has been rounded. The wire is being rotated against the cutoff wheel until almost through.

The end of the wire is rounded by rotating it against the side of the cutoff wheel. With the rounded end of the wire placed against the vise, rotate the wire against the edge of the cutoff wheel to cut a groove in the wire. Do not cut completely through or the pin will likely be lost. Snap off the pin instead. Set the pin aside and round and cut the remaining pins. Make a few extra pins just in case some are lost. Using a pin vise or fingers, press the back of each pin against the cutoff wheel to remove the pip. Then rotate the edge of the pin while lightly touching the cutoff wheel to remove any burrs and produce a slight bevel to aid insertion into the escape wheel.

Lay the escape wheel flat on a soft wood block and insert the pins into every other hole on one side of the escape wheel. Tap the pins in with a small hammer or press them in with an arbor press. Use a touch of Loctite to ensure they do not come loose. Flip the wheel over and position it near a corner of the block so 4 or 5 pins are on the block. Mark the position of the pins on the block and drill these holes deep enough to allow the wheel to lay flat on the block. Insert the remaining pins in the other side of the wheel.

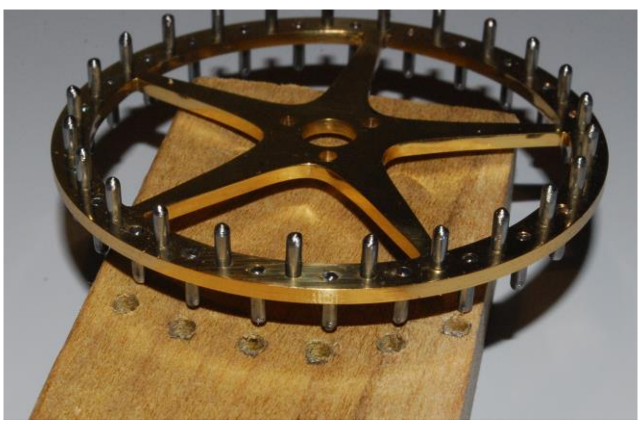


Figure 14: *Small holes drilled in a block of soft wood allows the wheel to lay flat while the pins are driven into the opposite side.*

Escape Wheel Collet

The escape wheel collet is machined from ½″ brass rod. Face the end and spot the arbor hole with a small center drill. Drill a little over ½″ deep with a #37 drill bit and then ream the hole to .106″. Reduce the end of the rod with a parting tool to form a shoulder that fits into the wheel center hole. Test fit the escape wheel to the collet often to achieve a snug fit. A left hand lathe tool or graver should be used to clean out the corner and make the hub slightly concave so that only the outer edge of hub contacts the wheel. The sleeve portion of the collet is then formed with multiple plunge cuts with a parting tool.

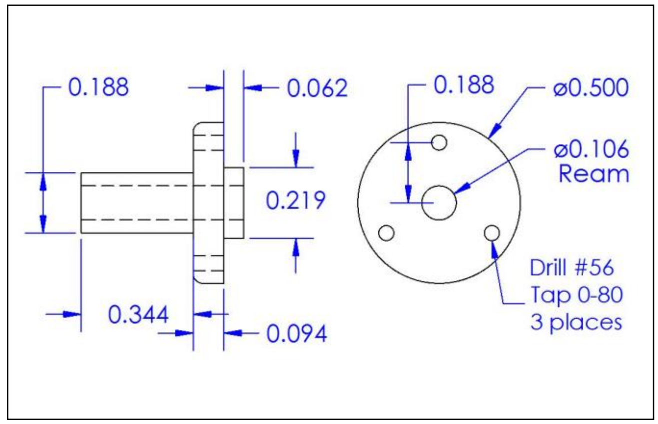


Figure 15: *Construction drawing for the escape wheel collet. Identical collets are used for the third and fourth wheels. The second wheel collet is similar except the center hole is reamed .125".*

The depth of these cuts should leave the sleeve slightly larger than specified so a cleanup cut can be made with the parting tool to achieve a uniform finish. A clean up cut is then made across the outer diameter of the hub. The back edge of the hub is rounded over with a file.

Mount an index plate on the headstock and the milling spindle on the cross slide. Offset the spindle 3/16″. The builder may wish to place the escape wheel on the collet to verify the spindle offset matches the escape wheel mounting holes. Spot drill and then drill through with a #56 drill bit. Tap all three holes 0-80. Finish the collet to a 600-grit finish before parting off.

Crutch Collet

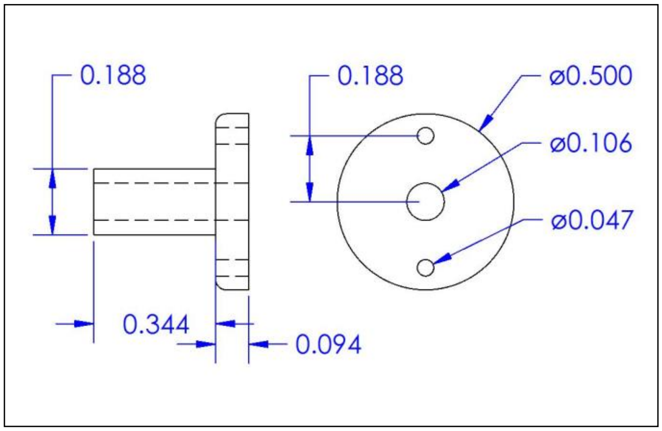


Figure 16: *Construction drawing for the crutch collet.*

The crutch collet is machined in the same manner as the escape collet except it has no wheel shoulder and only 2 mounting screw holes are drilled and tapped.

Pallet and Escape Wheel Arbor

The fourth wheel, pallet and escape arbors are all machined to the same dimensions. These are made from blued pivot steel or music wire. A collet is recommended for holding the work as the arbor will need to be removed for measuring and machining the 2.375″ distance between the shoulders. If a collet of this size is not available, a bushing can be made from a ½″ length of brass rod with a center hole drilled and reamed to .106″. A slot is then cut down the side of the bushing to allow it to squeeze around the work piece. This bushing is fine for driving the arbor but may not run perfectly true. To ensure the pivot runs true, a steady rest is used to hold the end of the arbor as it is machined as shown in Figure 19. After the pivot is machined to a diameter of .051″, clean out the corner of the pivot with a pointed graver and reduce it to the final .049″ dimension with a pivot file or very fine (#6) flat file.

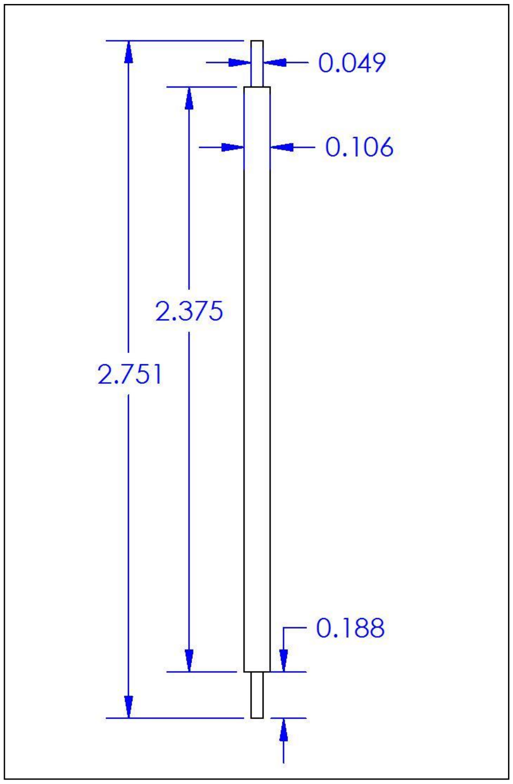


Figure 17: *Construction drawing for the fourth wheel, pallet and escape arbors. The material is #36 music wire.*

Polish the pivot with a fine Arkansas stone and oil. Then burnish to bring up a mirror finish and work harden the pivot. The second pivot should be turned in the same way with the shoulder spacing as close to 2.375″ as possible, but not less. Remove the arbor and check the distance with a dial caliper. When the proper distance is achieved, finish the pivot as above.

__Figure 18:__ A reamer made from .106" drill rod. A flat is ground at a 20° angle and then sharpened on an India stone. After hardening and tempering, it is ready for use. Use oil with this type of reamer to prevent it from binding during use. Also shown is a bushing inserted into a Taig collet. The slit in the side of the bushing allows it to pinch down and hold the material when the collet is tightened.

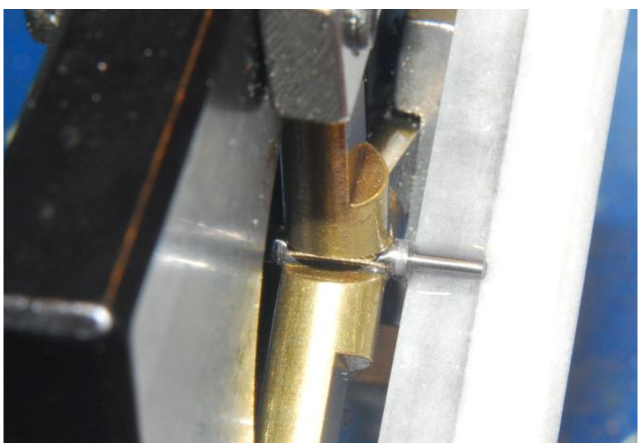


__Figure 19:__ After filing, a pivot is polished with an Arkansas stone lubricated with mineral oil prior to burnishing. The even distribution of gray metal on the white stone indicates the pivot is flat across the entire surface. Machining the pivot held in a steady rest ensures the pivot is concentric with the outside diameter of the arbor.

Pallet Spacer

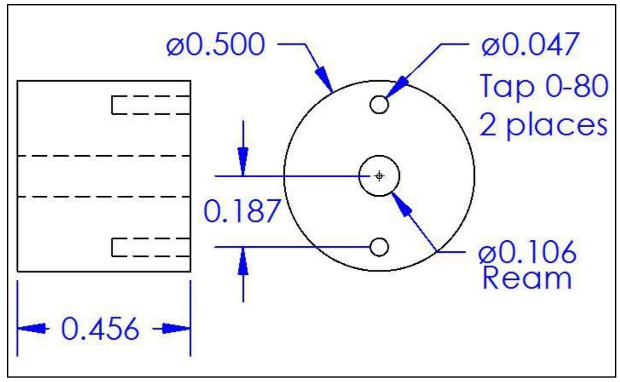


__Figure 20:__ Construction drawing for the pallet spacer. One set of #56 holes (.047") are initially drilled and tapped. The location of the remaining set of holes is determined by positioning the pallets on the test assembly.

The pallet spacer serves several key purposes. It holds the pallet arms at the correct distance from the escape wheel and also positions the pallet arms to obtain the necessary amount of drop for the escapement. A 1" piece of ½" diameter brass rod is chucked in the lathe. Face the end and make a cleaning pass over the side. Center drill, drill and ream the center hole to .106" for a slip fit over the pallet arbor. Finish the surface of the spacer to 600-grit. Part-off the spacer at .456" in length. This distance was determined from actual measurements of each pallet width (approximately .134" each. This will vary depending on the bend radius of the pallet tab, thus measurement is required.) the thickness of the escape wheel (1/16") and clearance between the pallets and escape wheel (1/16" each side).

Using a short piece of .106" drill rod as a guide, position one of the pallet arms on the end of the spacer and spot the two mounting holes. Remove the pallet arm and drill the holes to approximately ¼" deep with a

#56 drill. Tap both holes 0-80. The mounting holes on the other side of the spacer will be drilled based on the escapement test later.

Test Crutch

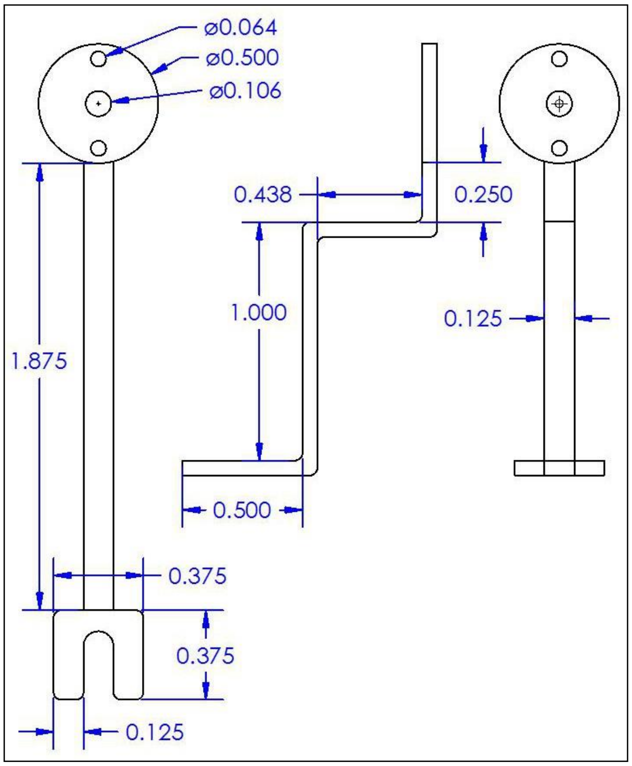


Figure 21: *Construction drawing for the crutch. Cut out the part according to the dimensions shown on the left drawing and then bend to the shape shown in the center and right drawing.* ***Note: The crutch shown here was built to test the escapement. An adjustable crutch will be built with the pendulum. Refer to that section for the final crutch design.***

The test crutch is formed from a strip of 1/16″ 260 brass sheet. A jeweler's saw is used to cut the shape shown in the left side of Figure 21. As with the pallet arms, the crutch will be filed to shape and sanded to a 600-grit finish while it is still flat. As the crutch is bent, approximately 1/16″ will be taken up in each bend. Clamp the crutch in the bench vise with the rounded end and 5/16″ of the arm exposed. The vise should be fitted with copper jaw liners to prevent marring the brass. Bend the exposed part forward using a wooden block and hammer to form a tight bend. Raise the crutch ½″ and bend the exposed part back in the same way. Finally, raise the crutch in the vise again so all but the foot is exposed and bend the part forward. The dimensions of the bent crutch arm in Figure 21 are not critical and the finished crutch may vary slightly without causing any problems.

Figure 22: *The completed crutch and collet. The collet is machined with a raised edge so the crutch and collet make contact only around the edge to prevent rocking.*

This completes construction of all of the parts needed to test and adjust the escapement. A temporary assembly is constructed from scrap material. The only dimensions that require particular attention are the plate spacing and the distance between the pallet and escape arbors. The distance between the plates should be 2.390″ to accommodate the 2.375″ arbors with an additional 1/64″ (.015″) for end shake.

The arbors are spaced so the escape wheel pins contact the pallets perpendicular with the pallet arms. Given that the pins are 1″ from the escape arbor and the distance from the pallet arbor to the top of the pallet is 1.468″ (1.53″ - .0625″ from Figure 8.) The distance between the arbors becomes the hypotenuse of a right triangle and its length is found by $\sqrt{(1)^2 + (1.468)^2} = 1.776''$. Figure 23 shows the construction of my test assembly.

If the collets do not fit tightly on the arbors, they can be temporarily held in place with low-strength 222MS Loctite. The pallets and escape wheel are mounted near one end of their arbors with the unattached pallet arm nearest the plate. This allows a drill bit to clear the pallet arbor when spotting the remaining mounting holes. A ½″ hole is drilled in one plate centered ½″ below the pallet arbor to allow the crutch to project outside the plate.

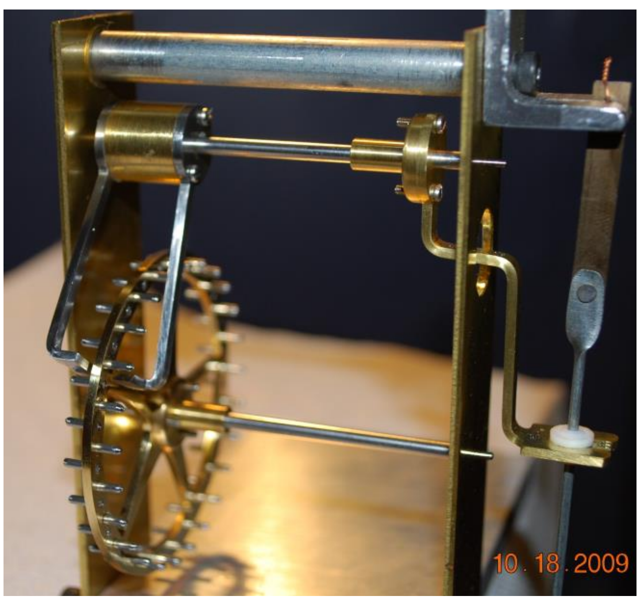


Figure 23: *The Escapement test assembly. Brass strips serve as the plates and scrap components are used to rig up a temporary pendulum.*

Initial alignment of the crutch and pallet arms is such that the crutch hangs straight down while an escape pin is centered on the impulse face. This alignment may need to be adjusted several times to put the escapement in beat.

A temporary pendulum is made from a store-bought suspension spring and pendulum wire assembly approximately 9″ in length with a brass weight attached to the end. The suspension spring is held by a piece of aluminum angle with a slot to accept the spring. A plastic or nylon spacer provides a slop-free fit between the pendulum wire and the crutch foot.

The pallets should be aligned with the impulse faces overlapping approximately 1/3 of the way as shown in Figure 24. More overlap provides more lock, but this requires more drive power and a wider pendulum arc. Less overlap produces a smaller pendulum arc and minimizes circular error, but the escape pins still need to land on the flat top of the pallet, not the impulse face. The remaining pallet arm is attached to the spacer with white Elmer's glue. Super glue can be used, but the white glue offers some degree of adjustment before it completely sets up. Attach the pallet arm and let the glue set for approximately 15 minutes.

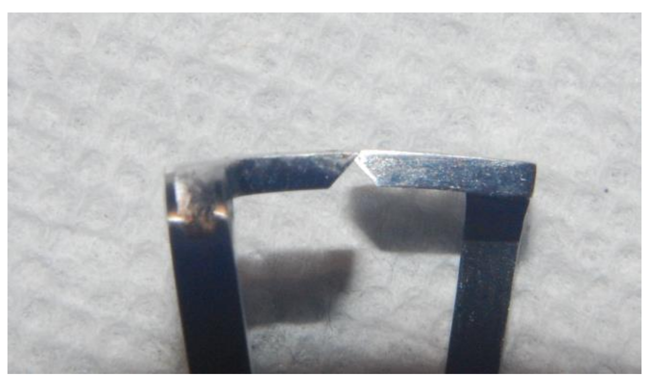


Figure 24: *Initial pallet alignment. Adjust as determined by test running the escapement.*

Apply a small amount of clock oil to the pallet impulse faces and arbor pivots. Test run the escapement using light finger pressure on the escape arbor to drive it. Adjust the crutch and pallets to obtain an even beat. Adjust the pallet arm alignment so the escape pins just fall on the top of the pallet. Some over swing of the pendulum is normal. Let the glue set up for several hours before proceeding.

Run the escapement for several revolutions of the escape wheel to verify that all pins lock and drop correctly and the impulse is sufficient to keep the pendulum swinging. The pendulum arc should be fairly small.

Remove the pallet arbor and spot drill the remaining mounting holes in the pallet spacer using the pallet arm as a guide. Remove the pallet arm with a light tap on the side with a plastic or rawhide hammer. Drill the mounting holes #56 and tap 0-80. Attach the pallet arm and reassemble the escapement assembly. Verify that the escapement runs as before. There should be enough slack in the pallet arm mounting screws to make slight adjustments to the pallet overlap if necessary.

Now that the escapement design has been confirmed, the remaining parts of the clock can be constructed.

A Pinwheel Skeleton Clock

3 - Pinions & Wheels

Introduction

Clock makers have a choice of lantern or cut pinions. Either style is acceptable and each has benefits and shortcomings. The original clock upon which this one is based used cut pinions and therefore they will also be used here.

Pinions

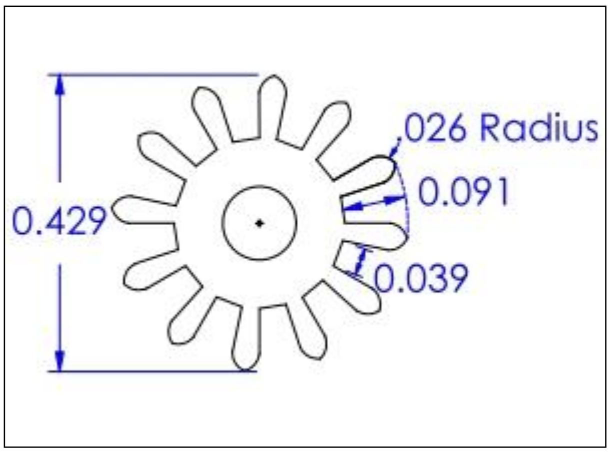


Figure 25: *Construction drawing of 12-leaf pinions. The module is 0.8. Three pinions require a center diameter of .106"; one pinion requires a center diameter of .1875"*

A 12-leaf pinion requires a cutter designed specifically for this module and leaf count. The cutter was built according to the method described by David Creed as posted on the Yahoo Mlhorology group. A test run was made with a piece of ½″ diameter hot rolled mild steel rod. After reducing the diameter to .429″, several slots are cut with a 1/32″ slitting saw to the full depth of .091″ in a single pass. The wheel cutter was then run through the slot at full depth producing a nicely formed leaf. These cutters were mounted on a second Taig headstock used as a milling spindle held with the milling attachment on the cross slide. The variable speed lathe motor was used to drive the second headstock via a ¼″ flex shaft similar to that shown in Figure 37.

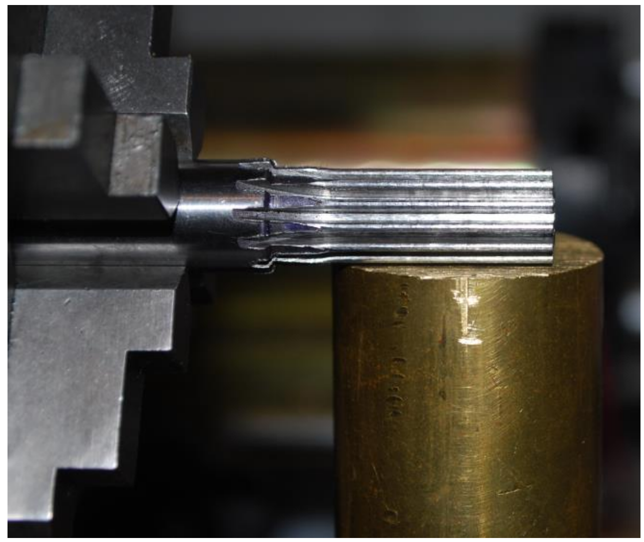


Figure 26: *Supporting the pinion stock with a brass rod to prevent flexing and chatter. This photo is a recreation, taken after machining and several pinions had already been cut from the stock.*

The Taig tailstock could not extend far enough to support the end of the rod, so a 1″ diameter brass bar served as a makeshift support as shown in Figure 26. The final pinions need to be hardened for optimum durability, but the hot rolled steel does not contain enough carbon to be sufficiently hardened. Therefore, a piece of ½″ oil hardening drill rod replaced the test piece and was turned to the .429″ diameter for a 12-leaf pinion. Even in its annealed state, drill rod is much harder than HRS. After cutting approximately ½″ of the first slot, the slitting saw lost its edge and was ruined. The pinion cutter was then run down the slot and quickly became dull. The flex drive shaft also jumped and vibrated significantly. Time to re-group.

A tachometer was temporarily attached to the milling spindle to check the speed of the cutters. It was found to be rotating at approximately 300 rpm. This speed is fine for the one-inch pinion cutter on mild steel, but much too fast for drill rod. The 1.75″ slitting saw needed to be slowed down to approximately 88 RPM and the pinion cutter should be run at approximately 150 RPM to achieve the proper surface feet per minute cutting speed. The milling spindle drive arrangement was also changed to correct the flex shaft problems. Since the Taig lathe is not heavy, it can easily be moved to obtain the configuration shown in Figure 27. The 1″ motor pulley drives the 4″ flywheel of the milling spindle. The lathe motor is loosely fastened to the lower plywood board allowing the weight of the motor to keep the belt tight.

The sequence of cutting the pinions is also changed. A slitting saw .025″ wide is used to cut the initial slots in 2 passes. The first pass cuts to a depth of .045″ with cutting oil liberally applied with an acid brush. The second pass is then cut to a depth of .089″ (Full depth, or tooth height, is .091″). The previous slot is filled with cutting oil for cooling and lubrication. The feed rate of the saw is very slow, taking approximately 2 minutes for each 2″ long cut. A new slitting saw is then used to widen the slots to .036″ in a single pass. Excessive vibration prohibited making a full depth pass with the pinion cutter. A first pass is made at a depth of .075″ and the second pass can then be made at the full depth of .091″. After many hours of work, the result is a pinion rod approximately 2.5″ inches long from which the individual pinions are cut.

Each pinion is drilled prior to removing it from the pinion rod. Three pinions ¼″ long are needed for the third, fourth and escape arbors.

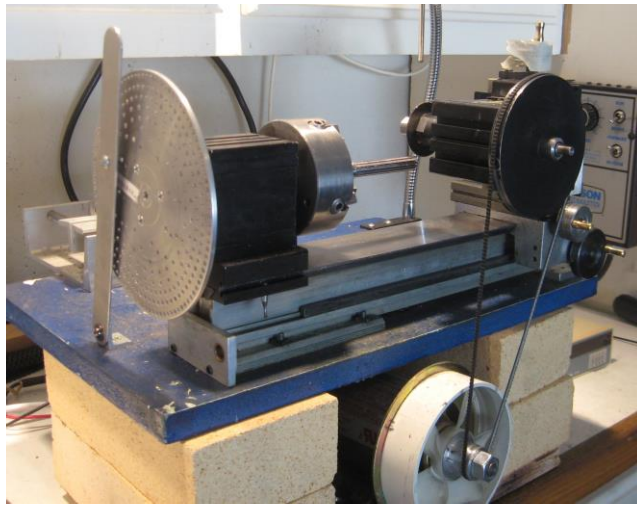


Figure 27: *Elevating the Taig lathe on bricks to allow direct drive of the milling spindle. A 4:1 reduction in the belt drive and a variable speed DC motor provides the low speeds and power needed to cut the drill rod without ruining the cutters. The brass rod supporting the end of the pinion stock is not shown in this photo. The variable speed controller is partially visible on the right.*

Each pinion should be drilled separately to minimize the tendency of the drill bit to wander. Each pinion is first drilled #38 to a depth of ¼″ and then #36 for the final diameter. It may be necessary to ream the hole if the builder's #36 drill bit leaves the hole over size. A smooth slip fit on the arbor is required for attachment with Loctite during final assembly. The pinion for the second arbor should be 5/16″ long and the center hole is step drilled and reamed to a final diameter of 3/16″. The larger diameter center hole allows the pinion to be mounted on the second wheel collet close to the wheel.

After each pinion is drilled, the pinion rod is slowly rotated in the lathe while a Dremel tool with a cutoff wheel grinds through the leaves. Attempting to cut the leaves with a parting tool will bend or break them. When the body of the pinion is reached, the lathe is rotated in reverse while the body of the pinion is cut with a jeweler's saw until the drilled hole is almost reached. Sawing the rod while rotating it ensures a clean straight cut. The lathe is then stopped and the remainder of the cut is completed with the jeweler's saw in the normal fashion. If the cut is completed with the lathe running, the saw will catch when it breaks through and the saw blade will be broken. Remove any burrs from the center hole and sand each end of the pinion flat to a 600-grit finish.

The pinions should be hardened to improve wear characteristics. Unfortunately, the pinions contain sharp corners and sections of various thicknesses that make the parts susceptible to cracking and deforming during the heat treatment process. Therefore, steps must be taken to minimize these potential problems. To even out the heat distribution, the pinion is placed in a wire cage. The cage is made of soft iron wire (rebar tie wire) that is formed by wrapping it around the remaining pinion stock. A small flat washer is placed at the bottom of the cage, the pinion is inserted and another washer or flat disk is placed on top of the pinion. The washers and wire cage deflect the direct heat from the torch and help heat the pinion evenly. To further help prevent cracks during quenching, the quench oil is heated to between 90 & 140 ºF. as recommended by Machinery's Handbook. Any oil will work, but mineral oil is preferred. It is clean, does not smoke, quenches well, is non-toxic, (it is actually sold as a laxative!) inexpensive and readily available at any drug or grocery store.

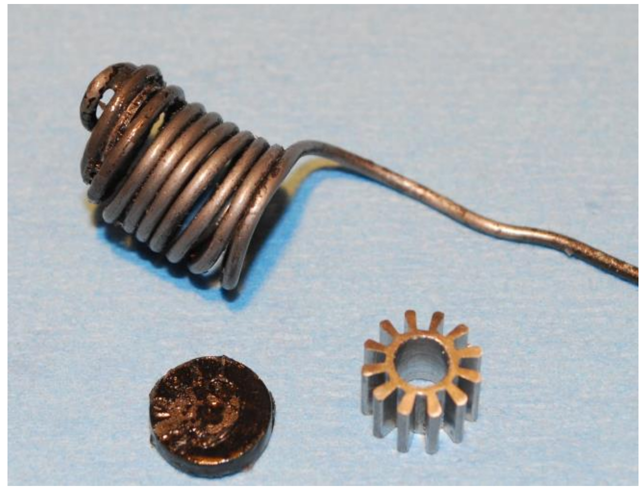


Figure 28: *The wire cage used to hold a pinion during heat treatment. A flat washer is located in the bottom of the cage and a solid disk goes on top of the pinion prior to heating. The hole in the bottom washer allows excess boric acid/alcohol solution to drain away. The disk shows a crust formed by the boric acid from a previous heat treatment. This crust may make it difficult to remove the pinion from the cage. Simply unwind the wire from the pinion and reform it for reuse.*

To prevent decarburization and scale build up, the wire cage and pinion assembly are immersed in a solution of denatured alcohol and boric acid (available as roach killer). The solution should be the consistency of pancake batter. The boric acid forms a barrier around the part and prevents oxygen from reaching the surface.

The recommended temperature for hardening O-1 drill rod is 1475 °F, which corresponds to a dull cherry red color. However, since the pinion cannot be easily viewed while inside the cage, a magnetic test is also used to indicate when the correct temperature is approaching. For O-1 drill rod, The Curie temperature, or temperature when it becomes non-magnetic, is approximately 1440 ºF. Heat the assembly slowly and evenly by rotating the cage in the torch flame. Begin testing with a magnet when it begins to glow. When the assembly is no longer attracted to the magnet, heat it a few seconds more and then quench in the oil. Remove the pinion from the cage and wash it in hot water.

After cleaning, temper the pinions in the kitchen oven at 325-350 ºF for one hour to prevent cracking and toughen the steel. The pinion ends are then cleaned up with sand-paper. A Cratex tapered edge rubberized abrasive wheel mounted in a Dremel tool works well to polish between the pinion leaves.

Figure 29*: *A pinion is held in a drill press vise for polishing with a Cratex rubberized abrasive wheel. The wheel shown in the lower right can be mounted on a Dremel arbor. The second pinion and collet shown in the upper right have been polished and assembled with 609 Loctite.

Wheels

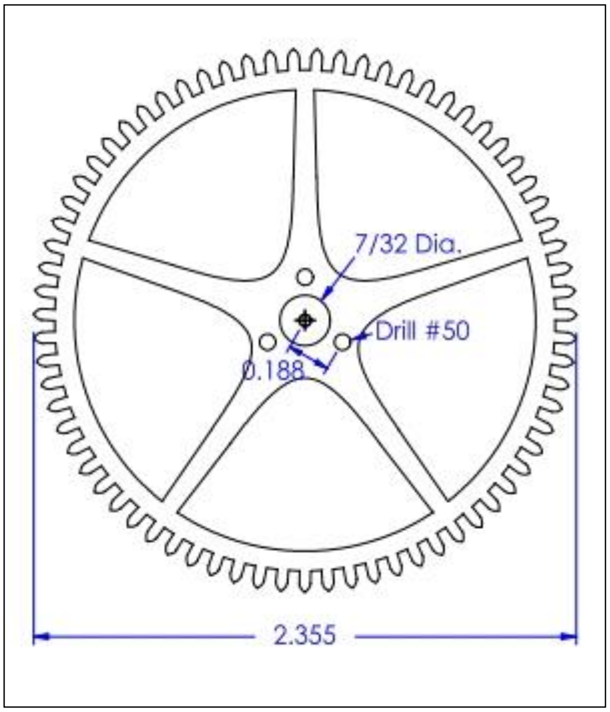


Figure 30: *Three 72-tooth wheels are required for the time train. The number of spokes can be changed to suit the builder's taste.*

Manufacture of the three 72-tooth wheels is accomplished next. Each disk is marked out and cut from a sheet of 1/16″ thick, 356 engraver's brass. The center hole is drilled and reamed to 7/32″. If the lathe arbor is long enough to hold all three disks at once, machining the diameter and cutting the teeth together can save a great deal of time. My arbor could accommodate only one wheel and a backing plate, so the wheels were machined separately.

Much information is already available regarding the cutting of clock wheels, so detailed information is not repeated here. The correct diameter for a 0.8 module, 72-tooth wheel blank is 2.355″. The lathe setup is shown in Figure 37 and is identical to that used for cutting the pinions except the milling spindle is driven by a ¼″ flex cable at approximately 300 RPM.

After the teeth are cut, the centerlines of the spokes are marked on the wheel with the aid of the index plate. Five spokes are used for this design, but any number and shape will work. The milling spindle is remounted as shown in Figure 32 to drill the three mounting holes with a #50 drill. These holes are located 3/16″ from the wheel center. Equal spacing of the three holes is also achieved with the index plate. The wheels are then removed from the lathe arbor and coated with layout blue on one side. The spoke outlines are transferred to the blued side of each wheel. Rough crossing out is accomplished with a jeweler's saw.

Figure 31: *The wheel outline and spoke layout are drawn in CAD and printed actual size. The printout is then used as a guide while filing to ensure the spokes are uniform.*

A difficulty that is often encountered with wheel crossing is getting the spokes symmetrical in spacing and size. The builder may find it helpful to draw the wheel and spoke outlines in CAD and print an actual size drawing. The wheel can then be laid on the drawing as a visual aid to indicate where adjustments are needed during the filing process.

It should also be noted that proper files make a big difference in the effort required to shape and smooth the wheels. The files should be sharp and reserved for use only on brass. Initial shaping is done with a #2, 4-inch crossing file for curved surfaces and a #2, 4-inch barrette file for flat surfaces. A #4, 4-inch crossing file is used for final shaping and initial draw filing. A #6 crossing needle file is then used for draw filing to achieve a finish equivalent to 400-grit paper. After filing, the wheels are then cleaned in denatured alcohol to remove any remaining layout dye and progressively sanded to a 600-grit finish.

Collets for the 72-tooth wheels are identical to the escape wheel collet except the center hole of the second wheel collet is reamed to 0.125″ and the diameter of the second wheel collet sleeve may be adjusted for a slip fit of the second pinion. Each collet is ½″ long and the drill bit may drift off-center when drilling a small hole this deep. A true running collet is especially important on the second wheel since the pinion mounts on the collet sleeve to increase the Loctite bonding area. To ensure the collet runs true, it is machined approximately 0.015″ oversize and the center hole is drilled and reamed to 1/8″ as shown in Figure 32 and Figure 33. The wheel mounting screws are drilled and tapped at this time to take advantage of the mechanical stability of this setup. The partially machined collet is then parted off. A piece of ¼″ mild steel rod is mounted in a collet and machined to 1/8″ diameter to form a perfectly true-running stub arbor.

The stub arbor configuration ensures the center hole, wheel hub and pinion-mounting sleeve run true with each other. The brass collet is super glued to the stub arbor with the wheel end of the collet facing out similar to Figure 33. Light cuts are taken until the hub is a snug fit in the second wheel. Heat the collet to break the super glue bond and remount the collet with the sleeve end facing out as shown in Figure 34. The sleeve is then machined for a slip fit into the second pinion. This technique of using a stub arbor is credited to W.R. Smith.

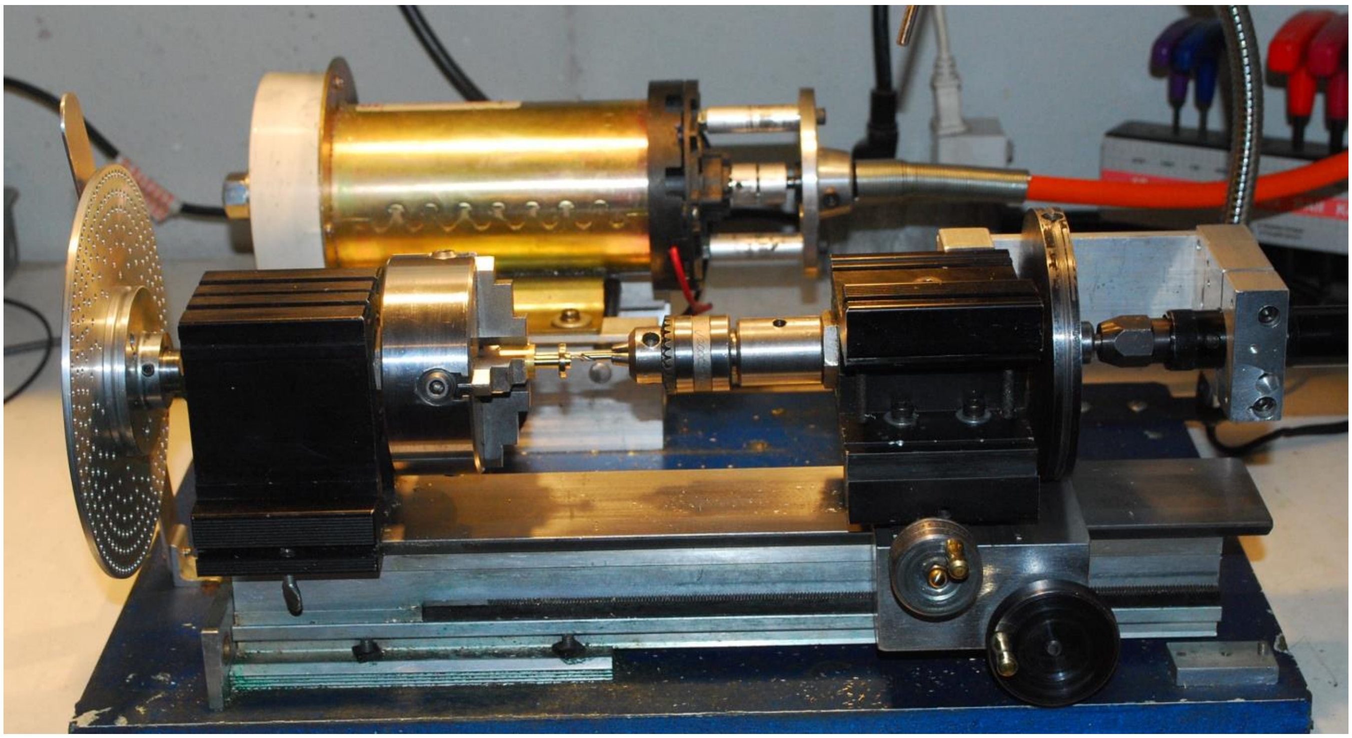


Figure 32: *Using a second headstock as a milling spindle to drill and tap the wheel mounting holes of a collet. As with wheel cutting, an index plate is attached to the headstock on the left. The right headstock is laid on its side and bolted to the cross slide. An aluminum plate (not shown) establishes the correct center-to-center height. The point of the center drill bit is aligned with the center of the collet, and then advanced 3/16", which is the radius of the wheel mounting screws. The orange flex cable attached to the right side of the motor drives the spindle.*

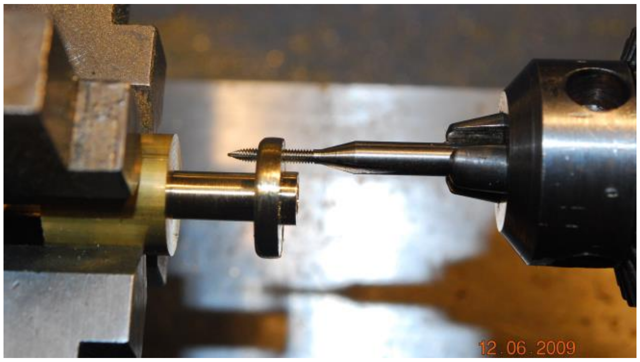


***Figure 33**: The collet is roughed out oversize, center-drilled and reamed to 1/8". The three wheel mounting screw holes are located, drilled and tapped 0-80. Using the milling spindle to hold the tap while turning by hand ensures the holes are straight and reduces the chances of breaking the small tap. This is a spiral-point tap, which pushes the chips out ahead of the tap and keeps the flutes from clogging. The results are faster tapping since the tap does not need to be backed out frequently to clear the chips, cleaner threads and less chance of breaking the tap.*

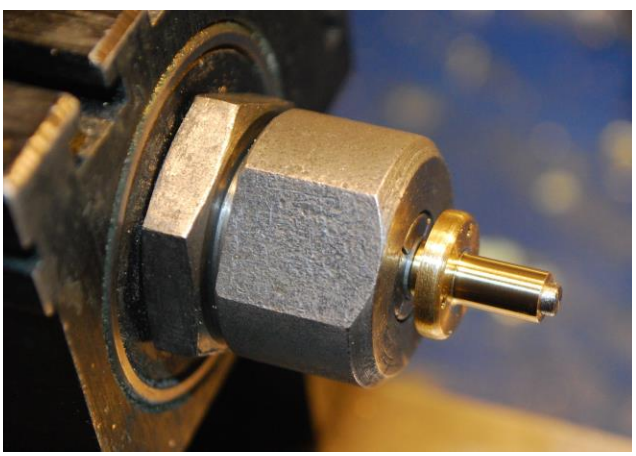


***Figure 34**: A 1/8" stub arbor is turned from a piece of ¼" mild steel. If the arbor is not disturbed after machining, it will run perfectly true. The wheel collet is super glued to the arbor and the sleeve is turned for a slip fit of the second pinion.*

Great Wheel

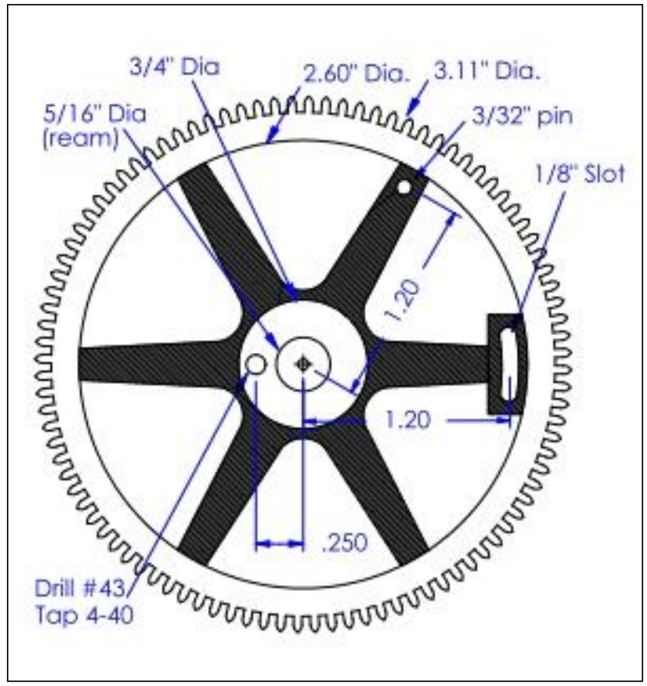


***Figure 35:** 96-tooth great wheel. Blank diameter = 3.111" Module = 0.8 Material = 3/16" 356 brass. Trepan shaded area to 3/32" thick.*

The great wheel is needed at this time to determine the power required to run the train. A different method is used to hold the great wheel while the teeth are cut. A block of wood is fastened to a small faceplate and turned to a diameter of 3 1/8". Facing cuts are made across the block to ensure that it runs true. A ½" center hole is then drilled into the block for clearance when the wheel center hole is bored.

The 96-tooth great wheel is turned from a blank with a diameter of 3.111". A 3/16" thick disc of 356 brass is center punched and the diameter is rough-cut oversize. How much oversize will depend on the accuracy of the sawing and how well the disk can be centered on the wood block. 3.250" is a recommended starting diameter. Three holes are drilled approximately 1.25" from the center and equally spaced around the blank. These holes will be removed later when the wheel is spoked. The blank is now placed on the wood block and approximately centered with the aid of the tailstock center. Wood screws are used to fasten the blank to the wood block.

***Figure 36**: Great wheel mounted to the wooden block shown here after the teeth have been cut and center hole bored.*

The diameter of the blank is now turned to the final diameter of 3.111″. I had to use riser blocks on the headstock and toolpost to obtain enough clearance on the small Taig Lathe. Cut the teeth as before. The wood block is sacrificial and easy cut by the gear cutter. After the teeth are cut, the center hole is drilled. Do not use the center punch mark used for laying out the blank, as it is very likely not exactly centered. It may be wise to machine away the punch mark before center drilling the blank. Step drill to a diameter of ¼″ and then open the center hole to an "almost final" diameter of .305″ with a small boring bit. By cutting the teeth and boring the center hole without disturbing the setup, the wheel is guaranteed to run true.

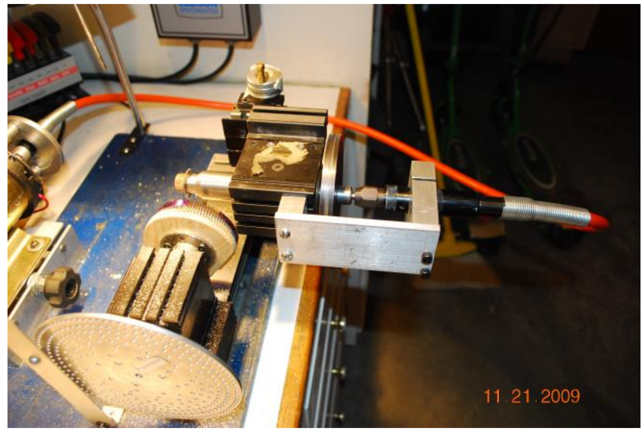


***Figure 37**: Setup used for wheel cutting on the Taig. An index plate is mounted to the headstock pulley and the index arm is fastened to the lathe mounting board. Several teeth have already been cut in the great wheel. A second Taig headstock is mounted on the milling attachment and used as a spindle. Drive power is provided by the orange, ¼" flex cable which connects via a coupling to a shaft exiting the back of the motor. Variable speed drive is required to slow-start the spindle to prevent the flex cable from twisting. A 4" diameter steel flywheel is mounted on the back of the spindle to smooth out vibration from the cutting operation. Everything except the carriage is locked down to prevent movement.*

Finish the hole to its final dimension with a 5/16″ reamer. Although the center hole could be bored to its final size, using a reamer to finish the great wheel and maintaining wheel center hole ensures they are exactly the same diameter.

Remove the wheel from the wood block and rub on 180-grit paper to remove any burs. The wheel must now be machined to make room for the maintaining spring. This is accomplished by removing half of the thickness of the wheel shown as the shaded area of Figure 35 in an operation known as trepanning. Mount the wheel on an arbor and remove the material with a round nose or Vee-shaped lathe bit. The corners are then cleaned out with a small boring bar as shown in Figure 38.

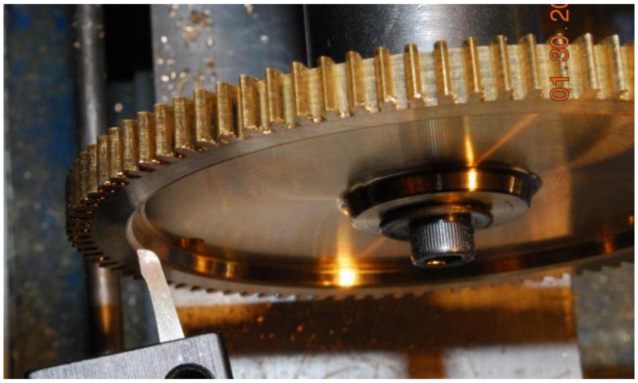


Figure 38: *Trepanning the great wheel. A parting tool can be used to clean up the inside corner, but will likely rub if used on the outside corner. Use a boring bar on the outside corner as shown here.*

After the trepanning is complete, remove the wheel and coat the flat side with layout blue, mark out the spokes and cross out in the same as previous wheels with the exception of the slot area at the end of one spoke. This slot will accept a pin from the maintaining wheel. Drill a 1/8″ hole at each end of the slot, cut out the remainder with a jeweler's saw and file to shape. A second spoke is drilled to accept a 3/32″ pin. The pin should be approximately 1/64″ shorter than the wheel thickness. Finally, drill a #43 hole in the hub and tap 4-40 for a screw that will hold the wheel retaining washer. Finish the wheel to a 600-grit finish. Fasten the 3/32″ pin in the wheel spoke with Loctite 609 so it is flush with the flat side of the wheel and slightly below the rim of the wheel on the trepanned side.

Figure 39: *The completed great wheel. The maintaining wheel will cover the trepanned area, so a few scratches are no concern.*

Maintaining Wheel

The maintaining wheel is made from 1/8″ brass. As with the great wheel, a slightly oversize blank is mounted to a wood block. Machine the outside to 2.8″ diameter and create the 5/16″ center hole. The 96 ratchet teeth are cut with a 60-degree ratchet cutter. The point of the cutter is offset 0.146″ to create an undercut of 6 degrees. (Sin 6 * 1.4″) The undercut prevents the ratchet pawl from slipping out of the notch. The depth of the notch is determined by trial and error, and it should not be very deep. A shallow notch helps minimize the noise made by the pawl as it drops in each notch when the wheel rotates during normal operation.

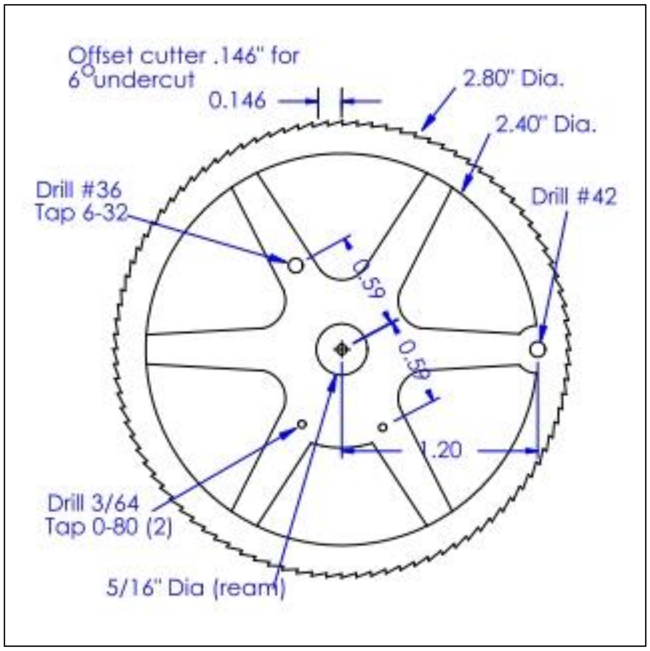


Figure 40: *Maintaining wheel construction drawing as seen from the fusee side.*

Figure 41: *A close-up view of the maintaining wheel teeth.*

A small flat spot may be left at the tip of each tooth. The notches shown in Figure 41 are approximately 1/32" deep.

After spoking the wheel, several holes are drilled for fastening various other components. The hole tapped 6-32 will hold the stud for mounting the fusee ratchet click. The two 0-80 holes are for mounting the click spring and the #42 hole near the edge is for a 3/32" diameter pin which protrudes out the back and through the slot on the great wheel. Figure 42 shows the great wheel side of the completed maintaining wheel.

Figure 42: *Maintaining wheel.*

Finish the wheel to 1500 grit and fasten the pin with 609 Loctite. A finer finish is applied at this point so polishing is the only remaining step. Additional sanding will be difficult after the pin is in place.

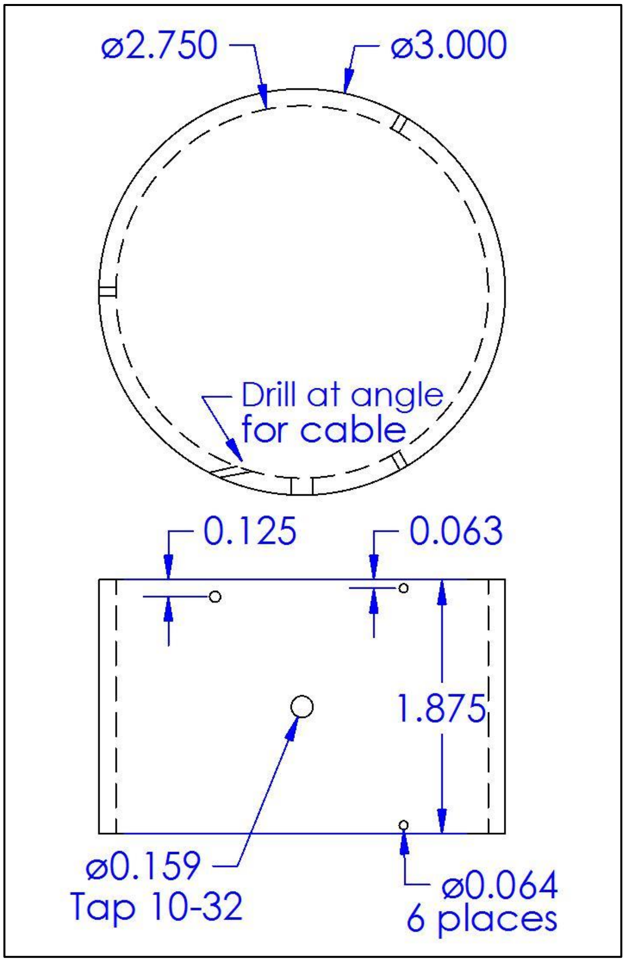


Figure 43: *Construction drawing of the mainspring barrel.*

Barrel

The mainspring barrel for this clock is somewhat larger that is typically seen on other fusee clocks. Dimensions obtained from scaling original photos indicate the outside diameter of the barrel is 3″. However, the proportions look good on the clock and work well with the chosen mainspring. The mainspring will be covered in more detail shortly.

A 3″ long piece of 3″ outside diameter, .125″ wall thickness brass tubing is used. (Note: A 2.5″ long piece would work fine, but the cost was the same for 3″ from this supplier.) The extra length allows all of the machining to be done with a single setup. The barrel is made somewhat wider than necessary to allow using mainsprings up to 1.5″ in width and to fill the space available between the plates.

Figure 44: *Boring the inside of the barrel. Light cuts are taken to prevent chatter from the long boring bar.*

Mount the tubing using the inside jaws of a 4-jaw chuck and set it to run true with a dial indicator. Do not over tighten the chuck jaws or the tubing will be distorted. Only light cuts are taken to reduce the chance of the tubing slipping in the chuck. Most brass tubing is non-leaded brass so a better finish will be obtained by using cutting oil. Face the end of the barrel until it runs true. Bore the inside of the barrel only as much as necessary to true up the first 2″. Slightly chamfer the inside edge with the boring bit to prevent interference with the barrel flange.

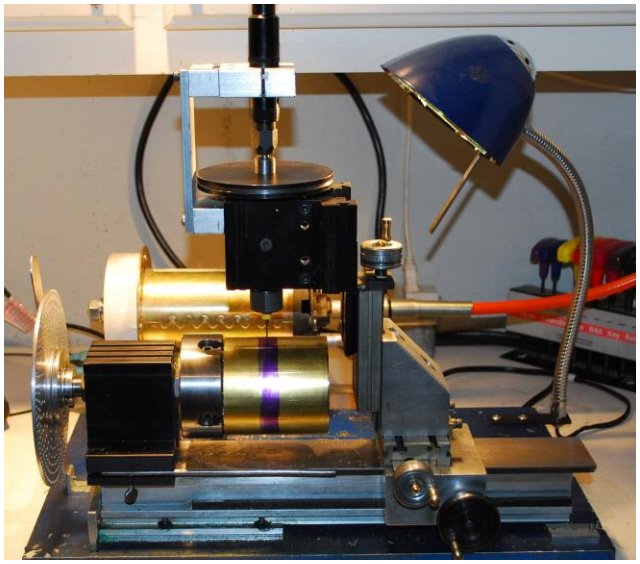


Figure 45: *Drilling the holes for the flange screws. A collet is used to hold the drill bits due to limited clearance of the milling head. Note the barrel is almost as large as the lathe chuck.*

Mark the barrel length at 1.875″ using lay-out dye and a dial caliper. Install an index plate on the headstock and attach a milling spindle to the cross slide for vertical drilling. A center drill is used to spot three equally spaced holes around the outside diameter 1/16″ from each edge of the barrel. Drill each hole through with a #52 bit. An additional hole is spotted and drilled with a #21 bit in the center of the barrel side for the spring hook. Tap the hole with a #10-32 tap and countersink the hole on the inside of the barrel approximately 1/32″ for the flat head screw that will serve as the barrel hook.

Drill a 1/16″ hole centered between two of the barrel flange mounting screw holes on one edge for the fusee cable. Drill at a 30-40 degree angle to reduce the bending stress on the cable. Finally, clean up and true the outside of the barrel taking light cuts for a length of 2″. Sand the barrel to a 600-grit finish. Part off the barrel to a length of 1.875″. Chamfer the inside edge as before with a file or deburring tool.

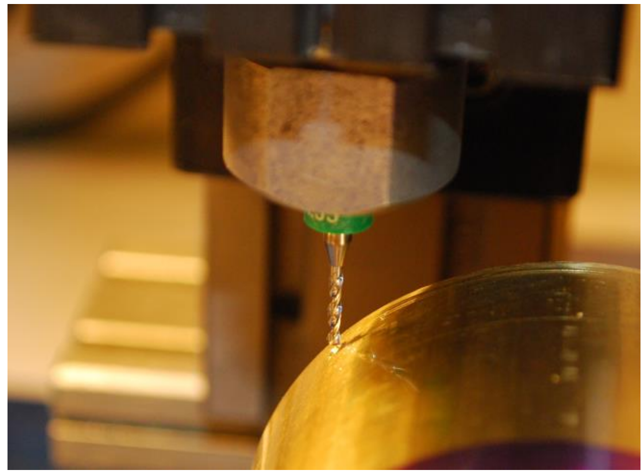


Figure 46: *Drilling the cable through-hole. A pilot dimple is first drilled straight on. The barrel is then rotated 30 degrees (one hole of a 12-hole circle) and the drill re-aligned with the dimple. Light pressure on the drill is required until the bit establishes it new direction.*

Barrel Flanges

Disks for the barrel flanges are cut from a sheet of 3/16″ 356 brass sheet. The final diameter will be 3.125″ so the disks are marked out and rough cut to 3.25″ allowing a little extra material to compensate for inaccuracies in drilling the center hole or saw slip-ups. A coping saw works fine on brass and the blades are not near as fragile as a jeweler's saw. After the disks are cut, the center hole is drilled and the disk is mounted on an arbor. My arbor takes a 7/32″ hole size, but a ¼″ arbor would be better.

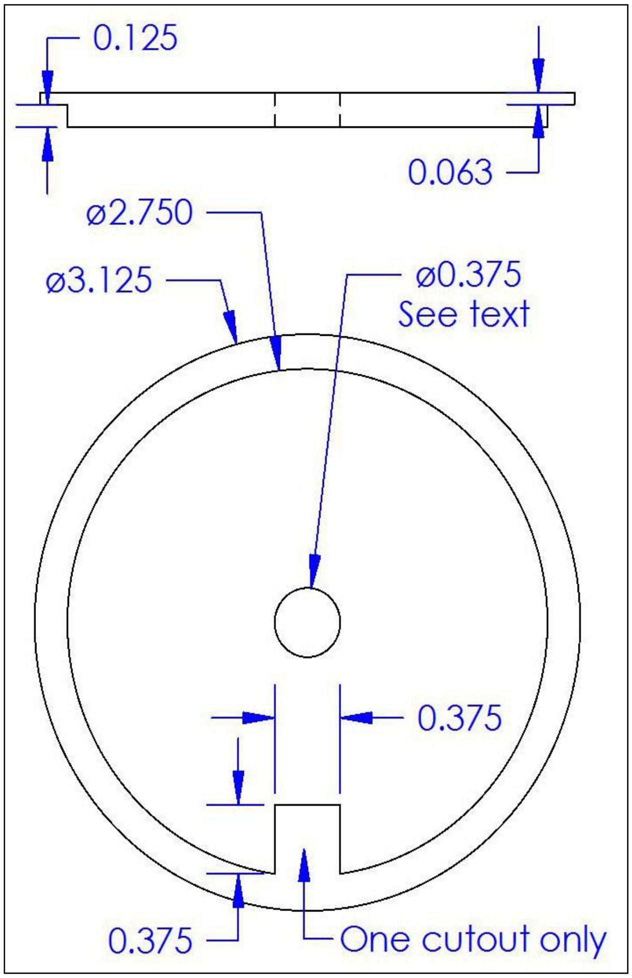


Figure 47: *Construction drawing for the barrel flanges. Material is 3/16" thick brass. Two flanges are required, but only one will have the cutout for the fusee cable.*

With the disk mounted on the arbor, turn the outside diameter down to 3.125". A 1/8" shoulder is then cut for a slip fit into the barrel. When the shoulder diameter is correct, clean out the corner with a graver or parting tool so the flange lip fits tightly against the edge of the barrel. The flange lip can now be rounded over with a file and progressively sanded to a 600-grit finish.

One flange will require a cutout for clearance of the fusee cable where it enters the barrel. Mount the flange on the milling attachment and use and end mill mounted in a collet to machine the cutout. Although the design drawing shows square corners, they can be left as rounded by the endmill since this side of the flange will be inside the barrel.

Remove the barrel flange from the arbor and install it in a 4-jaw chuck using the outside jaws to grip the shoulder as shown in Figure 49. Carefully adjust the 4-jaw chuck until the barrel flange runs true, first on the face and then on the flange lip. Bore the center hole of the flange to approximately .360" with the last cut being light and slowly advanced to obtain the best finish possible.

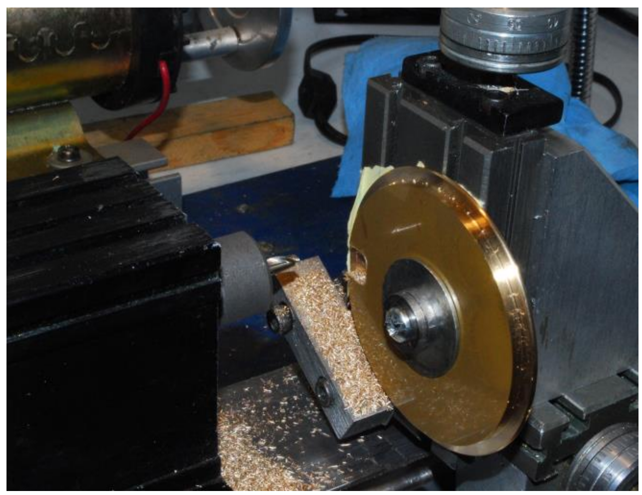


Figure 48*: Milling the cable cutout in the barrel flange. Clamp the flange tightly and take light cuts so the flange does not spin like this one did as evidenced by the endmill "tracks" around the barrel shoulder.*

The center holes of the barrel flanges serve as bearing surfaces on the barrel arbor so a good fit and finish are desired. Typical clock construction techniques would use large cutting and smoothing broaches to size, burnish and work harden the hole. Unfortunately, broaches of this size are expensive and not widely available. Instead, a simple but seldom seen technique (in horology anyway) called "ballizing" or "ball sizing" is used.

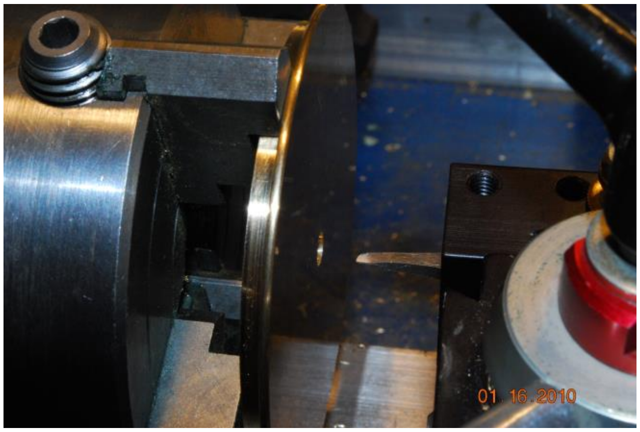


***Figure 49**: Hold the flange by the shoulder in a 4-jaw chuck. A small boring bar is used to enlarge and center the hole.*

A ball bearing is pressed through a slightly undersize hole to expand, smooth and work harden the surface. Some spring back will occur, so the barrel arbor will be machined to fit the hole in a later step. An arbor press or bench vise provides the power to push the ball through the hole. A light coat of oil is applied to the surface of the hole for lubrication. Figure 50 through Figure 52 show the ballizing process.

***Figure 50:** Shown on the flange are the 3/8 inch chrome steel bearing ball and a ¼" steel pusher. The end of the pusher is lightly drilled to form a concave surface so the ball stays centered. This flange has the cable cutout.*

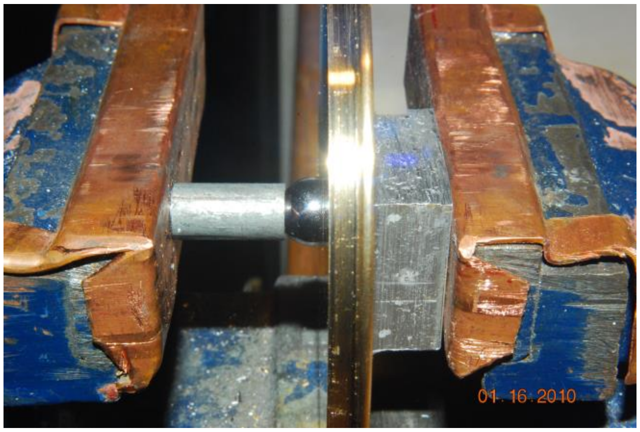


***Figure 51**: The metal block to the right of the flange has a ½" hole through it to receive the ball after it passes through the flange. Make sure the pusher is straight. The pusher should be short to reduce the tendency to twist.*

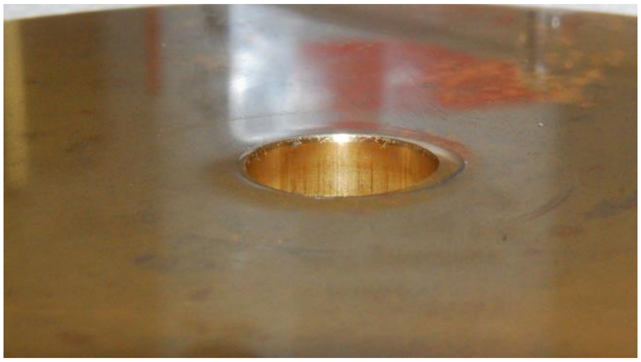


***Figure 52**: A great deal of force is required to push the ball through the hole and a burr will be raised on both sides of the flange. The burr is easily removed by facing each side of the flange followed by progressively finer grits of paper until a 600-grit finish is achieved.*

The barrel flange holes are located by installing a flange in each end of the barrel. Make sure to line up the cable cutout in the flange with the cable hole of the barrel. Clamp the flanges in place and make a dimple through each hole with a #52 drill bit.

Figure 53: *Both flanges are inserted into the barrel and held in place with a clamp. A #52 drill is used to transfer the position of the mounting screws to the flanges.*

It may be tempting to drill the flange holes completely at this time, but this often results in broken drill bits when chips lodge in the hole at the barrel/flange interface. Instead, remove the flanges from the barrel to complete the drilling with a #56 drill. Tap the holes in the flanges #0-80 to a depth of approximately ¼″. As a final construction step, countersink the 6 flange screw holes in the barrel so that a flat head #0-80 screw sits flush with the surface. This is quickly completed with a slowly rotating countersink mounted in the lathe and pressing the barrel by hand into the countersink as shown in Figure 54.

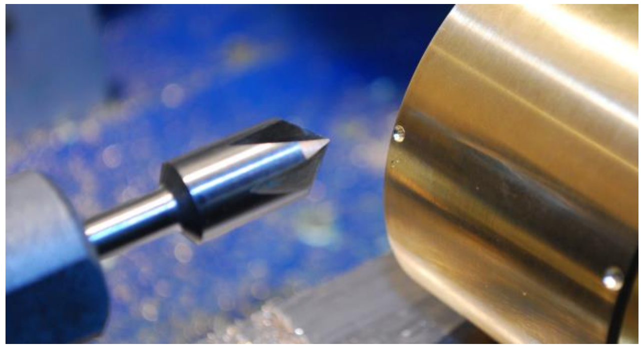


Figure 54: *The flange screw holes are countersunk so the flat head machine screws sit flush with the barrel surface. A countersink bit is mounted in the lathe and slowly turned while the barrel is positioned by hand.*

We can now obtain a measurement from the completed barrel that is needed to machine the barrel arbor. With the flanges installed, measure the inside distance between the flanges with the tail end of a dial caliper as shown in Figure 55. The measurement obtained is from the inside of one flange to the outside of the flange where the caliper is inserted. Subtract the thickness of the flange to obtain the inside dimension. Alternately, the outside dimension of the flanges can be measured from which the thickness of both flanges is subtracted. Regardless of the method used, remember to measure each flange thickness. Since facing cuts have been taken on each flange, they will no longer be 3/16″ thick. Finally, subtract 1/64″ from the inside dimension to allow for end shake of the arbor inside the barrel. For ease of explaining the next step, we will assume this measurement is 1.625″ as shown in Figure 56.

Figure 55: *Measuring the inside dimension of the barrel with the tail of a dial caliper. The tip of the tail should sit on the inside edge of the bottom barrel flange. The end of the dial caliper should sit flat on top of the top flange.*

Barrel Arbor

Raw stock for the barrel arbor is a 4″ length of mild steel rod 1″ in diameter. I used drill rod because it was on hand, but machining hard steel of this size works the small Taig lathe to capacity. Although the finished length will be 3.25″, 3/8″ is added to allow for center drilling each end. The center drill holes will be cut off near the end of the machining process. Also, **note that the arbor will be roughed out slightly oversize** and turned between centers to the final dimensions.

Mount the rod in the 4-jaw chuck and set it true with a dial indicator positioned close to the chuck. Install a steady rest near the chuck and adjust the arms for a sliding fit before moving the steady to the unsupported end of the rod. Face the end and drill with a center drill to accept a dead center. Remove the steady rest and install the dead center. A live center would be better if you have one.

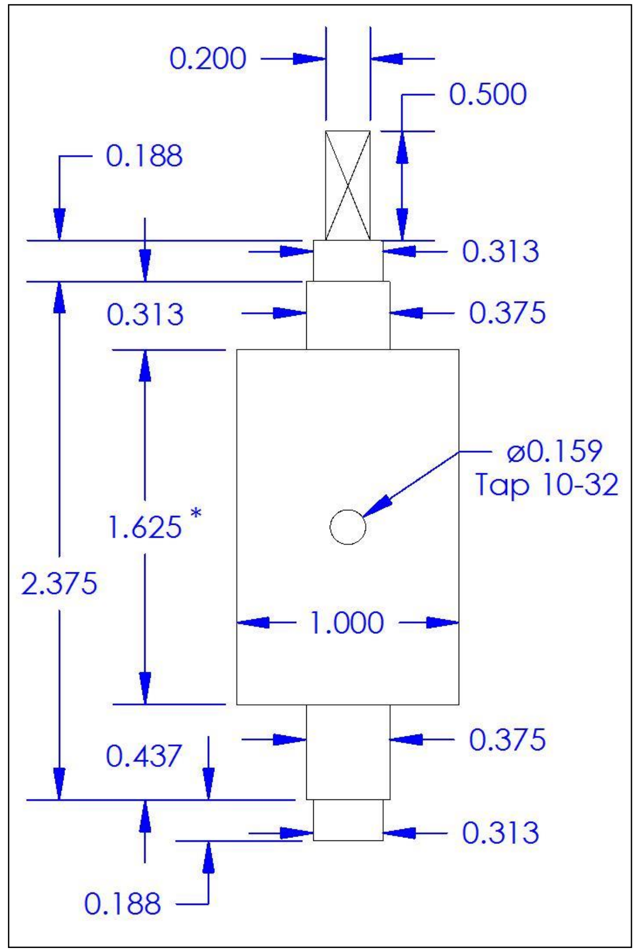


Figure 56: *Construction drawing for the mainspring barrel arbor. The dimensions shown are rough estimates of the finished arbor. Most dimensions will be machined to fit various other parts.*

Figure 57: *Turning the barrel arbor. A dead center is made from a piece of 3/16" drill rod with a 60 degree point turned on the end.*

I use a short piece of 3/16″ drill rod turned to a point and held in a drill chuck. Reduce the outside diameter of the exposed arbor to .910″. Then reduce the end of the arbor to .385″ for a length of 1.25″ as shown in Figure 57. With the cutting tool against the shoulder just cut, back the carriage off .320″ and set the carriage stop. Reduce the remaining end of the end of shaft to .320″. As before, back off the carriage .190″ and adjust the stop as show in Figure 58. Reduce the remainder of the shaft to .283″. This concludes the roughing out of this end of the arbor. Reverse the arbor with the reduced end passing through the lathe chuck. The chuck should grip on the large diameter portion of the arbor, not the section that was just reduced.

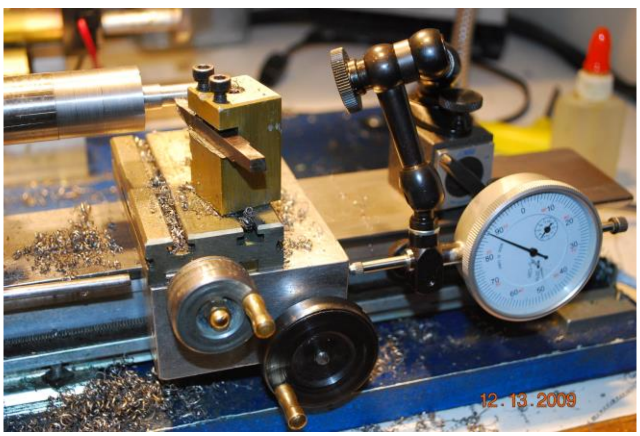


Figure 58: *The tailstock is removed to make room for a dial indicator. The carriage has been backed off and the carriage stop (rod to the left of the carriage dial) will be repositioned to touch the carriage.*

Adjust the chuck so the arbor indicates true on the previously machined surface. Using a steady rest, face and center drill the end to accept the dead center as before. With the dead center in place, reduce the outside diameter of the arbor to .910″ to match the previously machined portion. Set the carriage stop to leave 1.625″ (the measured barrel inside dimension obtained previously) at the .910″ dimension and reduce the remainder of the shaft to .385″. Back off the carriage .440″ and reduce the remainder of the shaft to .320″. This completes the roughing out of the barrel arbor and it can now be machined to its final dimensions. Mount the barrel arbor as shown in Figure 59, being extra careful to true the work in the 4-jaw chuck. Verify that the large diameter center section is 1.625″ (as measured) and adjust as necessary. Next reduce each barrel pivot for a tight fit into the barrel flanges. The pivots are the areas that where roughed out to .385″. They should end up close to .375″, but the actual dimension is determined by test fitting to the barrel flanges.

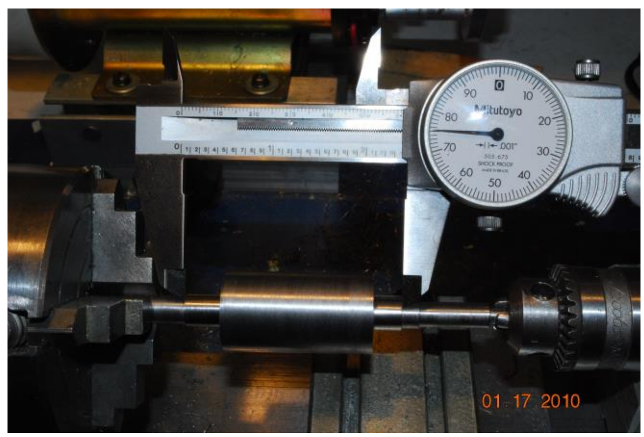


Figure 59: *Measuring the distance between pivots at 2.375". When creating this length, try to keep the pivot lengths close to the dimensions shown in figure 14 so the barrel will line up properly with the fusee.*

The arbor will need to be removed to test fit the pivot on the chuck side of the arbor. True the arbor each time it is returned to the lathe.

After the pivot diameters are correct, the pivot lengths are trimmed to obtain a distance of 2.375″ needed to fit between the plates. This measurement is shown in Figure 59. Note the barrel will not be centered on this dimension. It is located slightly closer to the front plate so the fusee will line up correctly. Now that the pivot lengths are correct, they can be finished in the same way as the previous pivots with a #6 file, Arkansas stone and burnisher. The barrel flanges should slip easily onto the pivots with very little wobble. The pivots that run in the plates can now be made, but since the plates do not yet exist, drill and ream a 5/16″ hole in a scrap piece of 3/16″ thick brass. Reduce each plate pivot for a tight slip fit into the test hole. Prepare the plate pivots in the same manner as the barrel pivots for a length of .2″. Cover pivots with masking tape to protect finish. The ends will be cut off to their final dimensions and the winding arbor flats formed in a later step.

Locate the center of the barrel arbor and drill a #18 hole approximately 5/8″ deep. Tap the hole #10-32 and countersink it approximately 1/16″ deep.

Mainspring hooks

The mainspring hooks in the barrel and arbor are made from 10-32 steel flat head screws. The head of the screw for the barrel hook should stand approximately .040″ above the inside surface of the barrel. Grind the head of the screw and test fit until this height is achieved and then remove the sharp edge with a file. Apply Loctite 609 to the screw threads and tighten the screw by gripping the threaded end with a pliers or bench vise. After the Loctite sets up, cut the screw off flush with the outside of the barrel with a jeweler's saw. Some masking tape on the barrel around the screw area will help prevent scratching the barrel surface. Carefully file and sand the screw until it blends in with the barrel.

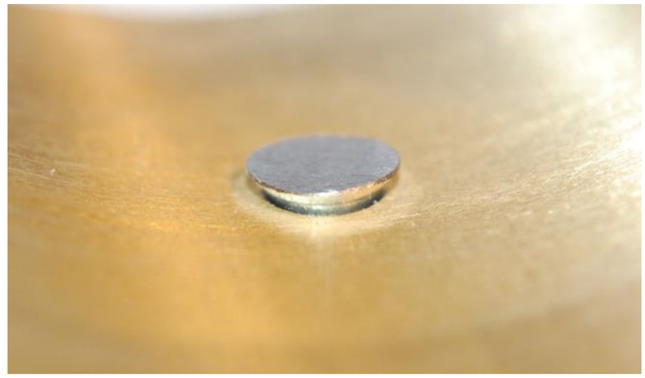


Figure 60: *The barrel hook ground down but not yet fully seated in the barrel.*

Install a flat head screw in the arbor and ensure that the threads are deep enough to allow the head to fully seat against the arbor. Cut off a few threads if the screw is too long. With the screw installed in the arbor, grind the head down so the front of the screw is approximately .040″ above the arbor. The back side should slope down to .020″ to prevent it from distorting the mainspring when it is wound.

Figure 61: *The barrel arbor hook as seen from the winding arbor end. Note the winding direction is clockwise and the hook slopes down from right to left.*

The arbor winds clockwise so the front of the hook will be on the right when the arbor is viewed from the winding side as shown in Figure 61. When the final shape is obtained, Loctite the arbor hook in place.

Mainspring

The mainspring used in this clock is made from a strip of blue spring steel. A thickness of 0.020″ and width of 1.5″ are chosen as these appear to be relatively common dimensions for fusee mainsprings. Unfortunately, there is no formula I am aware of that provides mainspring dimensions to obtain a given force. Any formula would be highly dependent upon the characteristics of the steel used and these characteristics are widely variable. Therefore, dimensions are chosen and the fusee shape will be based on actual measurements. If a stronger or weaker spring is needed, new spring material will need to be obtained. According to a rule-of-thumb found in a 1905 book (available from Google Books) called “Lessons in Horology” by Jules and Hermann Grossmann, it is customary to make the radius of the arbor equal to 1/3 the internal radius of the barrel to obtain the maximum number of turns from the spring. Using this ratio with an internal barrel radius of 1.375, the arbor radius should be .45″ or 0.9″ diameter. The same book also states the minimum arbor diameter should be 32 times the thickness of the mainspring. This is to avoid excess stress when the spring is wound, causing it to break or take a “set”. Applying this rule yields a minimum arbor diameter of .64″ so our arbor diameter of .91″ provides an additional margin.

The commonly used formula shown below gives the mainspring length that provides the maximum number of turns of the barrel.

$$L = \frac{\pi\left(R^2 - r^2\right)}{2t}$$

Where:
L = the length of the mainspring
R = inner radius of the barrel
r = radius of the arbor
t= mainspring thickness

Plugging in the values of our components we get:

$$L = \frac{\pi\left(1.375^2 - .45^2\right)}{2x.020} = 132.6 \text{ inches}$$

The blue spring steel supplier sells the material in 10 ft. or 70 ft. lengths. Rather than order excess material that may need to be replaced if the mainspring size does not work out a 10 ft. piece is ordered. At 120″, this spring is too short to obtain the maximum number of turns. Just how many turns we will lose with the given spring requires a more complex equation; (also from the Grossmann book):

$$N = \frac{\sqrt{R^2 - r'^2 + r^2} - r - R + r'}{t}$$

Where:
N = the number of turns
r′ = the inner radius of the mainspring coils when the spring is fully unwound against the barrel, which is given by the equation:

$$r' = \sqrt{R^2 - \frac{Lt}{\pi}}$$

At L=120″ $r' = \sqrt{1.375^2 - \frac{120x.02}{\pi}} = 1.061$

Plugging this into the turns equation gives:

$$N = \frac{\sqrt{1.375^2 - 1.061^2 + .45^2} - .45 - 1.375 + 1.061}{.02}$$

= 10.98 turns

At L=133″ $r' = \sqrt{1.375^2 - \frac{133x.02}{\pi}} = 1.022$

Again, plugging this into the turns equation gives:

$$N = \frac{\sqrt{1.375^2 - 1.022^2 + .45^2} - .45 - 1.375 + 1.022}{.02}$$

= 11.05 turns

This shows the 120″ spring will provide substantially the same number of turns as a 133″ one. The mainspring calculations given here may be more detail than some clockmakers care to bother with. However, these equations will be useful if the builder chooses to use a different mainspring.

The blue spring steel is unwound, cleaned and inspected for cracks or rust. The steel is provided in a hardened and tempered state and must be annealed at the ends to drill the holes. Approximately 4″ of one end is heated to a dull red and cooled slowly by gradually removing the heat source. The corners are easy removed with tin snips with final shaping done on the bench grinder. A file is used to remove any burs or rough edges caused by the grinder. Center punch and drill a 5/16″ hole approximately ¾″ from the end and remove any burs. Clamping the steel to a bar and wrapping it around while heating the spring steel with a propane torch forms the inner loop. The inner loop should consist of approximately ¾ of a turn.

The other end of the spring is annealed and drilled in the same manner but end is left straight.

Figure 62: *A 7/8" steel bar is held in a vise with the mainspring clamped to it.*

Clean both ends of the mainspring with a brass or steel brush to remove any scale or loose particles.

Winding a spring of this size should always be done with a mainspring winder. Previous experience showed that my winder was not robust enough and a new .9″ winding arbor would be needed to match the barrel arbor of this clock. Instead, the Taig lathe is used to safely wind the mainspring.

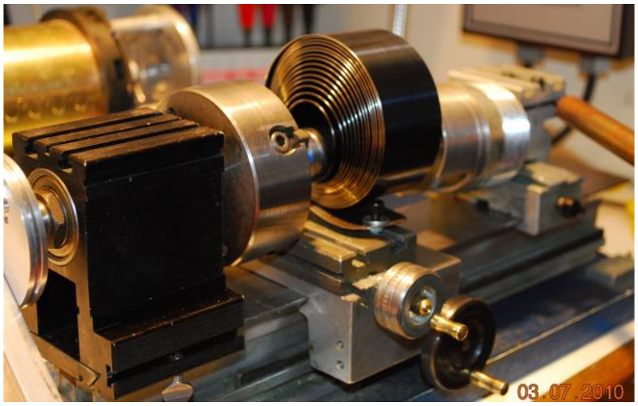


Figure 63: *Taig lathe used as a mainspring winder. Part of the handle is just visible in the lower left corner. A retaining sleeve is installed over the tailstock end ready to slip over the spring when it is fully wound. A machine screw, washer and two nuts fasten the free end of the mainspring to the cross slide.*

A handle is fitted to the headstock pulley and the barrel arbor for this clock is mounted in the 4-jaw chuck with the outboard end supported by a center held in the tailstock. A 10-32 screw with two nuts and a washer are used to fasten the free end of the mainspring to the cross slide. With this setup, the mainspring is cleaned and then wound and released while dry. This initial wind provides a "feel" for how the spring will behave before the additional complication of oil is added. With the spring relaxed, it should be cleaned one last time and then lubricated. I used "Slick 50" as a synthetic lubricant, but any oil or grease designed for mainspring service should work fine. After lubricating, the spring is fully wound, released and wound again to distribute the lubricant. The spring is held in place with a retaining sleeve made from a galvanized pipe fitting.

Figure 64: *The mainspring installed in a home-made retaining sleeve made from a 2.5" conduit fitting. A slot cut in one end allows the spring to protrude and catch the barrel hook.*

The sleeve needs to be big enough to fit over the fully wound spring and small enough to fit inside the barrel with a little room to work. A 2.5" sleeve was used in Figure 64. Bend the free end of the mainspring with a slight curve to matches the barrel. Install the spring in the barrel, rotating it to catch the hook.

Make sure the spring coils in the same direction as the cable hole as shown in Figure 65. Re-install the arbor and mount the entire assembly back in the winder. With the barrel firmly in hand, wind the spring until the retaining sleeve can be removed. (Have someone remove the retainer, as your hands will be busy with the winder and barrel.) Finally, let the spring down into the barrel.

Figure 65: *The mainspring installed in the barrel. The direction of the cable hole is indicated on the edge of the barrel with a black line. The spring as coiled will turn the barrel clockwise.*

Now that the barrel arbor has completed its service as a winding arbor, final machining can be completed. Mount the arbor in the lathe with the long end towards the tail-stock. Traditionally, the end is filed square with a file rest. A quicker and easier method is to mill the flats with an end mill as shown in Figure 66. The index plate is used to hold the arbor in position while it is milled. Shorten each end of the arbor to the dimensions shown in Figure 56 to remove the center drill holes and finish each end to a 600-grit finish.

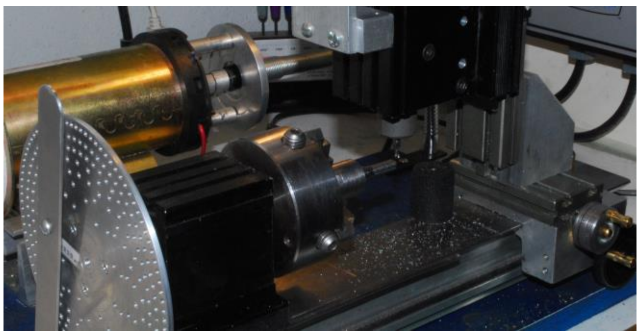


Figure 66: *Milling the flats on the winding arbor. Several light passes work well to avoid chatter.*

Barrel Ratchet

The barrel ratchet is made from 1/8″ mild steel. Similar to the wheels, the raw disk is cut slightly over size from the sheet stock. A center hole is drilled with a #18 bit and mounted on a ¾″ diameter arbor with a #8-32 machine screw.

Reduce the diameter to 1″. An attempt was made to cut the teeth with a fly cutter, but the sharp point of the cutter became rounded after the first few passes. Instead, a slitting saw works much better. A 0.025″ thick slitting saw blade is mounted on the milling attachment and centered over the ratchet arbor. The saw is then offset 0.052″ to give each tooth a 6 degree undercut.

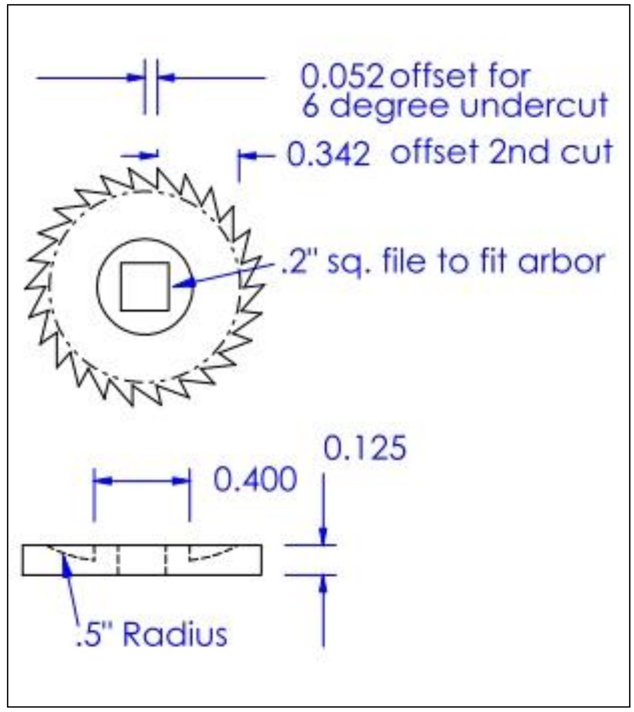


Figure 67: *Construction drawing for the barrel ratchet. It has 26 teeth and is made from mild steel.*

The saw is lowered until it just touches the edge of the disk and then lowered again to cut a slot 0.068″ deep. The configuration is shown in Figure 68. As with the pinions, slow speed and cutting oil are required to preserve the slitting saw. 26 slots are cut to form the face of each tooth. The number of teeth was chosen so the geometry of the teeth is obtained without re-indexing the ratchet. After the first cut is complete offset the saw an additional .341″ and cuts to a depth of .129″ as shown in Figure 69. Some adjustments to these dimensions may be needed so the second cut intersects the first cut without hitting the face of the tooth. The hub of the ratchet is dished out as a decorative feature. The hub is then smoothed and polished with Cratex abrasive wheels mounted in a Dremel tool while the ratchet is slowly rotated in the lathe.

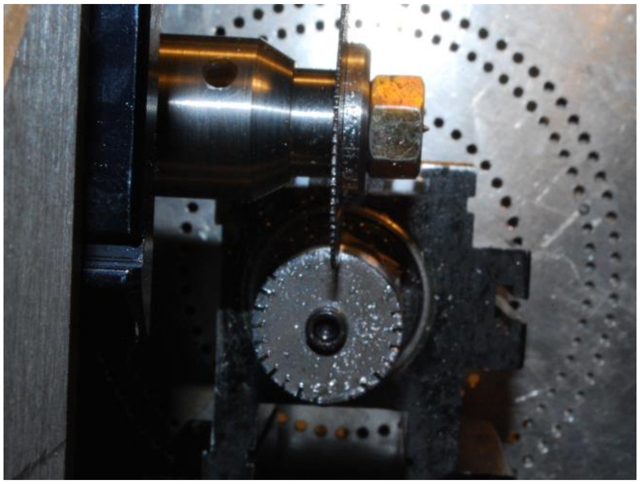


Figure 68: *Cutting the face of the ratchet teeth. Looking from the tailstock, the slitting saw is offset .052" to the right. The saw blade is cutting to a depth of 0.068" in a single pass.*

Burs are removed from the back of the ratchet with a file or parting tool before removing the ratchet from the arbor. The center hole of the ratchet is then roughed out to a square with a jewelers saw and filed to its final shape for a slip fit over the square end of the barrel arbor. The completed ratchet is shown in Figure 70. An overcut can be seen at the base of each tooth face.

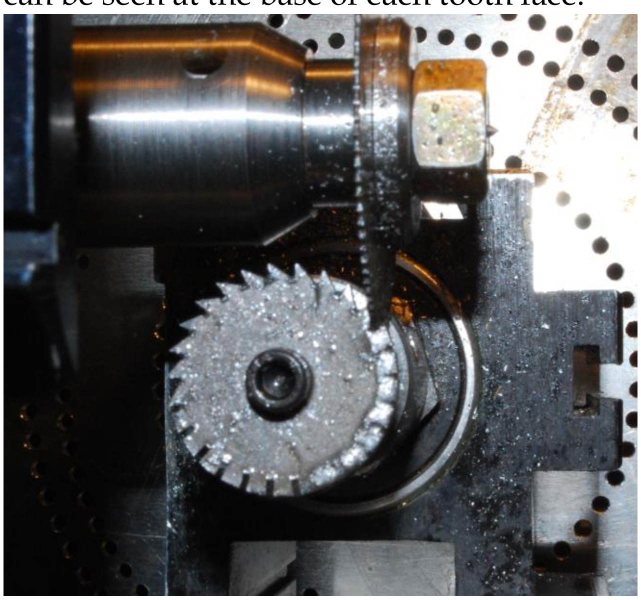


Figure 69: *Cutting the back slope of the teeth. The saw is offset an additional .341" to the right and cutting to a depth of .129"*

Figure 70: *The completed barrel ratchet. Final polishing will be performed later.*

This trade-off was made in order to obtain the maximum tooth height and a square corner at the face of the tooth. Alternately, the saw would have left an angled cut in the corner that would prevent the click from seating properly and requiring additional filing to square up the corner.

Barrel Click & Click Screw

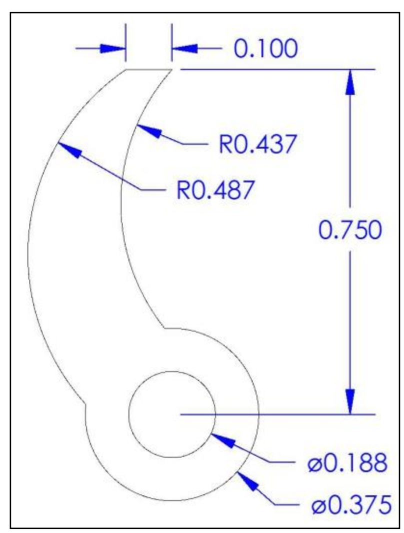


Figure 71: *Construction drawing for the barrel click. The click is made from 1/8" mild steel.*

The barrel click is marked out and formed according to the dimensions shown in Figure 71. The actual shape can vary according to the builder's taste. The click screw has a shoulder that allows the screw to be tightened securely to the plate while allowing the click to pivot freely. Additional information on making screws can be found in the Plates & Pillars section.

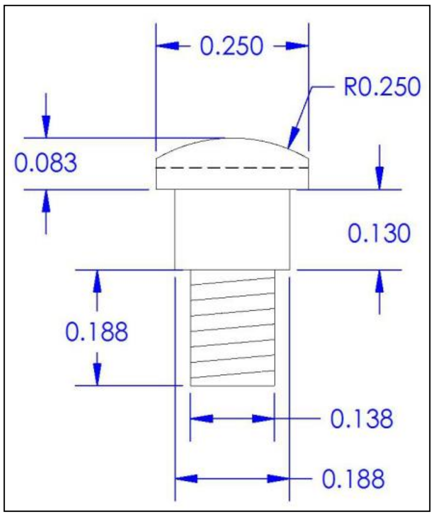


***Figure 72**: Construction drawing for the barrel click screw. The screw is made from drill rod and the head is rounded to a radius of .25"*

***Figure 73:** The barrel click and shoulder screw.*

Click Spring

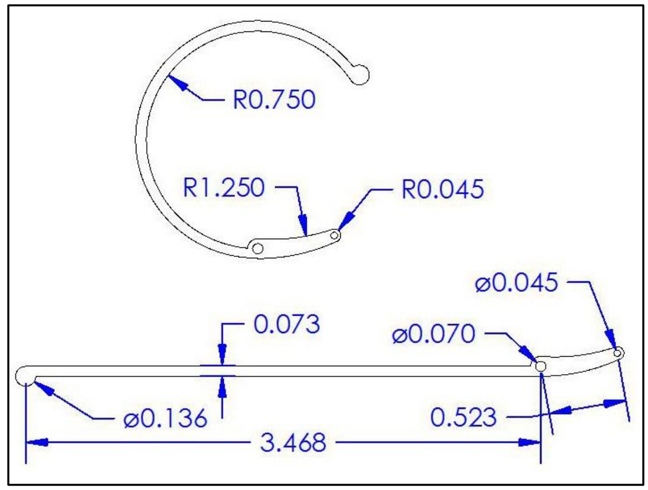


***Figure 74:** Construction drawing for the barrel click spring. The spring is cut from 1/16" tool steel according to the dimensions of the lower drawing and then bent to the shape of the upper drawing.*

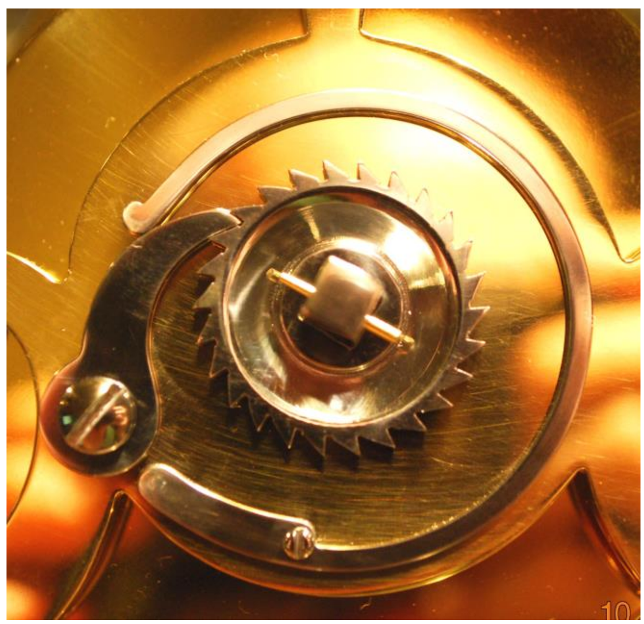


***Figure 75:** The complete barrel ratchet and click assembly.*

The barrel click spring is made from 1/16" thick tool steel since tool steel will hold its shape better than mild steel. The shape shown in the lower portion of Figure 74 is marked out and cut with the jeweler's saw and then filed and sanded smooth. The curve is then applied by bending the spring around a round bar. Final finishing is done after the final shape is achieved.

2nd & 3rd Arbors

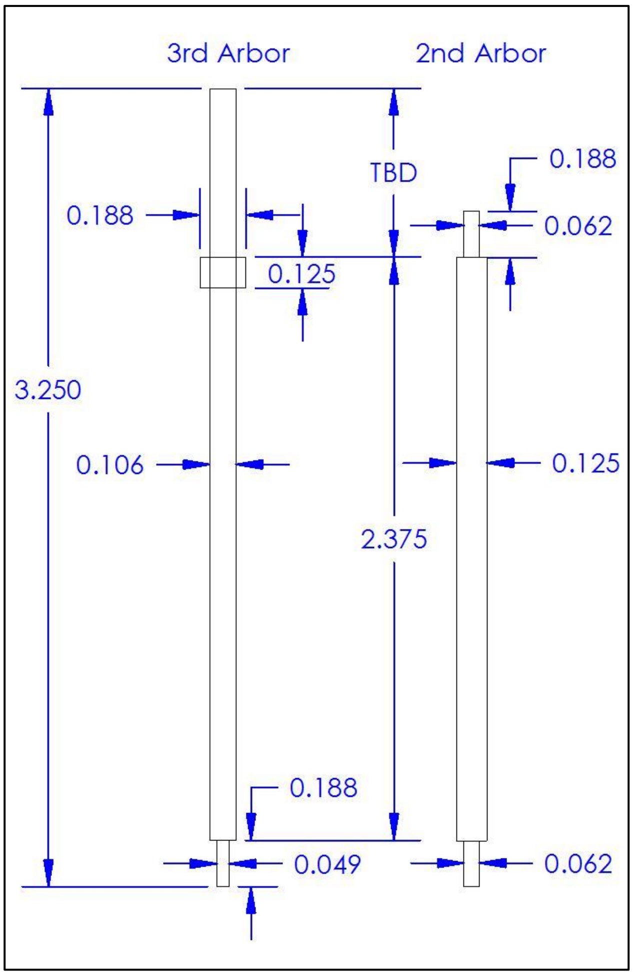


Figure 76: *Construction drawing for the second and third arbors. Final length of the 3rd arbor is determined when the motion works is assembled.*

The fourth wheel arbor is identical to the escape wheel arbor and dimensions are provided in that section. The second wheel arbor is very similar except it is made from 1/8″ music wire and the pivots are slightly larger as shown in Figure 76.

The third wheel arbor will extend through the front plate and drive the motion works. The final length of the arbor will be determined later and the 3.250″ overall length shown will provide ½″ of arbor protruding with which to work. A standard pivot is cut on one end and a mild steel sleeve is used on the other end to establish the 2.375″ distance between the plates. The sleeve is reamed for a slip fit on the arbor and held in place with Loctite 609.

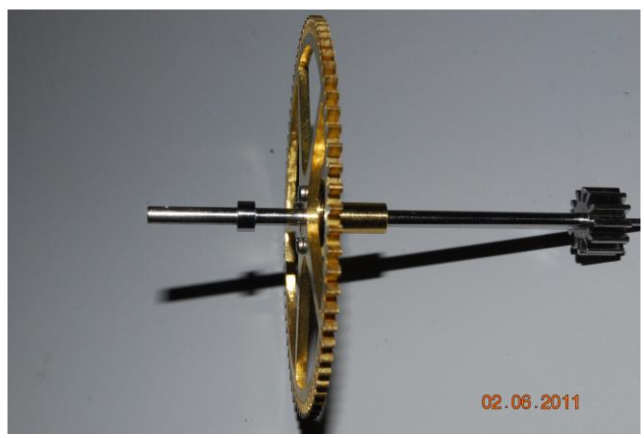


Figure 77: *The third arbor, wheel and pinion. The arbor passes through the front plate to hold the motion works drive pinion. A sleeve is used to set the 2.375" distance between the plates.*

A Pinwheel Skeleton Clock

5 - The Fusee

Introduction

The fusee matches the power needed to drive the clock with the power available from the mainspring. A fully wound spring will deliver more power than a spring that is only wound a turn or two. Typical clock construction books will specify a certain mainspring size and fusee shape, but often do not go into detail about how these dimensions are determined. For this project, the force available from the mainspring and the force required to run the clock will be measured. The fusee shape will then be calculated to match the two forces.

Measuring the mainspring force

A 10-foot length of 3/64" wire rope serves as the fusee cable and is fed through the barrel and knotted to keep it from pulling through the hole. The barrel is then mounted between temporary plates and secured firmly in a bench vise. The ratchet and click are installed to keep the barrel arbor from turning. A digital fish scale is attached to the free end of the cable to measure the force available from the mainspring. A flat tape measure (not shown) is fastened to the bench vise and held next to the scale to determine the 1-inch intervals where readings will be taken.

Pull the cable until the mainspring is fully wound. Note the length on the tape measure and then slowly allow the spring to return. Keep an eye on cable as it winds back onto the barrel so it does not overlap or run off of the edge of the barrel.

Repeat the wind/unwind process several more times to distribute the mainspring oil and condition the spring.

This would be a good time to locate an assistant to write down the data as you take the readings. The first reading will be taken with the spring fully wound and subsequent readings are taken at 1-inch intervals as the cable winds back onto the barrel. This is the direction the spring will be working under normal operation. If the readings are taken as the cable is pulled out, the higher force required to wind the clock will be measured. Keep an eye on the cable as it winds back on the barrel so it does not run over the edge of the barrel!!!

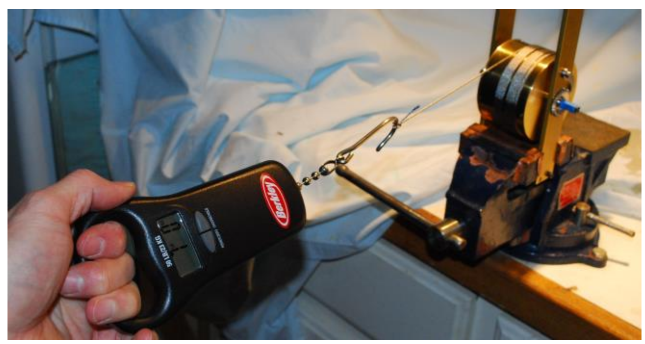


Figure 78: *Measuring the mainspring force with a digital scale.*

Readings taken from the hand held scale proved to be somewhat erratic. A ratchet or other mechanical means of steady support would provide more stable readings. However, the data is usable by making a few manual adjustments and using some averaging techniques. The data is entered in a spreadsheet similar to Table 1. Since the first reading is taken with the cable fully extended, the values are entered from the bottom up. The scale readings in pounds and ounces are entered in columns 2 and 3 and then converted to ounces (OZ) in column 4. These raw ounce values are plotted as the magenta line in Graph 1 and also copied into the adjusted ounces (Adj. OZ) in column 5 to use as initial starting values. The average of nine Adj. OZ values is calculated in column 6 (Avg. OZ). The first average value is shown in row 5 and is the average of the Adj, OZ for rows 1-9. The average for row 6 is the average of rows 2-10 and so on. These averages are then plotted on the same graph as the raw values. Even with the averaging, the curve is still influenced by the erratic scale readings and manual intervention is required. For example, the graph of the raw values shows a bump from about inch 6 to inch 9. Therefore, the values in the Adj. OZ column are manually adjusted down to more reasonable values to smooth out the graph of the average value. It may be helpful to include the Adj. OZ values on the plot during this step. Continue adjusting the values as needed until the plot is smoothed out to your satisfaction. This "fudging the numbers" appears rather arbitrary, and it may well be. However, it seems no more arbitrary than calculating the curve mathematically where a single force constant is applied across the entire range of the mainspring.

Initial Fusee Construction

In order to measure the power required to run the clock, the fusee arbor is needed to mount the great wheel. The fusee blank is also needed to hold the great wheel and serve as a hub for the weight cord. The fusee blank will be cut oversize for now and turned between centers to its final dimensions in a later step. Figure 79 shows a piece of 1 7/8″ brass rod cut to approximately 1.6″ in length. Face both ends, center drill to 19/64″ and ream to 5/16″. The arbor is cut from 5/16″ drill rod faced to a length of 4-3/16″ and drilled with a center drill so the arbor can later be mounted between centers. Clean the arbor and center hole of the fusee blank with acetone to remove any grease. Install the fusee blank with 609 Loctite as shown in Figure 79 approximately 1.22″ from one end of the arbor. After the Loctite cures, mount the assembly in the 4-jaw chuck and support the other end with a dead (or live) center.

Make light cuts to true up the ends and surface of the fusee blank and note the final diameter; mine measured 1.856″. Machine each end of the arbor to create the pivots that will fit into a ¼″ ballized hole. A ¼″ ballized test hole in a piece of scrap brass serves as a gage.

Remove the assembly from the lathe. Drill and tap a #4-40 screw hole on the surface of the fusee blank near the long end of the arbor which can be seen in Figure 80. Slip the great wheel over the short end of the arbor and transfer the location of the retaining washer screw hole to the fusee blank. Drill and tap the fusee blank to #4-40 and fasten the great wheel to it with a #4-40 screw. These #4-40 holes are temporary. One hole will be removed when the fusee blank is cut to shape and the fusee ratchet will cover the other hole.

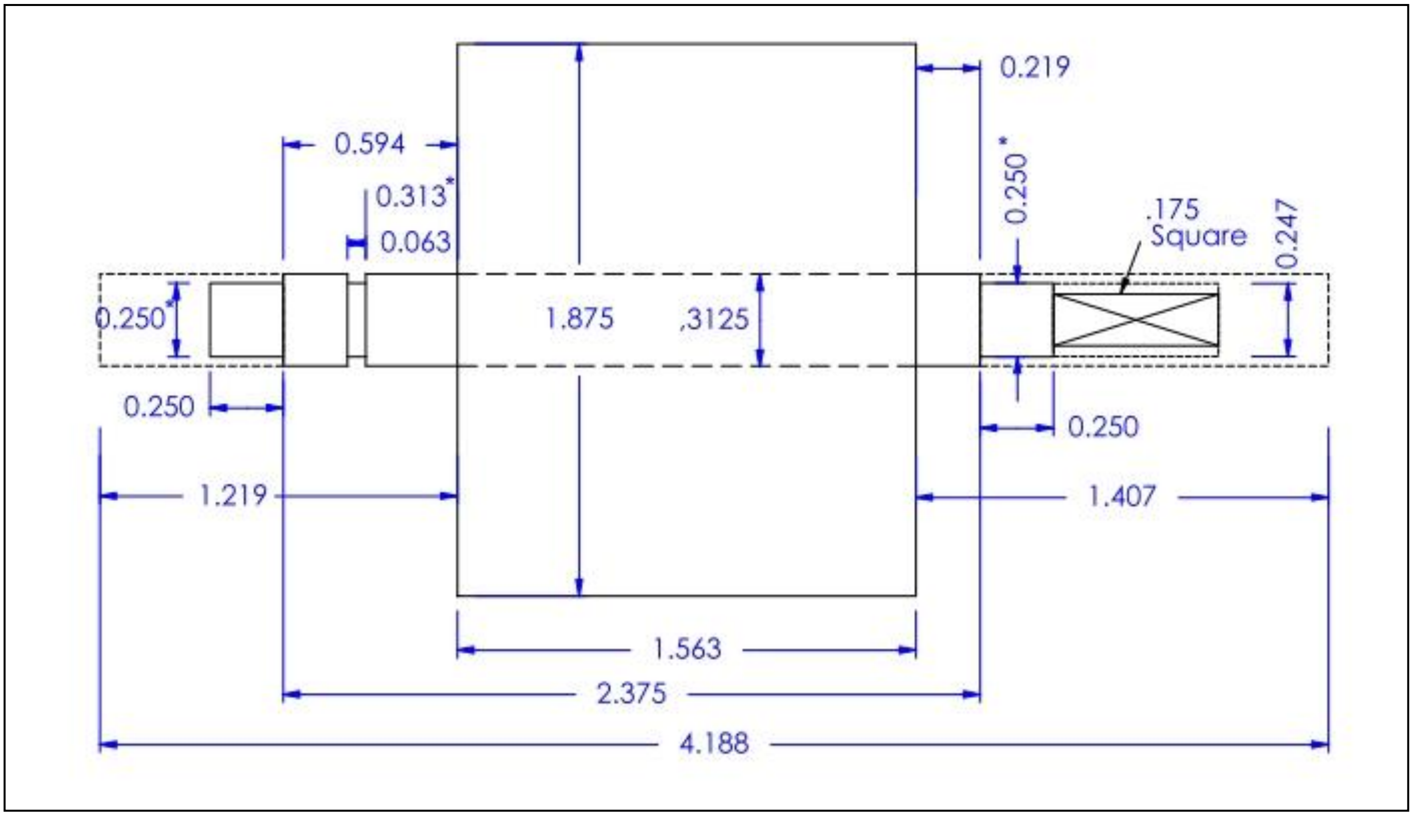


Figure 79: *Construction drawing of the fusee blank and arbor. Dimensions marked with an asterisk are determined by measurement. The pivots are turned to fit a ¼" ballized hole. The slip washer groove location is found after the fusee is grooved and the great and maintaining wheels are installed on the arbor. The dotted lines at the ends of the arbor indicate extra length to accept center holes for mounting the assembly between centers.*

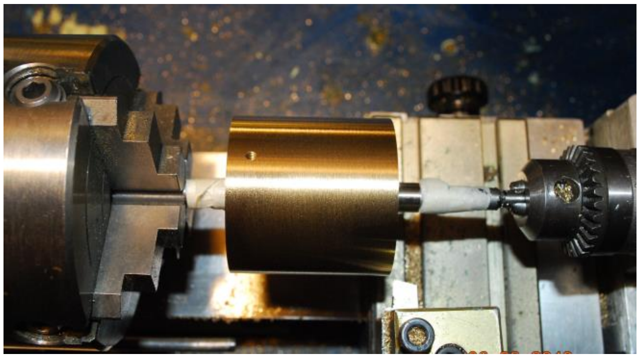


Figure 80: *The fusee blank. Note the temporary screw hole to attach the weight cable. Masking tape is used to protect the pivots.*

Mock up the wheel train

We now have all of the parts needed to assemble the train in the temporary assembly used to test the escapement. A home-made depthing tool designed by John Wilding is used to determine the placement of the arbors.

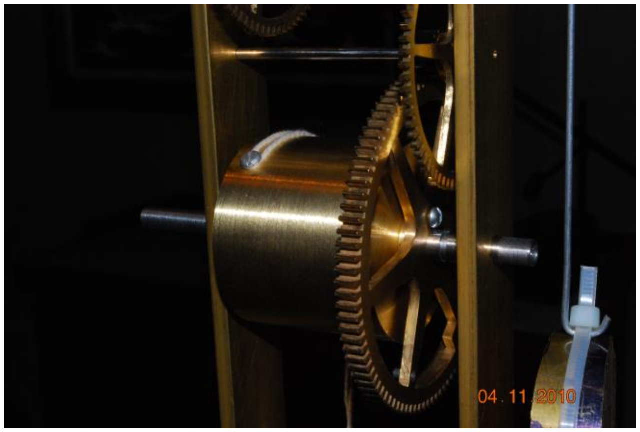


Figure 81: *Temporary holes in the fusee blank are used to fasten the great wheel and cable.*

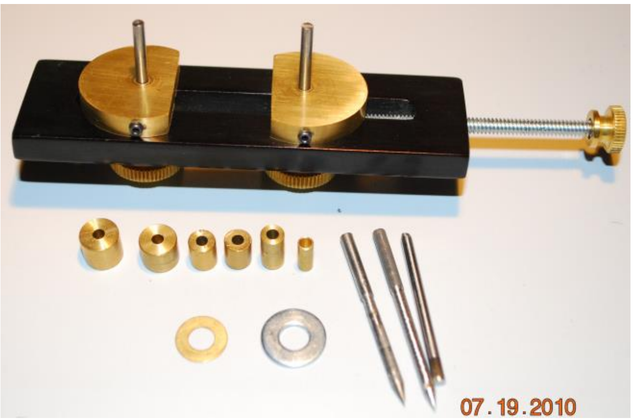


Figure 82: *The depthing tool along with an assortment of bushings and shafts used to fit wheels and pinions with various size hubs.*

The spacing is the same between the escape, fourth, third and second arbors since the pinions and wheels are identical. Because the escape arbor is already placed from the Escapement test, work should proceed from there down the train. Drill each pivot hole slightly undersize, then enlarge and finish with cutting and smoothing broaches. The spacing between the great wheel and second pinion is different from the others and a separate depth measurement is required. The fusee arbor hole will be drilled to .238″ (letter B drill bit). Drills this large tend to wander from their original starting point so it is good practice to scribe several concentric circles around the center mark with a small dividers and slowly increase the size of the drill bit. After each increase in size, check the new hole against one of the scribed circles to make sure it is properly centered. Re-center the hole with a file if necessary before moving up to the next drill size. The fusee arbor holes are then brought to their final size of ¼″ with the ballizing technique used for the barrel flanges. Remove the burr raised by the ball with a file and check the plates to ensure they are straight.

A hole is needed in the base of the temporary plate assembly to pass the weight cord. This hole should be offset from the arbor centerline by the radius of the fusee blank, .928″ in this case and the same distance from the inside of the plate as the temporary #4-40 screw hole. A ½″ diameter hole provides ample room for clearance.

Install the wheels, pinions and arbors in the temporary assembly, but do not install the pallets at this time. Determine the location of each wheel and pinion on the arbor, similar to the arrangement shown in the introductory section. Fasten each part to the arbor with low-strength Loctite so the parts can easily be disassembled later. Since the second pinion is already fastened directly to the second wheel collet, this assembly can be left floating on the arbor if desired. Allow the Loctite to set up, apply clock oil to the pivots and test run the train using finger pressure to drive each wheel. Adjust any pivot holes or the plate spacing where binding occurs. If everything is correct, the train will coast for 5-10 seconds when given a good spin from the great wheel. Install the pallet and pendulum assembly and test run by driving the train with finger pressure.

Attach a weight cord to the temporary screw in the fusee blank as shown in Figure 81. The digital scale is attached to the other end of the cord. A container is suspended from the scale and scraps of metal are added to adjust the weight. Adjust the amount of weight until the clock runs well with a small amount of over swing after each escape pin lands on the pallet. This clock required 7 pounds of weight that includes the weight of the scale. The clock may be run for a period of time to ensure proper operation and enjoy the moment of seeing your creation come to life. However, the low-strength Loctite should not be considered a permanent bond so do not leave the assembly unattended.

Final Fusee Calculations

From a drive weight of 7 pounds (112 oz) and a fusee blank radius of .928″ (1.856″ diameter), the torque required to drive the clock is 112 X .928 = 103.88 inch-ounces. The radius of the fusee needs to be matched with the force of the spring so it always delivers 103.88 in-oz of torque to the clock. We also want to operate in the linear portion of the mainspring curve. From graph 1, the average plot is fairly straight from about 12 inches through 70 inches, so 13 inches is chosen as the starting point. This tells us that we need 13 / 3π = 1.4 turns of preload for our 3″ diameter mainspring barrel. With a starting point of 13 inches of cable, we can now fill in the remainder of Table 1. Column 7 is the radius of the fusee required to deliver 103.88 in-oz of torque from the force available from the mainspring at that point. For example, at 13 inches of cable, 148 ounces of force is provided by the mainspring, so 103.88 / 148 = .701 inches for the fusee radius. Column 8 is the cumulative number of turns the fusee will make based on the previously calculated radius. One inch of cable and a radius of .701″ equates to 1/(2πr) = 1/(2π(.701)) = .23 turns of the fusee. At the next inch increment, the new radius of .686″ is used to obtain an increment of .23″ and that increment is added to the previous value to obtain a cumulative total of .46 turns. This provides a stepped approximation to the actual number of turns of the fusee. Now that we know how much the fusee turns for each incremental inch of cable, we can calculate how far along the fusee each increment will be.

Figure 83: *Test assembly to determine the weight required to run the clock. The weight of the scale must be added to the weight in the container.*

The fusee groove will be cut at 13 turns per inch so the groove will travel 1/13 = .077″

per turn. Column 9 shows the amount of travel at each increment. This is calculated as .077 times the number of turns. For example, inch 14 is .077 X .23 = .017 for the fusee width. (Note: the spreadsheet calculates without rounding, so the numbers will vary slightly from those shown here. The rounding is not cumulative and is of no concern.)

The fusee will be cut using an incremental step method as described in volume 1 of Guy Lautard's Machinist's Bedside Reader. This method entails making a series of plunge cuts with a parting tool leaving a step pattern that approximates the fusee shape. The steps are then filed off to create the final shape. Cuts can be made for every inch of cable increment, but it is more efficient to skip every other step at the expense of a little more filing. Column 10 is the step increment. This is the width of each step and determines how much the lathe carriage should be advanced from its previous position. It is the difference in fusee width in column 9 from the previous cut. For example the difference in fusee width from inch 15 and inch 17 is .072 - .035 = .037. Column 11 is the depth increment and determines how much the cross slide will be advanced from its previous position. It is the difference in fusee radius in column 7 from the previous cut. For example the difference in fusee radius from inch 15 and inch 17 is .675 - .652 = .023 (the table shows .022 in column 11 for inch 17, more rounding variation). The step and depth increment for inch 13 are highlighted in blue to indicate this is the starting position. The diameter shown in column 12 is simply twice the radius of column 11 plus the thickness of the fusee cable (.046") and is provided as a convenience for checking dimensions while cutting. It is necessary to add the thickness of the fusee cable since diameter will be reduced by the same amount when the groove is cut. We now have all of the information needed to cut the final fusee shape.

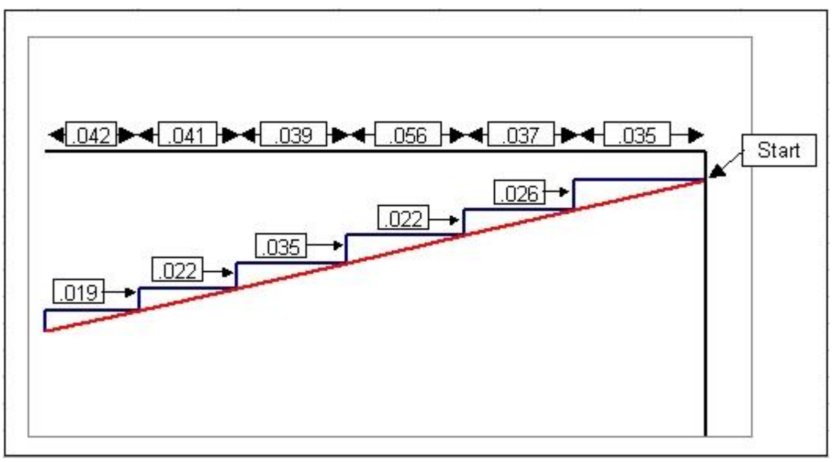


Figure 84: *Illustration of the incremental cut method of forming the fusee curve (not to scale). The start position corresponds to the first row of data for columns 10, 11 and 12 resulting in a diameter of 1.449". The carriage is then moved left .035" and another cut is taken .026" deeper than the previous. The carriage is then moved left .037" and another cut taken .022" deeper than the previous; and so on. The blue stair-step line is the result. After coating with layout dye and filing until the dye is removed, the red line remains which is the actual fusee curve.*

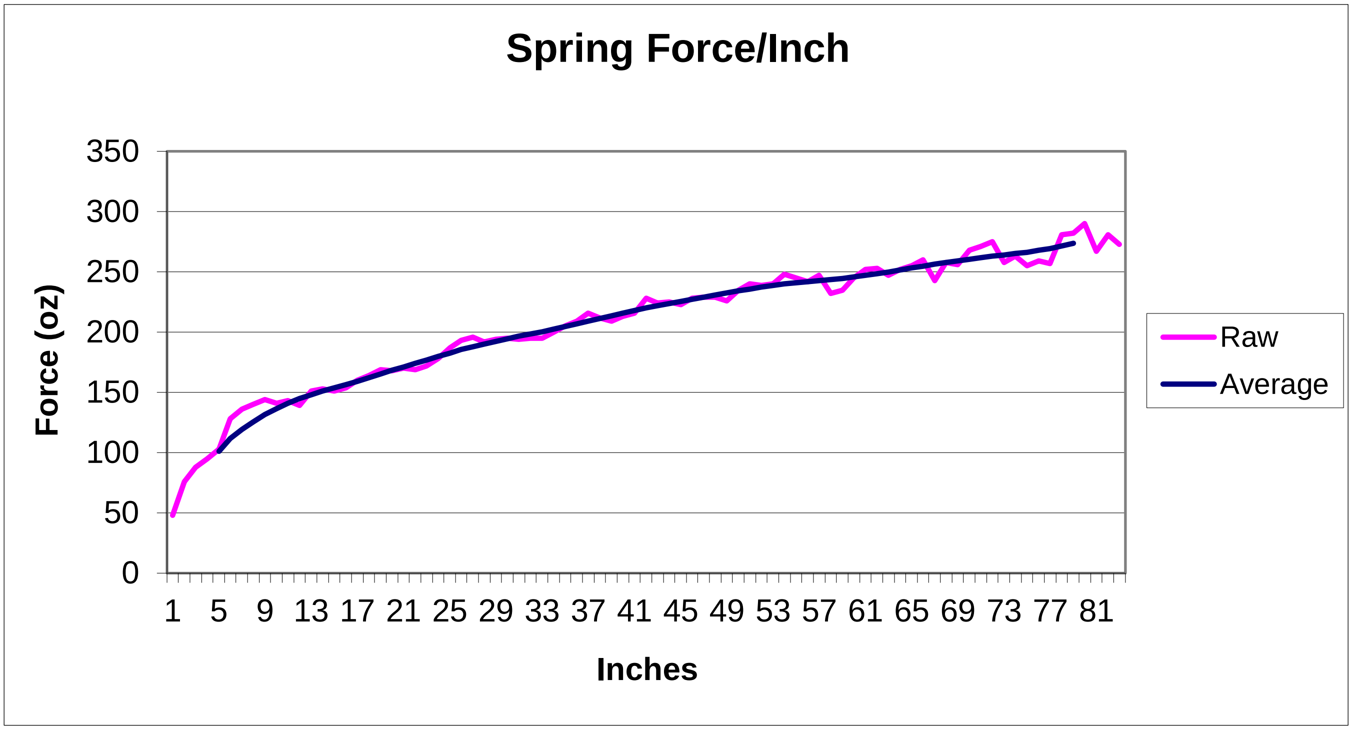
Table 1 – Fusee Calculations

1	2	3	4	5	6	7	8	9	10	11	12
Measured Values				**Adj. OZ**	**Avg. OZ**	**Radius**	**Turns**	**Fusee Width**	**Step Inc.**	**Depth Inc.**	**Fusee Dia.**
Inch	**lb**	**oz**	**OZ**								
1	3	0	48	48							
2	4	12	76	76							
3	5	8	88	88							
4	5	15	95	95							
5	6	7	103	103	101	1.026					
6	8	0	128	114	112	0.931					
7	8	8	136	122	119	0.872					
8	8	12	140	129	126	0.827					
9	9	0	144	136	131	0.790					
10	8	13	141	141	137	0.760					
11	8	15	143	144	141	0.737					
12	8	11	139	146	145	0.718					
13	9	7	151	148	148	0.701	0	0.000	0.000	0.000	1.449
14	9	9	153	150	151	0.686	0.23	0.017			
15	9	7	151	153	154	0.675	0.46	0.035	0.035	0.026	1.396
16	9	10	154	156	157	0.664	0.69	0.053			
17	10	0	160	160	159	0.652	0.93	0.072	0.037	0.022	1.352
18	10	4	164	164	162	0.641	1.18	0.091			
19	10	9	169	165	165	0.629	1.43	0.110	0.056	0.035	1.304
20	10	8	168	167	168	0.618	1.68	0.129			
21	10	10	170	170	171	0.607	1.94	0.149	0.039	0.022	1.260
22	10	9	169	174	174	0.597	2.20	0.169			
23	10	12	172	178	177	0.587	2.47	0.190	0.041	0.019	1.221
24	11	2	178	180	180	0.578	2.74	0.211			
25	11	11	187	183	183	0.568	3.01	0.232	0.042	0.019	1.184
26	12	1	193	186	186	0.560	3.29	0.253			
27	12	4	196	189	188	0.553	3.58	0.275	0.043	0.016	1.152
28	12	0	192	192	190	0.546	3.87	0.297			
29	12	2	194	193	192	0.540	4.16	0.320	0.045	0.013	1.126
30	12	3	195	195	195	0.534	4.45	0.342			
31	12	2	194	196	197	0.528	4.75	0.365	0.046	0.011	1.104
32	12	3	195	198	198	0.523	5.05	0.389			
33	12	3	195	200	200	0.519	5.36	0.412	0.047	0.010	1.084
34	12	8	200	202	202	0.513	5.66	0.436			
35	12	13	205	204	205	0.508	5.97	0.459	0.047	0.011	1.062
36	13	1	209	206	207	0.502	6.29	0.484			
37	13	8	216	208	209	0.497	6.60	0.508	0.048	0.011	1.040
38	13	4	212	212	211	0.491	6.92	0.533			
39	13	1	209	215	214	0.487	7.25	0.558	0.050	0.010	1.020
40	13	5	213	217	216	0.482	7.57	0.583			
41	13	8	216	218	218	0.477	7.91	0.608	0.051	0.010	1.000
42	14	4	228	220	220	0.472	8.24	0.634			
43	14	0	224	222	222	0.468	8.58	0.660	0.052	0.009	0.983
44	14	1	225	224	224	0.465	8.92	0.686			
45	13	15	223	225	225	0.461	9.26	0.712	0.053	0.007	0.969
46	14	4	228	227	227	0.457	9.60	0.739			
47	14	5	229	229	229	0.454	9.95	0.766	0.053	0.007	0.954
48	14	5	229	230	231	0.450	10.30	0.793			

Table 1: Continued

1	2	3	4	5	6	7	8	9	10	11	12
49	14	2	226	232	233	0.446	10.66	0.820	0.054	0.007	0.940
50	14	11	235	235	234	0.443	11.01	0.847			
51	15	0	240	237	236	0.440	11.37	0.875	0.055	0.006	0.928
52	14	15	239	238	237	0.438	11.73	0.903			
53	15	0	240	240	239	0.435	12.10	0.931	0.056	0.005	0.917
54	15	8	248	241	240	0.433	12.46	0.959			
55	15	5	245	241	241	0.431	12.83	0.987	0.056	0.004	0.909
56	15	2	242	241	242	0.429	13.20	1.015			
57	15	7	247	243	243	0.428	13.57	1.044	0.057	0.003	0.902
58	14	8	232	244	244	0.426	13.94	1.073			
59	14	11	235	244	245	0.425	14.32	1.101	0.057	0.003	0.896
60	15	5	245	245	246	0.422	14.69	1.130			
61	15	12	252	246	247	0.420	15.07	1.159	0.058	0.004	0.887
62	15	13	253	248	248	0.418	15.45	1.188			
63	15	7	247	249	250	0.416	15.83	1.218	0.058	0.005	0.878
64	15	12	252	252	252	0.413	16.21	1.247			
65	15	15	255	253	253	0.410	16.60	1.277	0.059	0.006	0.867
66	16	4	260	255	255	0.407					
67	15	3	243	257	256	0.405					
68	16	2	258	260	258	0.403					
69	16	0	256	260	259	0.401					
70	16	12	268	261	260	0.399					
71	16	15	271	261	262	0.397					
72	17	3	275	263	263	0.395					
73	16	2	258	262	264	0.393					
74	16	7	263	265	265	0.392					
75	15	15	255	267	266	0.390					
76	16	3	259	269	268	0.388					
77	16	1	257	268	270	0.385					
78	17	9	281	271	272	0.383					

Graph 1



Cutting the Fusee Profile

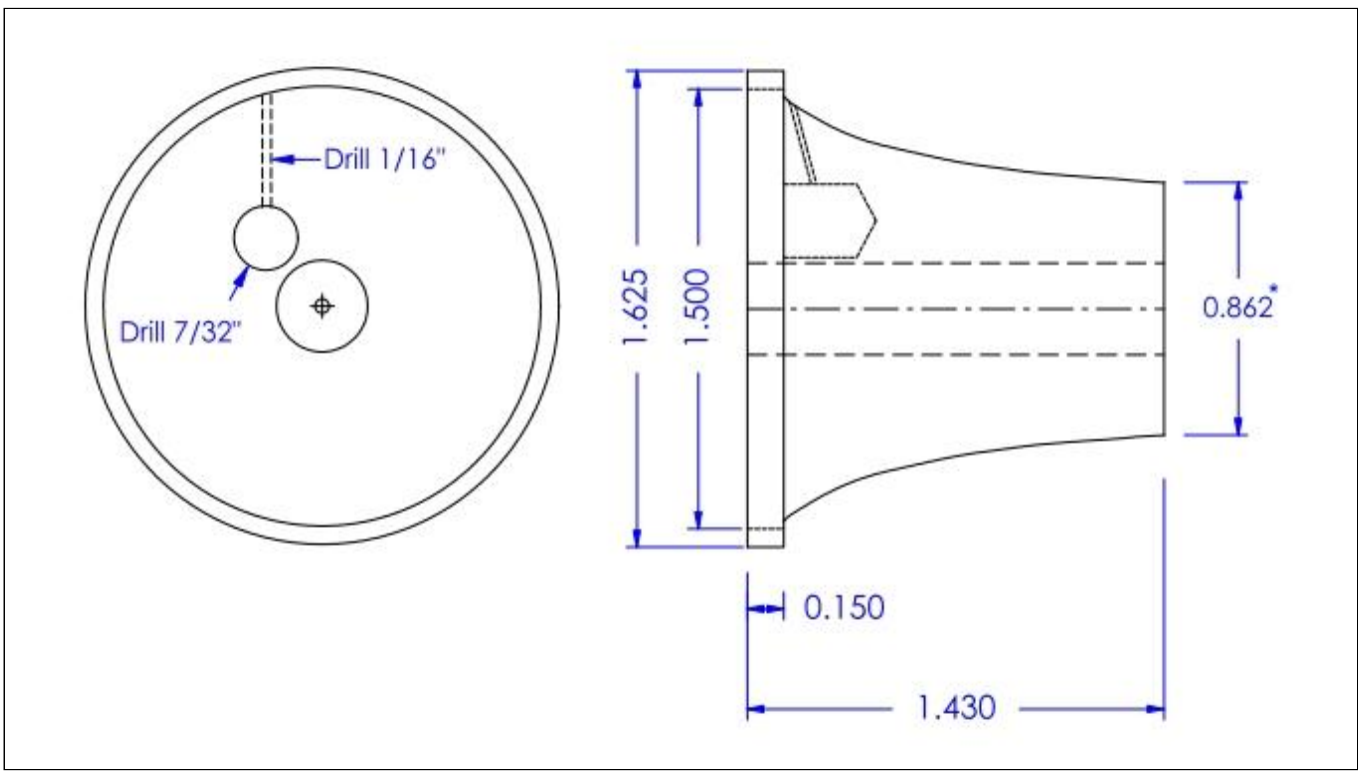


Figure 85: *Construction drawing of the fusee profile. Note the small end diameter is determined from actual measurements of the spring and power required to run the clock.*

Return the fusee assembly with the long end of the arbor in the chuck just like it was when the fusee blank was trued in Figure 80. Verify that it runs true. Masking tape is placed over the exposed pivots to protect their surface. With a dial indicator mounted to measure carriage position, offset the right edge of the parting tool .150″ from the right edge of the fusee blank and lock the carriage. Make a plunge cut with the parting tool until the diameter measures 1.449″. Note the reading on the cross slide dial before backing out. Let's say it is 8 for our example. Move the carriage to the left by the amount shown in column 10 for inch 15, .035″ in this case. Calculate the next cross slide reading by adding the amount shown in column 11, .026″ in this case, to the previous cross slide reading of 8. For our example the new cross slide reading will be 26 + 8 = 34. Write this number down so it is not forgotten. Make another plunge cut until the cross slide reaches the depth of the previous cut and then continue until the cross slide dial reads the calculated value of 34. Continue this process until the end of the table is reached. It may be necessary to remove excess material from the fusee blank if the parting tool cannot cut to sufficient depth. If this is required, make a note of where you left off. Also, remember to adjust your cross slide dial calculations when crossing zero. For example, the next cut will add 22 to the present cross slide reading of 34 equaling 56. Since the Taig dial rolls over at 50, subtract 50 from 56 so the new dial reading is 6.

Figure 86: *First plunge cuts to shape the fusee. The dial indicator is mounted to read carriage position to set the width of each cut.*

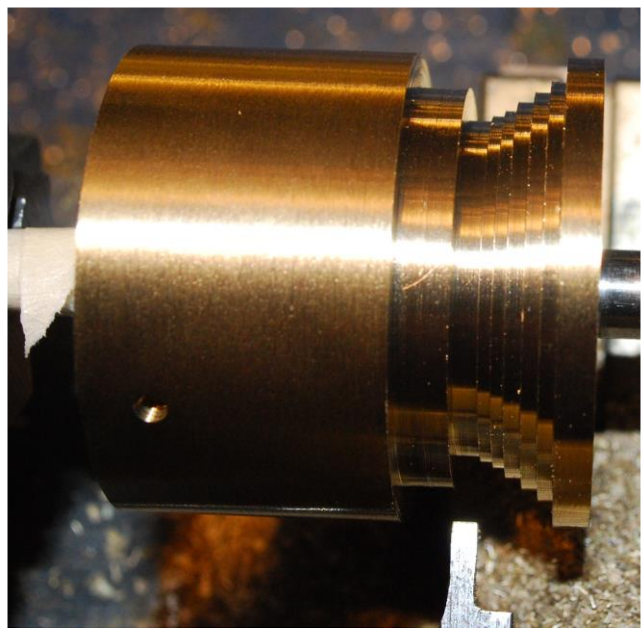


Figure 87: *Excess material is removed to the left of the parting tool since the depth of cut has exceeded the length of the tool.*

Again, write these numbers down since it is easy to lose your place. Figure 86 through Figure 90 show the fusee cutting progress. The final shape is achieved by coating the fusee with layout dye and then filing the surface with a half-round file until the dye is removed as shown in Figure 89.

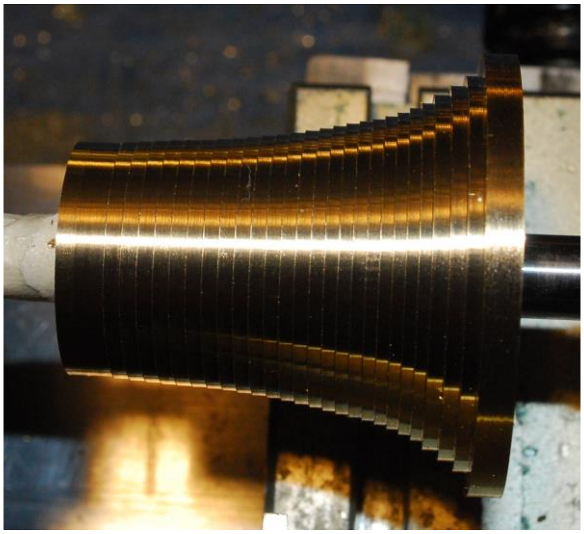


Figure 88: *All step cuts complete.*

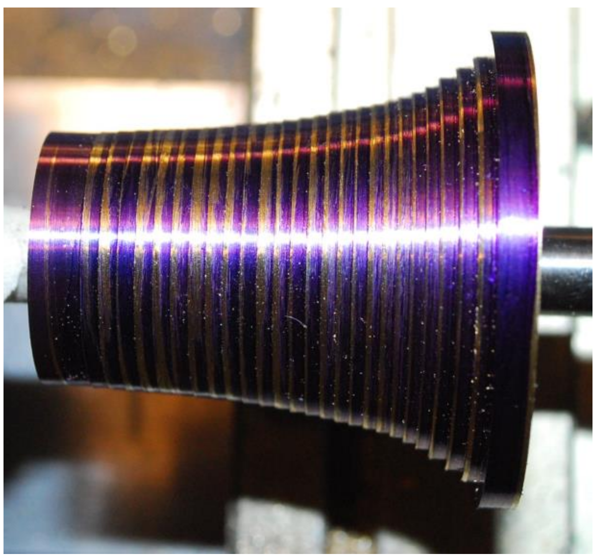


Figure 89: *Coated with layout dye and partially filed. Continue filing until all of the dye is removed except for the far right side that serves as a shroud for the click mechanism and will not be grooved.*

Grooving the Fusee

The Taig lathe is not configured to cut threads so another method must be used to move the carriage in sync with the spindle. If your lathe has thread cutting capabilities, feel free to skip ahead. Figure 91 shows a drive center made from ½″ threaded rod with 13 threads per inch. The 60-degree point of the drive center should be trued each time the center is installed on the lathe. A linkage made from a nut welded to a ¼″ diameter rod connects the drive center to the carriage. The rod is secured to the carriage with machinist's clamps.

Figure 90: *Final fusee shape after filing. The fusee is now ready for grooving.*

Figure 91: *The drive center above the scale provides 13-thread per inch drive capability to the Taig carriage. See Figure 94 for additional details regarding its installation. The cross brace on the connecting rod reduces flexing.*

Remove the cross slide nut from the cross slide so the cutting tool can be fed into the fusee by hand.

A special form tool is used to cut the groove. The main body is made from ¼″ key stock drilled approximately ¾″ deep to accept a section of .055″ music wire. The profile of the body is shaped before inserting the wire.

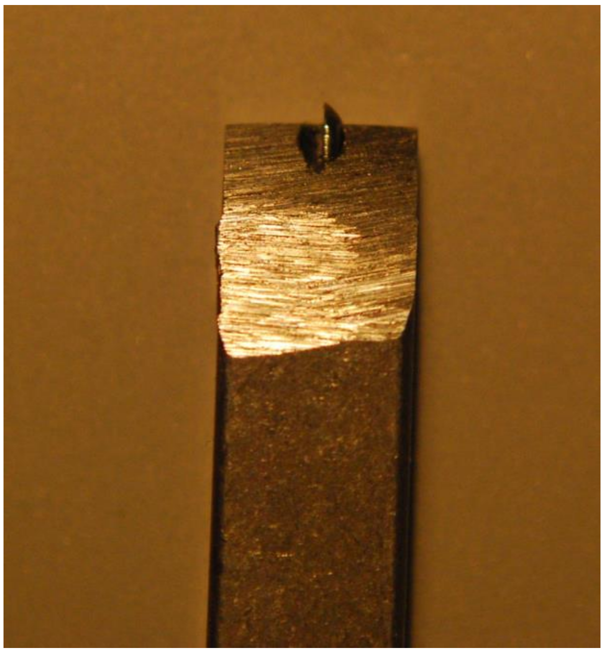


Figure 92: *Side view of the fusee groove cutting tool.*

Since the tool is fed into the fusee by hand, it is difficult to produce a groove of consistent depth. The shoulder acts like a depth stop, preventing the tool from cutting more than .025″ deep. The shoulder has a polished edge to provide a smooth surface to prevent scratching of the fusee. The protruding portion of music wire does the actual cutting. Round the end of a piece of music wire and grind the side to the center to make the cutter. Sharpen and smooth the cutting end on an emery stone. Fasten the wire inside the cutter body with Loctite so it stands .025″ proud of the shoulder.

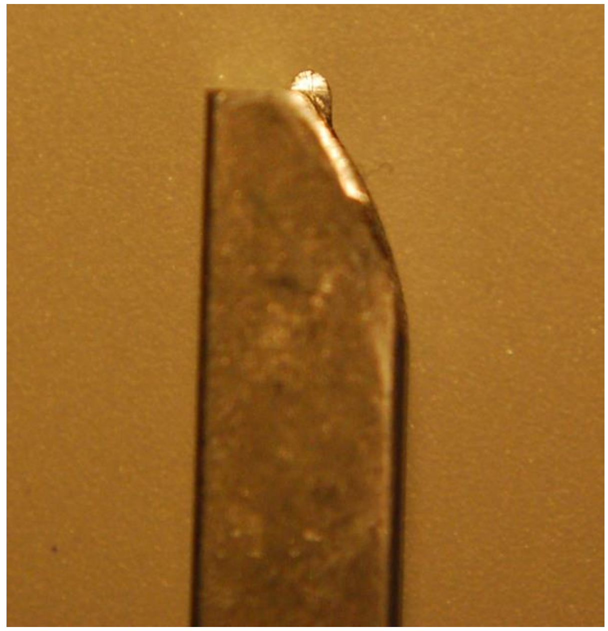


Figure 93: *Top view of the fusee groove cutting tool.*

Install the fusee assembly between centers with the large end towards the tailstock and verify that it runs true. Lathe dogs are used to couple the fusee arbor to the drive center. Before cutting, verify that the carriage will move from one end of the fusee to the other and that the cross slide has enough movement to reach the largest and smallest diameters of the fusee surface. The motor belt is removed and a hand crank is attached to the headstock pulley. See Figure 94.

Mark the starting position with a felt pen at the large end of the fusee and start each cut at this mark. All cuts are made from the large end to the small. Go slow and take light cuts to prevent the cutter from digging in or chattering.

After the groove is complete, trepan the large end of the fusee to a depth of 1/8″. Leave the rim approximately 1/8″ wide. Next, locate the cable access hole in the trepanned area by placing the start mark of the fusee groove at the 11 o'clock position.

***Figure 94:** Taig **l**athe configuration used to cut the fusee groove. Note the threaded drive center mounted in the lathe chuck. A connecting rod is welded to the ½" nut.*

***Figure 95:** Overhead view of the grooving operation. Note the machine clamps on the back of the cross slide fasten the connecting rod to the threaded drive center.*

***Figure 96:** The 7/32" access hole has been drilled and the cable through-hole line up is shown.*

Draw a line straight down as shown in Figure 96. Drill the 7/32″ hole to a depth of ¼″. Then drill the 1/16″ cable hole from the starting mark of the fusee groove to the access hole.

The cable hole should be drilled at a slight angle as shown in Figure 97 to prevent breaking through the side of the fusee. This technique was suggested in one of W.R. Smith's books. Be careful not to let the drill bit cut through the sidewall of the fusee groove. Start the hole with a small end mill if necessary.

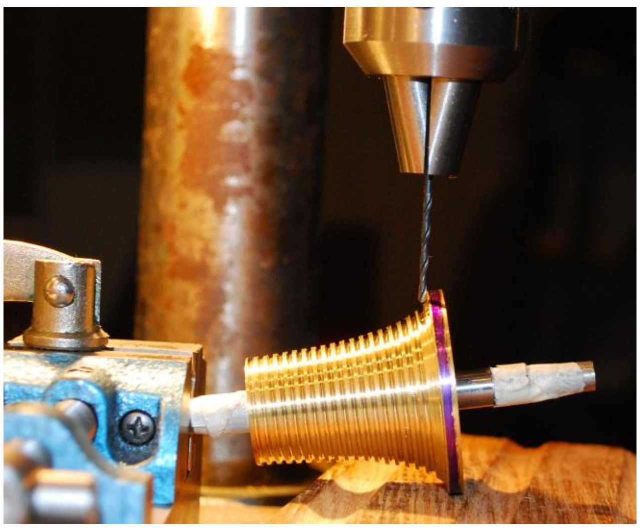


Figure 97: *Drilling the cable through hole at a slight angle.*

Round the corner of the hole with a needle file where the cable will exit and begin tracking the groove. This will reduce bending stress on cable. Next, remount the fusee in the lathe and trim the small end of the fusee to length, making sure there are at least 16 turns available on the finished fusee. Finally, install the maintaining wheel and great wheel, mark the position of the slip washer groove and machine the groove with a 1/16″ wide parting tool.

The fusee can now be sanded to a 600-grit finish. The winding flats are machined on the fusee arbor in the same manner as the barrel arbor, except the finished flats should measure .175″. The smaller size for the fusee winding arbor is intended to prevent the winding key from fitting over the barrel arbor as both are located on the front of the clock. Accidentally winding the barrel arbor would require resetting the fusee preload. The ends of the fusee arbor can now be trimmed to their final length to remove the center holes.

Fusee Ratchet

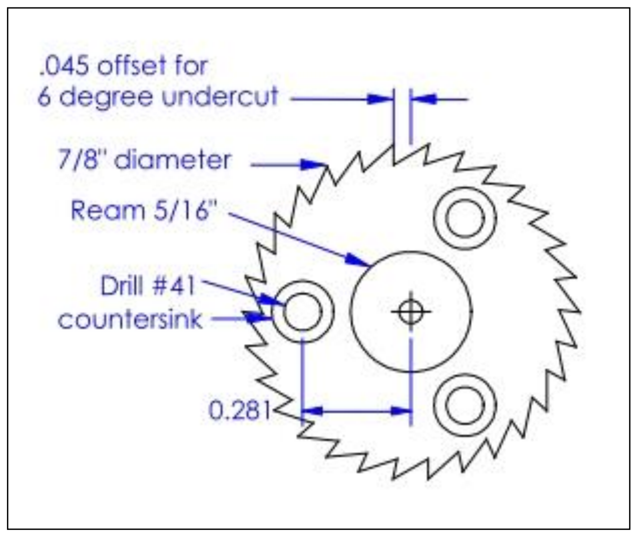


Figure 98: *Construction drawing of the 30-tooth fusee ratchet.*

Because of its small size the fusee ratchet is turned from a piece of 7/8″ diameter brass rod. The end of the rod is cut with the same 60-degree ratchet cutter that was used for the maintaining wheel. In this case, the teeth are cut as deep as possible, bringing them to a sharp point. The 6-degree undercut is achieved by offsetting the cutter .045″. The three mounting holes are drilled with a #41 bit in the milling spindle mounted to the cross slide and offset .281″. Drill and ream the center hole to 5/16″. The ratchet is then parted off to a thickness of 3/32″ as shown in Figure 99. If multiple ratchets are desired, cut the teeth further along the rod, drill the holes deeper and part off as many ratchets as needed. Countersink each of the mounting holes so a #2 flat head machine screw sits just below the surface of the ratchet.

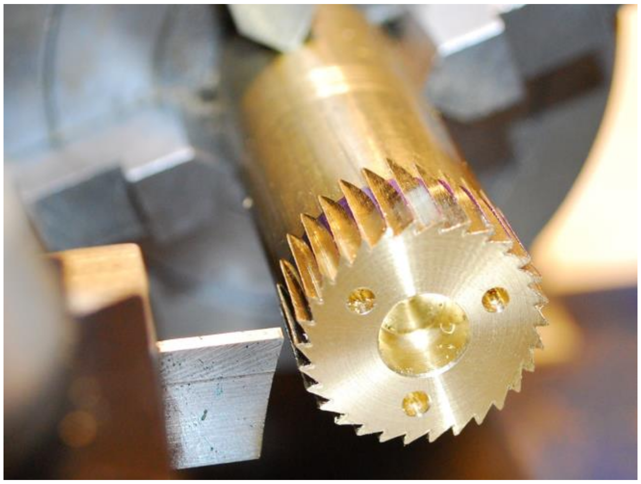


Figure 99: *The fusee ratchet ready to be parted from the end of the brass rod.*

Figure 100: *The ratchet mounted inside the trepanned area of the fusee.*

Slip the ratchet into position on the fusee arbor and transfer the mounting holes to the fusee. The holes are drilled with a #50 bit and tapped #2-56. Mount the ratchet to the fusee with three 3/8″ long #2-56 flat head machine screws.

Fusee Click and Click Spring

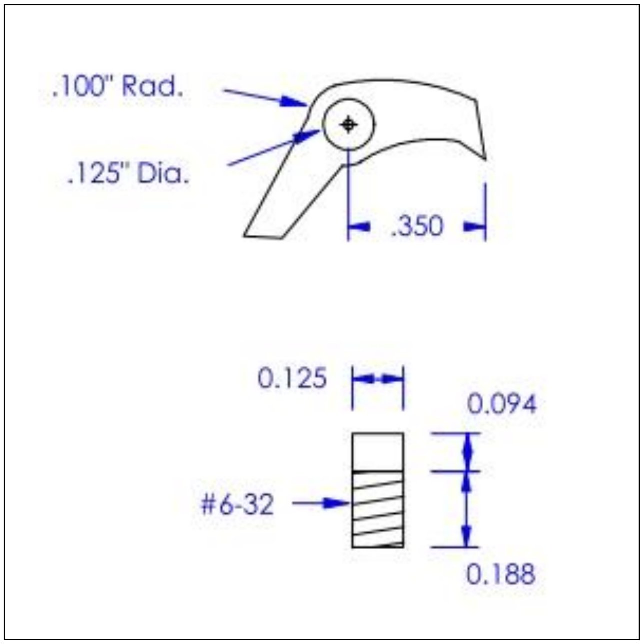


Figure 101: *Construction drawing of the fusee click and click stud. The click is made from 3/32" tool steel. Other than the pivot hole, all other dimensions are determined by test fitting the click into the available space.*

The fusee click pivots on a stud made from 1/8″ drill rod. Thread the rod approximately 3/16″, then reverse the die and chase the thread so the rod can be screwed all of the way into the maintaining wheel without any exposed threads. This allows a smooth bearing surface for the fusee click.

The fusee click is located in the trepanned area of the fusee and space is rather tight so the click is cut from 3/32″ tool steel to the approximate shape shown in Figure 101 and then filed to fit. The pivot hole should be reamed to 1/8″ for a close fit on the stud. Cut or grind off the excess threads flush with the maintaining wheel. The smooth section should be flush with the top of the fusee click. Test-fit the fusee click into the end of the fusee and shape it with a file until the pawl fits into the teeth of the ratchet and does not interfere with the rim of the fusee. Sand the click to a 400-grit finish.

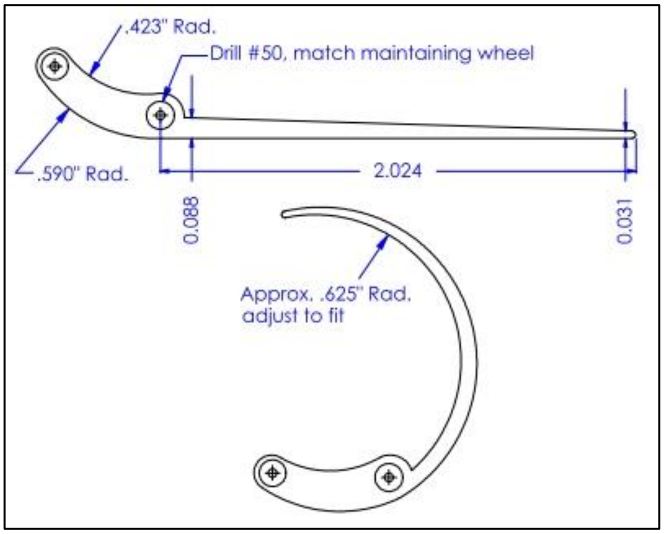


Figure 102: *Construction drawing of the fusee click spring. As with the click, dimensions are approximate. The spring is cut from 1/32" brass sheet shown in the upper drawing and then bent into the shape of the lower drawing.*

Lay out the shape of the fusee click spring on a piece of 1/32″ brass sheet as shown in the upper drawing of Figure 102. Drill the holes before sawing out the shape to provide a safe amount of material to clamp while drilling. After sawing, hammer the narrow section of the spring to harden it and then bend it to the shape shown in the lower drawing. Determining the exact shape is also a trial and error process. Adjust the shape so that it fits in the end of the fusee and provides the proper amount of tension on the click. When the final shape is achieved, file and sand the click spring to a 400-grit finish. Install the click assembly and verify that the ratchet action is satisfactory. The click and spring are shown installed on the maintaining wheel in Figure 104.

Maintaining Spring

The maintaining spring shown in Figure 106 is made from music wire. Experimentation with several shapes and sizes indicated a wire diameter of .047″ provided about the right "feel". The actual thickness and shape may need to be adjusted for more or less force based on tests after the clock is reassembled.

Slip Washer

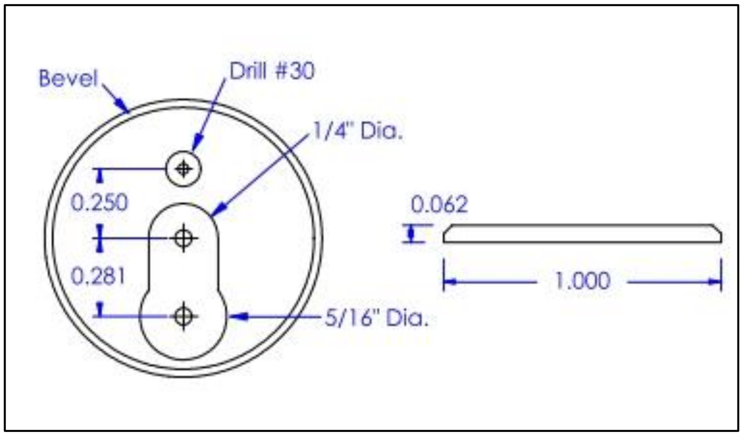


Figure 103: *Construction drawing for the great wheel slip washer. The material is brass.*

The slip washer is cut from a section of 1″ diameter brass rod. Face the end of the rod and make a light cleanup pass on outside circumference. The edge is then filed to a 45-degree bevel. Locate the center of the washer and make a dimple with a center drill. The partially completed washer is then parted off to a thickness of 1/16″.

Figure 104: *The fusee click and spring mounted to the maintaining wheel. The majority of the shaping of these parts is determined by test fitting the parts to the fusee. Note when the maintaining spring pin is installed, it should be flush with the side shown and protrude from the back.*

The screw hole and clearance hole are spotted from the center dimple and all three holes are drilled through on the drill press. Removing the material between the larger holes with a jeweler's saw then forms the slot. Clean up the saw marks with a file. File the washer down if it is too thick.

If the washer is too thin or the great wheel is loose, the washer can be domed to produce a tighter fit. This is accomplished by squeezing the washer against a pliable surface (such as leather or soft wood) and a hard curved surface as shown in Figure 105.

Increase or decrease the curvature as necessary until the great wheel moves freely with minimal play. Complete the washer by sanding to a 600-grit finish. The slip washer screw will be made later along with the plate screws.

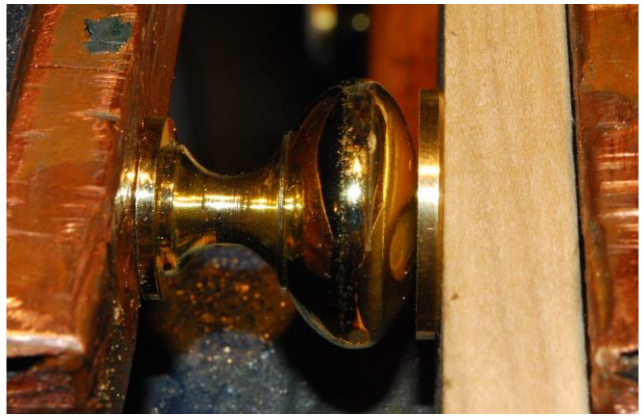


Figure 105: *A round drawer knob and soft poplar wood block are used in the bench vise to add a slight concavity to the slip washer if needed.*

Sand the maintaining wheel to remove any visible marks and bring it to the desired finish before fastening the maintaining spring pin and click stud in place with 609 Loctite.

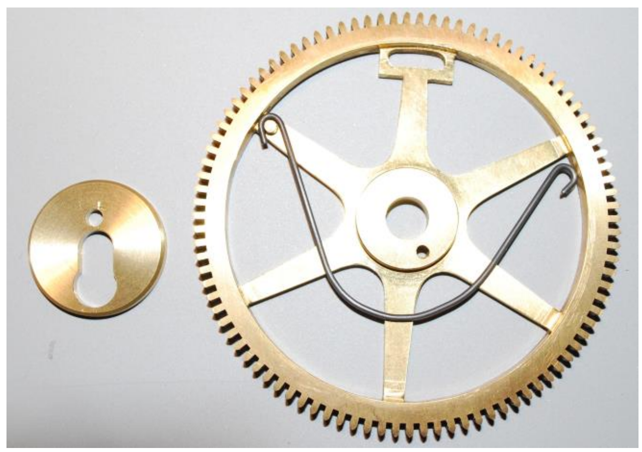


Figure 106: *The slip washer and maintaining spring. The loop on the free end of the spring will attach to the maintaining spring pin on the back side of the maintaining wheel. The spring as shown is fully relaxed and will come under tension when it is positioned at the slot on the top spoke.*

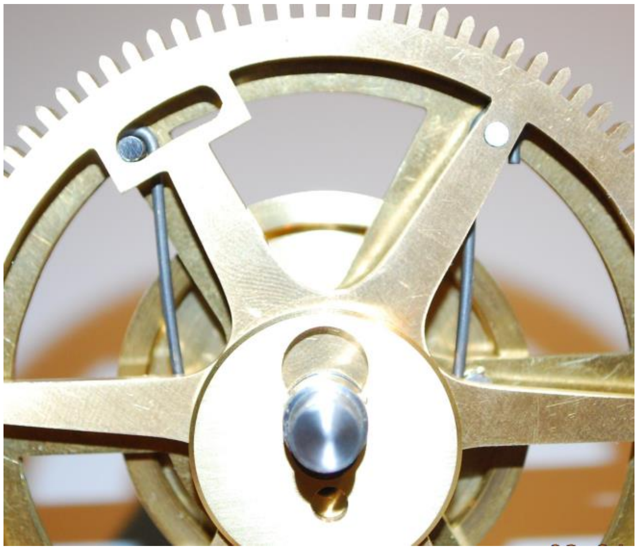


Figure 107: *The maintaining spring installed between the great and maintaining wheels. The fusee rotates clockwise, further tensioning the spring as the pin moves to the right side of the slot under normal operation. During winding, the fusee rotates counterclockwise while the maintaining wheel is held in place by a pawl. The maintaining spring continues to push the great wheel clockwise, providing power to run the clock while the fusee is wound.*

A Pinwheel Skeleton Clock

6 - Plates & Pillars

Introduction

It is finally time to cut out the plates and pillars. Typically, clocks built from a "how-to" book build the plates first. This makes sense if you already know where you are going. However, when building from scratch, it is necessary to prove various concepts and the design may change as the build progresses. It is better to experiment on inexpensive strips of brass rather than a large, expensive sheet.

Plates

There is a large degree of artistic freedom that can be expressed in the plate design. The simple test frame used up to this point would serve perfectly well as a fully operational, yet very boring clock. The creators of the original clock developed a wonderfully elegant design that is worthy of duplicating.

A photograph of the original clock was imported into CAD as a background image and each line on the left side was "traced" with a series of points connected to form lines that approximated the plate structure. The photo was then removed and the lines were cleaned up by moving misplaced points and substituting curves, circles or straight lines where appropriate. This proved to be a very tedious process. After the left side of the plate was completed, it was copied over as a mirror image to form the right side of the plate. This ensures the plate is symmetrical. Center holes for the pillars, mainspring barrel and fusee were added to the CAD drawing to aid in drilling the major holes. The location of the gear train will be determined with the depthing tool.

Before mounting the patterns to the brass, check the material for flatness and adjust as necessary. Two copies of the plate are printed actual size on 11"X17" paper and laid out on 3/16" 356 brass sheet. One end of the paper is taped to the brass to retain alignment. The paper is then folded back and the paper and brass are coated with a spray adhesive. Make sure the paper does not distort as it is folded back into position and adhered to the brass. After the adhesive sets, rough cut the major sections apart as shown in Figure 108.

Figure 108: *Plate patterns laid out to minimize waste. The black line shows where the two halves will be separated. A power saw and chain drilling was used to make this rough cut. Note the brass sheet rests on towels to protect it from scratches.*

The outsides of the plates are cut to shape with a jeweler's saw. Because of the large number of curves and corners, it is inevitable that the saw will need to reach across large sections of the plate. For these situations, a fret saw with a 12-inch frame comes in handy. The fret saw holds standard jewelers saw blades. It takes some practice to become adept at working the long, heavy frame with the fragile blades.

After the outside is cut, the lower interior sections can also be removed since the frame structure in this area is very thick. The interior sections of the upper part of the plates will be left for the time being to prevent the thin, delicate parts of the frame from becoming bent during handling. This will also make material available in the event a component needs to be relocated during the later stages of construction.

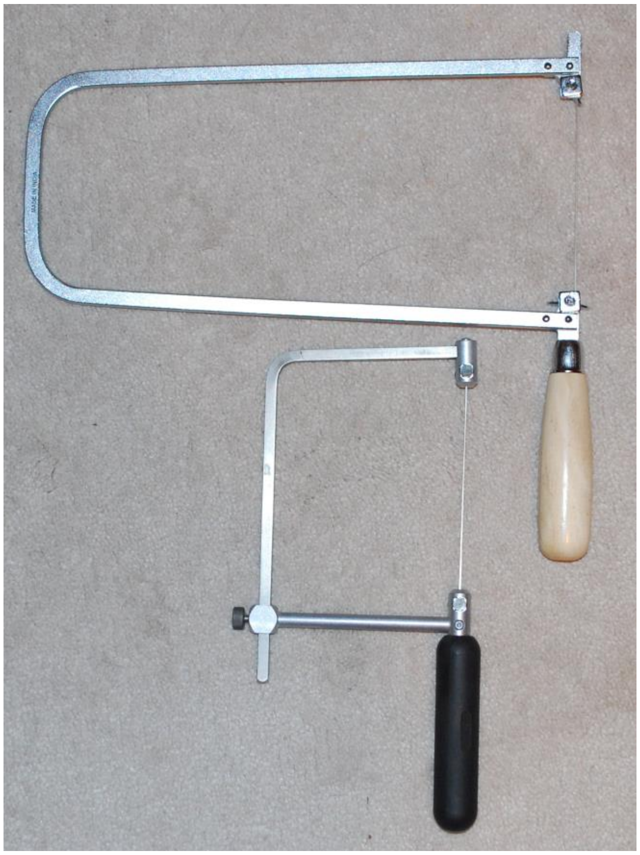


Figure 109: *Most cuts are made with the 4" jeweler's saw shown on the bottom. The 12" fret saw is used only when a long reach is needed.*

Approximately 15 hours and 20 blades were required to cut both plates as shown in Figure 110. Ironically, most of the blades were broken backing out of a cut or when repositioning the work piece. Those equipped with suitable power equipment such as a variable speed scroll saw may choose to use it here.

Figure 110: *One plate partially cut out.*

The outside edges can now be filed to remove the saw marks and make the plates more comfortable to handle. Final finish work will not be completed until the entire plate is cut out. When working the edges, care should be exercised to keep them square and not round the corners.

The plates must be kept aligned with each other, or “registered”, to prevent the arbors from binding. Typically, clockmakers will drill small holes and insert taper pins to align the plates.
This leaves unsightly holes in the plates. A superior method uses alignment bushings made from ¼″ drill rod drilled to pass a 6-32 screw and cut to a length just short of the thickness of both plates, 5/16″ in this case. Drill and ream to ¼″, the lower left pillar hole on the front plate and lower right hole on the back plate. Align the plates with the patterns facing out and install an alignment bushing and fasten it with a screw, washers and nut. Clamp the plates together and install a second bushing in the upper right pillar hole. The alignment bushings should always be installed in the same holes for consistent results when registration is required. With the alignment bushings in place the remaining pillar holes can be drilled and reamed. The barrel arbor hole can also be drilled and reamed to 5/16″ at this time.

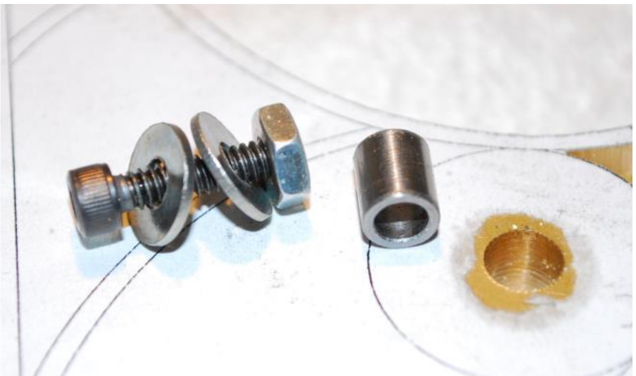


Figure 111: *An alignment bushing next to a pillar hole. Since the bushing is longer than a single plate thickness, it will always contact both plates. The cap screw passes through the bushing, holding the plates together and the bushing in place at the same time.*

The fusee pivots are also drilled and ballized at this time. It is advisable to spot the second arbor location from the fusee arbor with the depthing tool before drilling the fusee arbor hole as it is easier to determine the spacing from a small mark rather than a ¼″ hole. Remember to draw concentric circles around the hole to confirm the drill does not wander while drilling. Remove the burr raised by the ballizing process.

Pillars

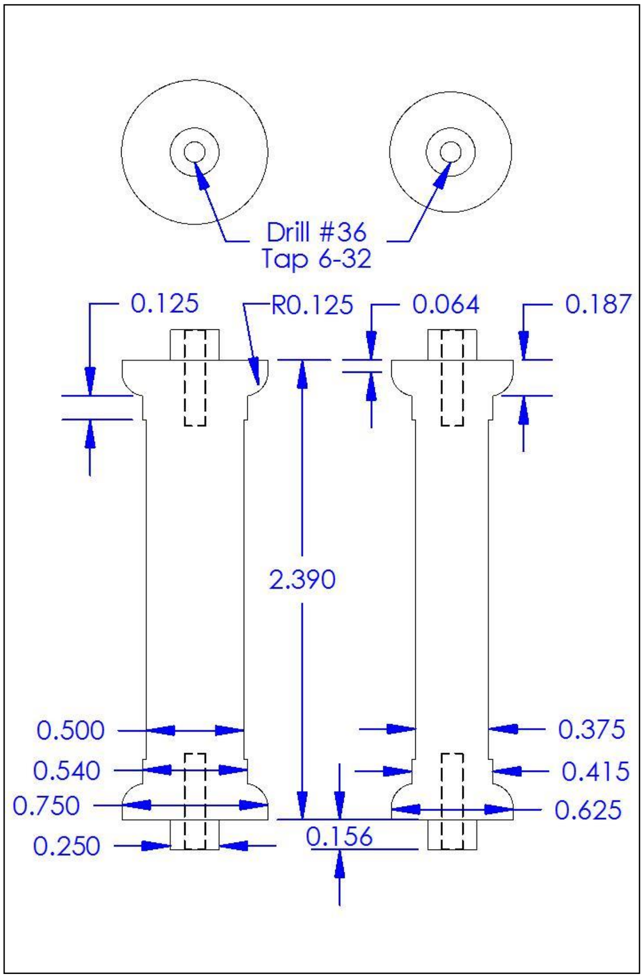


Figure 112: *Construction drawing for the pillars.*

Six pillars are required, 4 lower pillars and 2 slightly smaller ones for the upper section. Efficiency is increased when making multiple parts by performing the same operation on all parts before moving on to the next step.

The pillars are 2.390″ long from shoulder to shoulder to provide .015″ (1/64″) end shake for the arbors. Cut a 3.25″ length of brass rod and insert one end as far into chuck as possible. This may leave a substantial amount of overhang so light cuts are required to prevent chatter. Face the end and cut the spigot to .250″ diameter for a nice slip fit into a .250″ reamed hole. To prevent rocking, the shoulder of the pillar is undercut slightly as shown in Figure 113. Center drill and drill a #36 hole to a depth of ¾″ and tap #6-32. Reverse the rod in the chuck and create the second spigot so that the shoulder-to-shoulder distance is slightly long, approximately 2.4″ works well. Repeat this process for the remaining pillars.

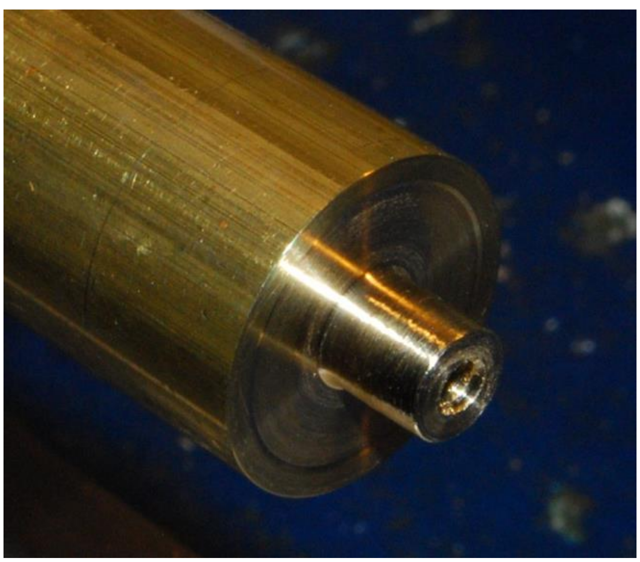


Figure 113: *The pillar spigot. Note the slight undercut on the shoulder to prevent rocking.*

Remove the chuck and mount one end of the pillar in a ¼″ collet with the free end supported by a live center as shown in Figure 114. This setup allows the pillar to be easily removed for measuring and returned to the lathe without re-centering. Face the shoulder to achieve the final length of 2.390″ and undercut the end as before. Repeat for the remaining pillars.

Install a large pillar and ensure it is tight against the collet. Set up a parting tool to cut .187″ from the shoulder and lock the carriage. Make a plunge cut to a diameter of .540″. Make a note of the cross slide reading. Flip the pillar end-for-end and make the same cut as shown in Figure 114.

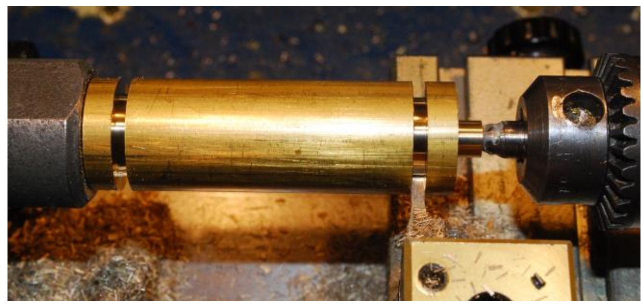


Figure 114: *Plunge cuts are made to form the shoulders.* ***Several changes should be noted between the photo and the text.*** *A dead center is shown but a live center will avoid erosion of the hole due to pressure from the parting tool or swarf entering the contact point. Cuts should be made at the collet end rather than the tailstock end to reduce chatter. It is also faster to lock the carriage and flip the pillar than to reposition the carriage for each cut.*

Repeat the process for the remaining large pillars. Cut the small pillars in the same way except the plunge cuts are made to a diameter of .415″.

Machine the center section of each pillar so the diameter matches that made by the parting tool. Further reduce the center section to .500″ on the large pillars and .375″ on the small pillars leaving a .125″ decorative band at each end.

The ends can be rounded by filing or with a graver, but a profile tool may be faster and will ensure that all of the radiuses are identical. A sharp tool and slow speed will produce a very nice finish as shown in Figure 115.

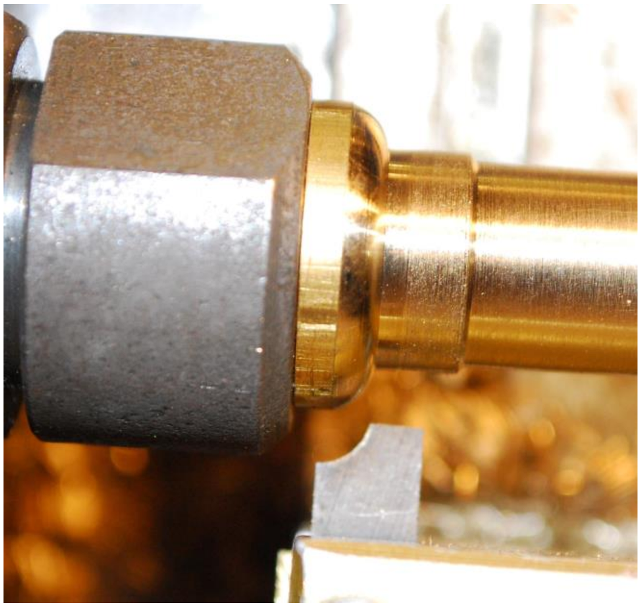


Figure 115: *A form tool is used to radius each end. The lathe can be turned by hand if necessary to shave off material to leave a fine finish. The tool must have all grinding marks removed or grooves will be left in the finish. This tool was ground to rough shape on a bench grinder and then finished against a ¼" diameter stone mounted in a Dremel tool.*

Extend the pillar slightly from the collet and remove any scratches from the remaining original surface with a fine file before sanding each pillar to a 600-grit finish. It may be necessary to touch up the threads that were in contact with the live center.

Pillar Washers

The pillar washers and plate screws will be constructed at this time although wear and tear will be saved on these parts if store-bought washers and screws are used for test fit-ups during construction.

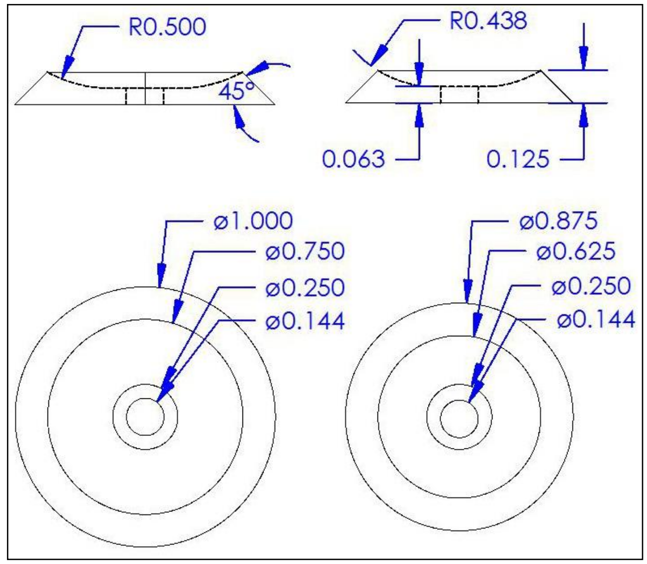


Figure 116: *Construction drawing of the pillar washers.*

A 2.5″ length of 1″ diameter brass rod is mounted and centered in the 4-jaw chuck. Face the end, center drill and drill with a #27 bit to a depth of approximately 2 inches. Counter bore the center hole with a 3/8″ end mill to a depth of .063″. The end mill leaves a flat bottom for the screw shoulder.

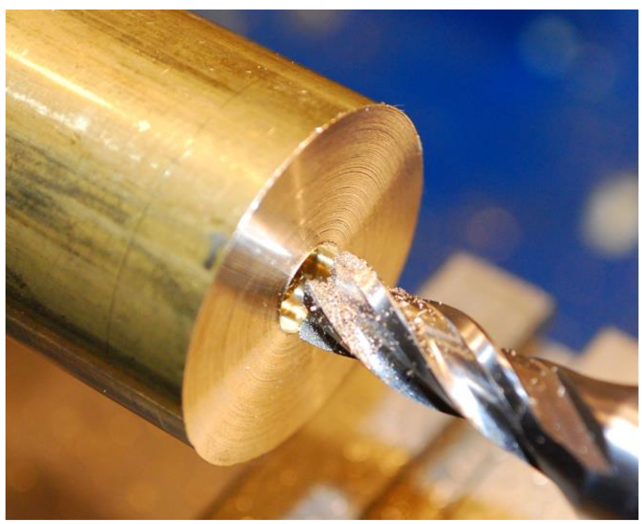


Figure 117: *Counterbore the center hole with an end mill to create a flat bottom.*

Chamfer the edge to 45 degrees and rough out the inner curved surface as shown in Figure 118.

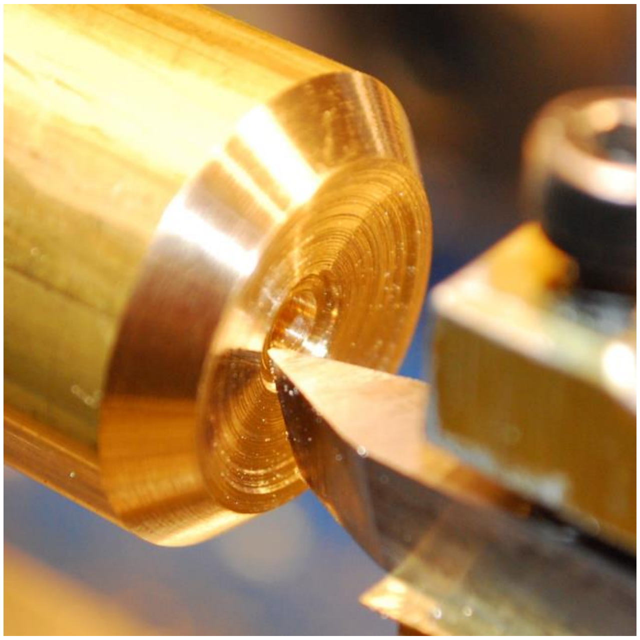


Figure 118: *Rough out excess material with a v-shaped tool after the chamfer has been cut. Leave enough material for final shaping with a profile tool.*

The internal curved surface is then shaped with a profile tool. The work may need to be turned by hand due to the amount of overhang on the first washers. The profile cut is complete when the edges of the chamfer and inner radius meet. Sand to a 600-grit finish before parting off the washer to .125″ thick. The washers can also be polished with a Dremel tool before parting off and then lacquered. Put the washers away for final assembly.

Repeat the process for the remaining large washers. The same process is used to machine the small washers according to the dimensions shown in Figure 116.

The same profile tool can be used to form the inner curve by rotating the tool slightly to increase the angle.

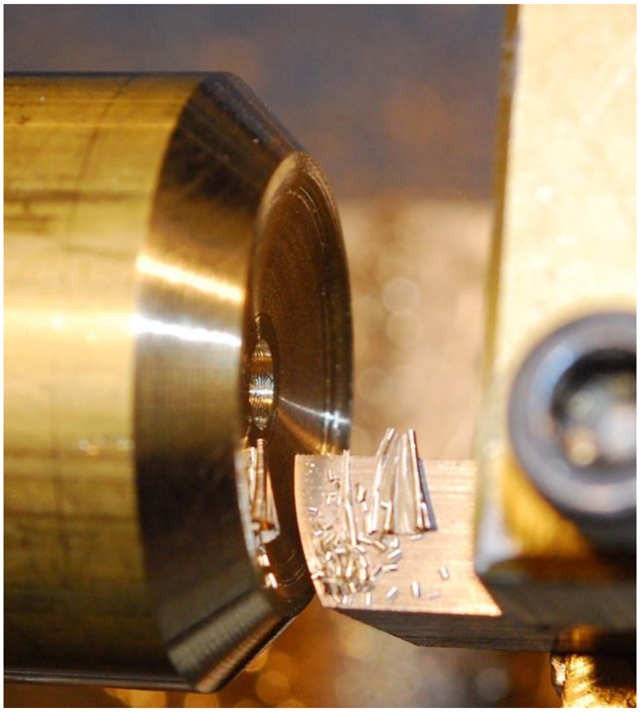


Figure 119: *Finishing the inner curve with a profile tool. This cut has a little further to go until the inner curved surface meets the chamfer.*

Figure 120: *The completed pillars and washers.*

Plate Screws

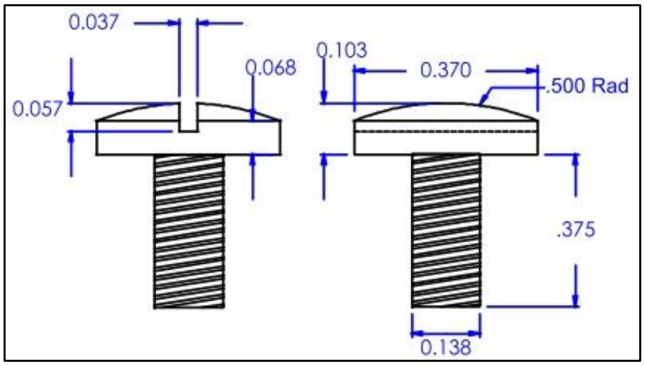


Figure 121: *Construction drawing for the plate screws.*

The plate screws are machined from 3/8″ diameter mild steel rod. An 8″ piece of rod is held in a collet with approximately ¾″ protruding. Note that the Taig headstock was bored out to 3/8″ and a custom 3/8″ collet was made to enable this operation. The 4-jaw chuck can also be used although the stock must be re-centered for each screw.

The following steps were used to speed production. Face the end of the rod. With the tool bit against the face, use a ½″ spacer to set the carriage stop. Reduce the diameter to .370″ for a length of ½″, just enough to remove the factory scale. Use a second 3/8″ spacer to reset the carriage stop and reduce the diameter to .138″ for a length of 3/8″. Thread this portion #6-32 with the die mounted in a tailstock holder to ensure the threads run true. Lightly chamfer the end of the thread with a file. Part off the screw leaving the head .103″ thick. Repeat these same operations for the remaining 11 plate screws. The three smaller screws shown in Figure 132 can also be made at this time as the lathe setup is the same.

A short section of rod is mounted in a collet and drilled and tapped 6-32. A shoulder is formed to allow full access to the screw head. This setup is used to finish the screw head as shown in Figure 123.

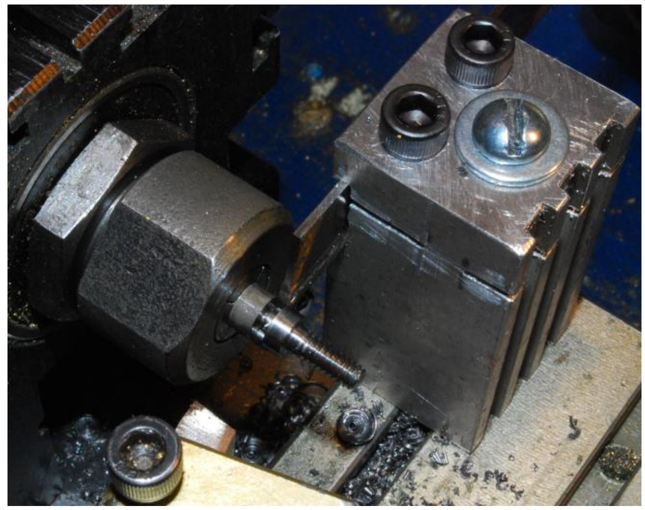


Figure 122: *Two tool holders are mounted on the lathe at the same time allowing the entire screw to be made without remounting the tools. The parting tool is mounted upside down in the rear homemade tool holder. The ribbing on the tool holder serves no purpose; it was part of the scrap aluminum used to make the holder.*

Install a partially completed screw in the fixture and tighten it with soft jaw pliers. Alternately, regular pliers can be used with a piece of brass shim stock wrapped around the screw head to prevent marking the work piece. A profile tool is used to round the screw head to the dimensions shown in the construction drawing. The head is then sanded and polished to a mirror finish at this time. A Dremel mounted buff and Tripoli provide the final finish. If finishing were performed after the slot were cut, the edges of the slot would be rounded which is undesirable. The screw is removed from the fixture with the same care used to install it to prevent scratching the newly polished surface. Repeat these steps for all of the screws.

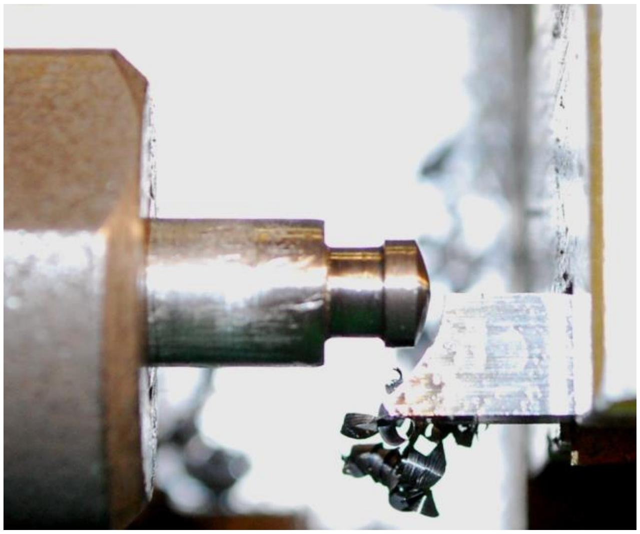


Figure 123: *A short piece of rod holds the screw while a profile tool is used to curve the head.*

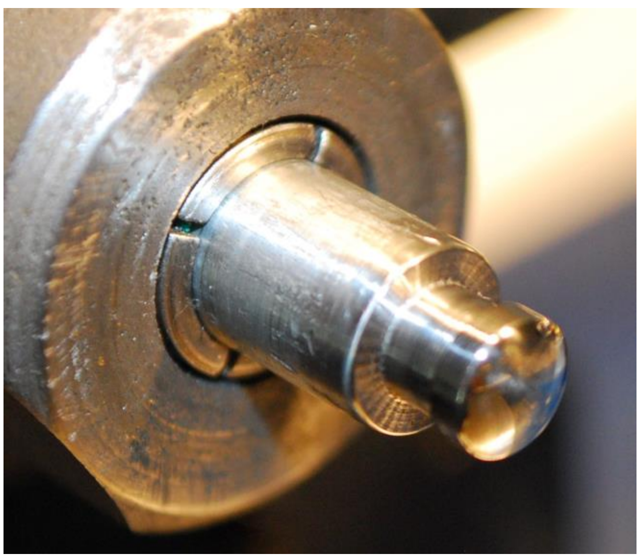


Figure 124: *The screw head after polishing. Note this is a smaller screw used for the fusee iron mount, but the process is the same.*

The slot is cut with a .035″ slitting saw set up in the milling head as shown in Figure 125. The dividing plate is mounted to the headstock to prevent the lathe from turning while the slot is being cut. Extreme care is required to cut the slot in the center of the screw. Even a few thousands offset will be visible. Advance the carriage until the saw just contacts the center of the screw head. Back off the cross slide and advance the carriage .057″ and lock it in place. The screw slot the then cut in one pass by advancing the cross slide. Even though a slot is now available, the screw should be removed with soft jaw pliers to prevent any damage to the screw slot. Check the slot on the first few screws to make sure it is centered. A file can be used to remove the burr on the exit side of the slot. Clean the screws thoroughly and apply car wax to prevent rust. Set the screws and washers aside until final assembly.

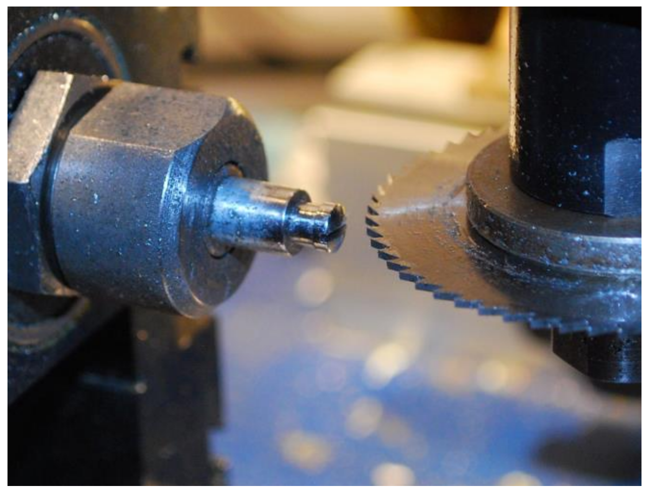


Figure 125: *Cutting the screw slot with a .035″ slitting saw blade. The lathe headstock is locked with an index plate during this operation.*

Fusee Stop Works

The fusee stop works is a safety device that prevents the fusee from being wound to the point where the cable runs off the end of the fusee. This could cut the cable which would be disastrous with a fully wound spring.

The fusee stop mounts on the small end of the fusee and provides a protruding tab that catches on the fusee iron when the cable pulls it into position. No special machining is required; just lay it out as shown in Figure 126 on a piece of 1/16″ thick brass sheet. Do not mount the stop to the fusee yet. Its position will be determined by test fitting after the stop assembly is complete.

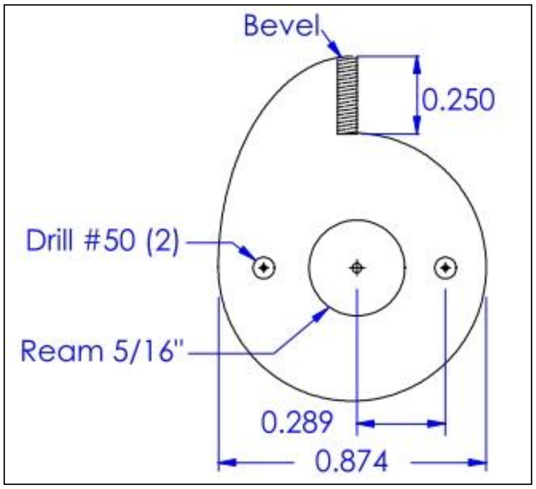


Figure 126: *Construction drawing for the fusee stop. The stop is cut from 1/16" sheet brass.*

Figure 127: *The finished fusee stop. The bevel is formed with a hand file as the angle is not critical.*

The fusee iron mount is made from a short length of 3/8″ brass rod. Mount the rod on the lathe using a 3/8″ collet. Face the end and drill #36 to a depth of ¼″. Tap the hole 6-32. Remove the rod, mark to a length of ½″ and part off the excess material. Round the rod with a profile tool in the same manner as the plate screw heads. Install an index plate to hold the lathe headstock and cut a slot to a depth of 5/16″ with a 1/16″ wide slitting saw. Rotate the rod 90 degrees and cross drill the #53 hole with the milling spindle. Remove the piece from the lathe and locate the spring wire hole with a very sharp center punch. Place the piece in a vise at a 65-degree angle and drill the hole with a #78 drill bit.

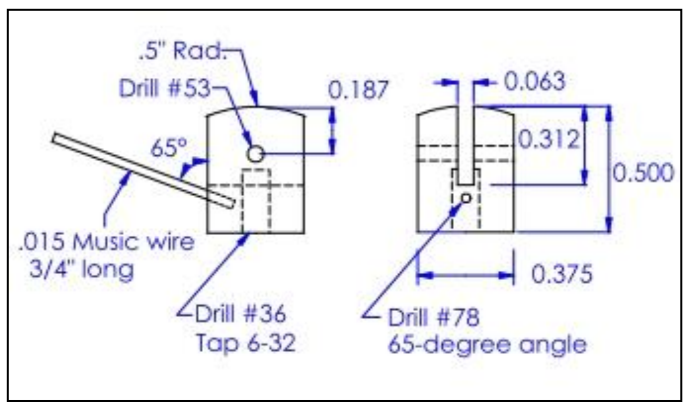


Figure 128: *Construction drawing for the fusee iron mount. The material is 3/8" brass rod.*

Small drill bits can be used in a bench drill press if the chuck will close down on the bit and runout is minimal. Alternately, a small, homemade drill press as shown in Figure 129 works much better when drilling small holes.

A short length of .015” music wire serves as the fusee iron return spring. This spring moves the fusee iron out of the way from the fusee stop when the cable is not fully wound. The wire may be cut to length at this time, but it will not be fastened to the mount until after final assembly so it does not become damaged during polishing.

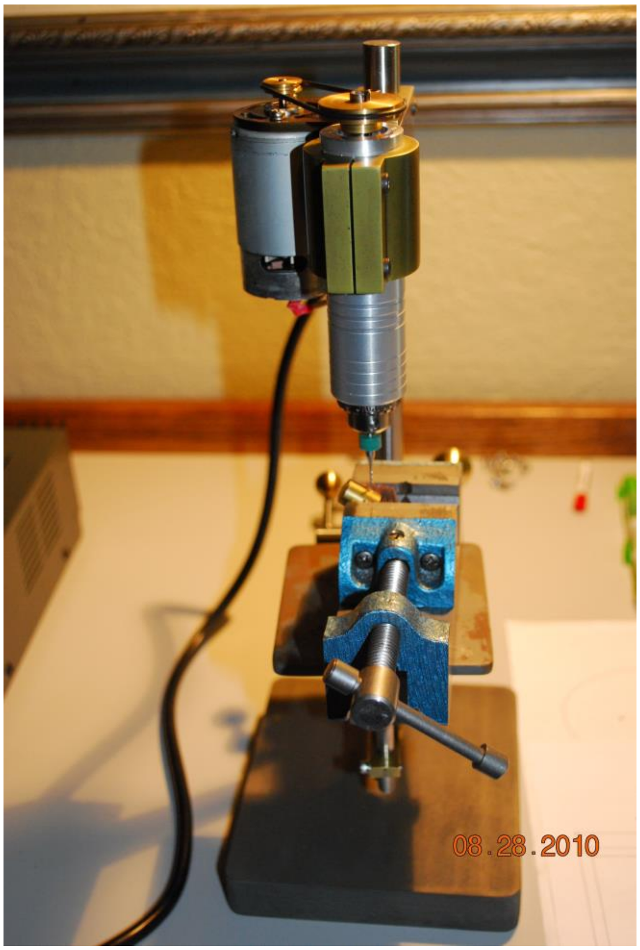


Figure 129: *The fusee iron mount is held at a 65-degree angle to drill a hole for the fusee iron spring. A miniature drill press is handy for drilling small holes like this. The table moves up to feed the work to the bit. The spindle assembly is a Fordom rotary handheld unit driven by a DC motor from a surplus battery-powered drill. An adjustable power supply provides a speed range of approximately 2000-20,000 RPM.*

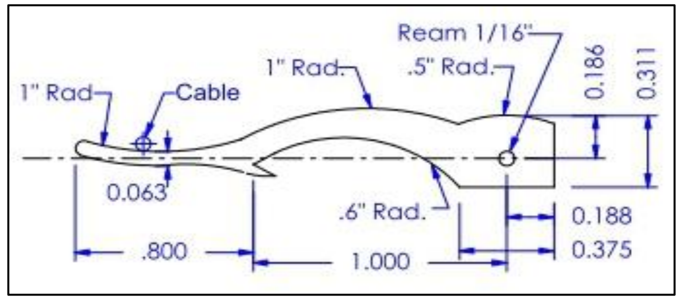


Figure 130: *Construction drawing for the fusee iron. The approximate location where the cable contacts the iron is shown in blue. Material is 1/16” mild steel. Note the mounting hole is reamed 1/16” diameter.*

The fusee mount will be located on the back of the front plate to the right of the fusee arbor as shown in Figure 133. Drill this hole #27 to pass a 6-32 screw. The section of plate beneath the fusee arbor should be cut out at this time to provide access to the fusee stop area. Dimensions of the fusee iron length are determined by partially assembling the fusee stop, fusee and spring barrel between the plates. A section of cable is strung between the barrel and the fusee and measurements are taken so the fusee stop and hook of the fusee iron are perpendicular as shown in Figure 133. The distance from the fusee stop to the cable is also measured, resulting in the dimensions shown in Figure 130.

Layout the dimensions on a piece of 1/16” mild steel plate, cut and file to shape. Temporarily assemble the iron, mount and spring and note where the spring contacts the iron as shown in Figure 134. A shallow groove is cut at this location with a Dremel cutoff tool to prevent the spring from slipping off of the edge of the iron.

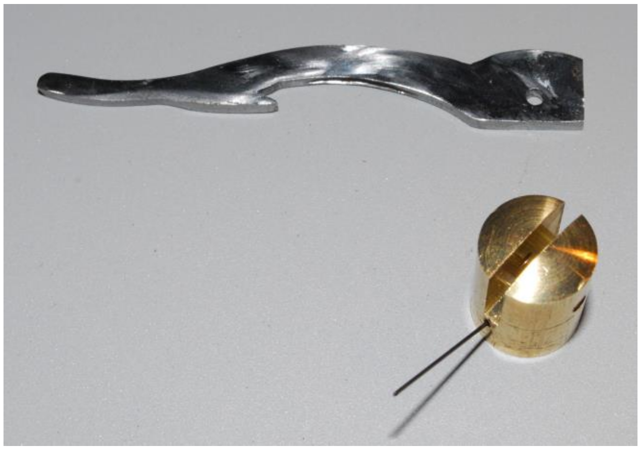


Figure 131: *The fusee iron, mount and spring. Note the edge groove between the hook and the mounting hole for the spring.*

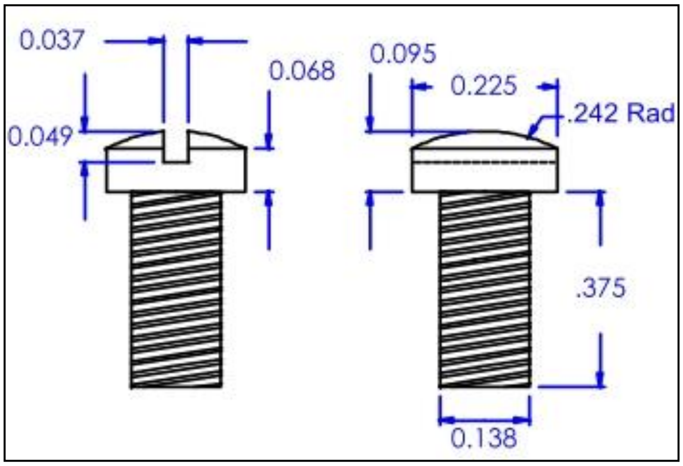


Figure 132: *Construction drawing of the fusee iron mount, suspension bracket and motion works bridge screws. Material is ¼" mild steel rod.*

The iron is then placed in its mount and the cable positioned as shown in Figure 133. Rotate the fusee, allowing the cable to track the groove to simulate the clock being wound. Locate the fusee stop so that the hook just clears the stop on one pass and just catches the hook on the next pass as the cable reaches the end of the fusee. Several attempts may be required to find the correct location. Mark the fusee stop location on the fusee and transfer the hole locations to the end of the fusee. Drill the holes #56 and tap 0-80.

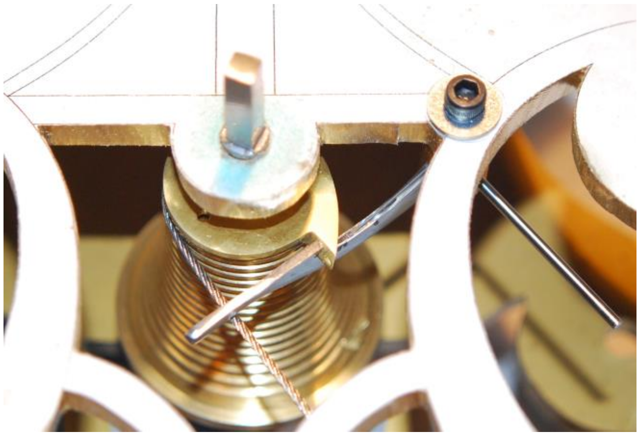


Figure 133: *Determining the location of the fusee stop. A temporary pin and socket-head cap screw hold the stop works in place.*

Cut a ½" length of 1/16" diameter rod or music wire for the fusee iron pivot pin. Enlarge the hole in the mount with a broach for a snug fit of the pin. Do not install the pin at this time; it will be installed after polishing.

The mounting screw is made in the same manner as the plate screws except the head is slightly smaller as shown in Figure 132. Make three screws since the motion works bridge and suspension bracket require the same size.

Figure 134: *A side view of the fusee stop works. The black marks indicate where the spring groove is cut.*

Maintaining Pawl and Arbor

The maintaining pawl prevents the maintaining wheel from rotating backwards when the clock is wound.

Mark the outline of the pawl on a sheet of 1/8" thick mild steel. Drill and ream the arbor hole to 1/8" and then cut out the shape with a jeweler's saw. File and sand to a 600-grit finish. The contact point should have a sharp edge to prevent slippage in the maintaining wheel teeth.

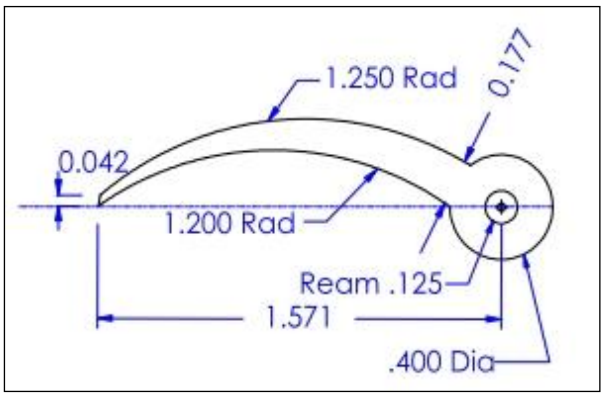


***Figure 135:** Construction drawing of the maintaining pawl. Material is 1/8" mild steel.*

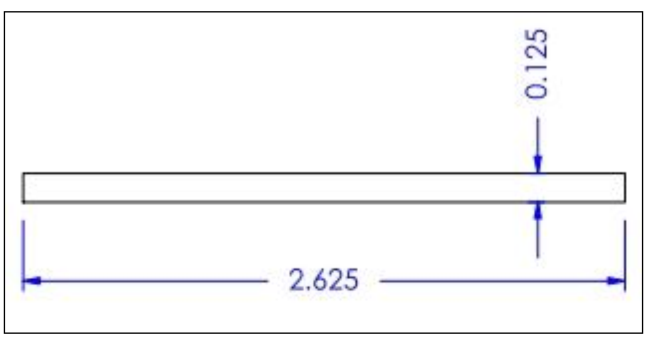


***Figure 136:** Construction drawing for the maintaining pawl arbor. This is simply a straight length of 1/8" diameter music wire.*

The arbor is a length of 1/8" diameter music wire cut to a length of 2.625". Note that this length is not long enough to pass completely through the plates; and that is intended. Rather than reduce the ends to form pivots or install collars on each end to hold the arbor in place, the pivot holes will not be drilled through. This provides a strong pivot without an unsightly hole on the outside of the plates. More on this later; first the arbor location must be determined.

The maintaining pawl rides across the ratchet teeth of the maintaining wheel and drops into place by its own weight. The ratchet teeth are rather shallow and have a slight undercut. Therefore, the maintaining pawl must be positioned so there are not any forces that would tend to push the pawl out of the ratchet tooth. At the same time, the pawl should not be so far from the wheel that excessive force is created on the arbor. A CAD drawing is used to determine a suitable arbor location. Previously created scaled drawings of a section of the plate, maintaining wheel, great wheel and the pawl are combined in Figure 137. Thick red construction lines are drawn through the center of the pawl and perpendicular to the point of the pawl. The pawl and these construction lines are then maneuvered into place such that the perpendicular line falls close to and slightly to the right of the center of the maintaining wheel arbor as shown. If the line falls to the left of center, there will be an upward force on the pawl that will tend to push it out of the ratchet tooth. This would happen if the pawl is too long or the arbor is located too close to the maintaining wheel. If the pawl is too short or the arbor is located too far from the maintaining wheel, the line will fall farther to the right. Although this would create more force to hold the pawl in the ratchet tooth, unnecessary force would also be created on the arbor, possibly bending it.

Make a light scribe mark on the inside of each plate at the location shown in Figure 137. Remember to offset in the opposite direction when locating the front plate, as it will be reversed from the figure. Figure 138 is provided as an additional reference. Clamp a plate in the drill press and set the depth stop to drill a 1/8″ deep hole with a 1/8″ diameter bit. You may wish to test with a piece of scrap to make sure the drill tip does not penetrate the outside of the plate. Replace the drill bit with a 1/8″ end mill. Turn the drill press by hand and feed into the drilled hole until the bottom is cut flat. Repeat for the other plate. Install the plates, pillars and maintaining pawl arbor. Verify the arbor has approximately 1/64″ end shake and the arbor spins freely in the holes. It is not necessary to burnish or polish the pivots or holes since the arbor does not rotate.

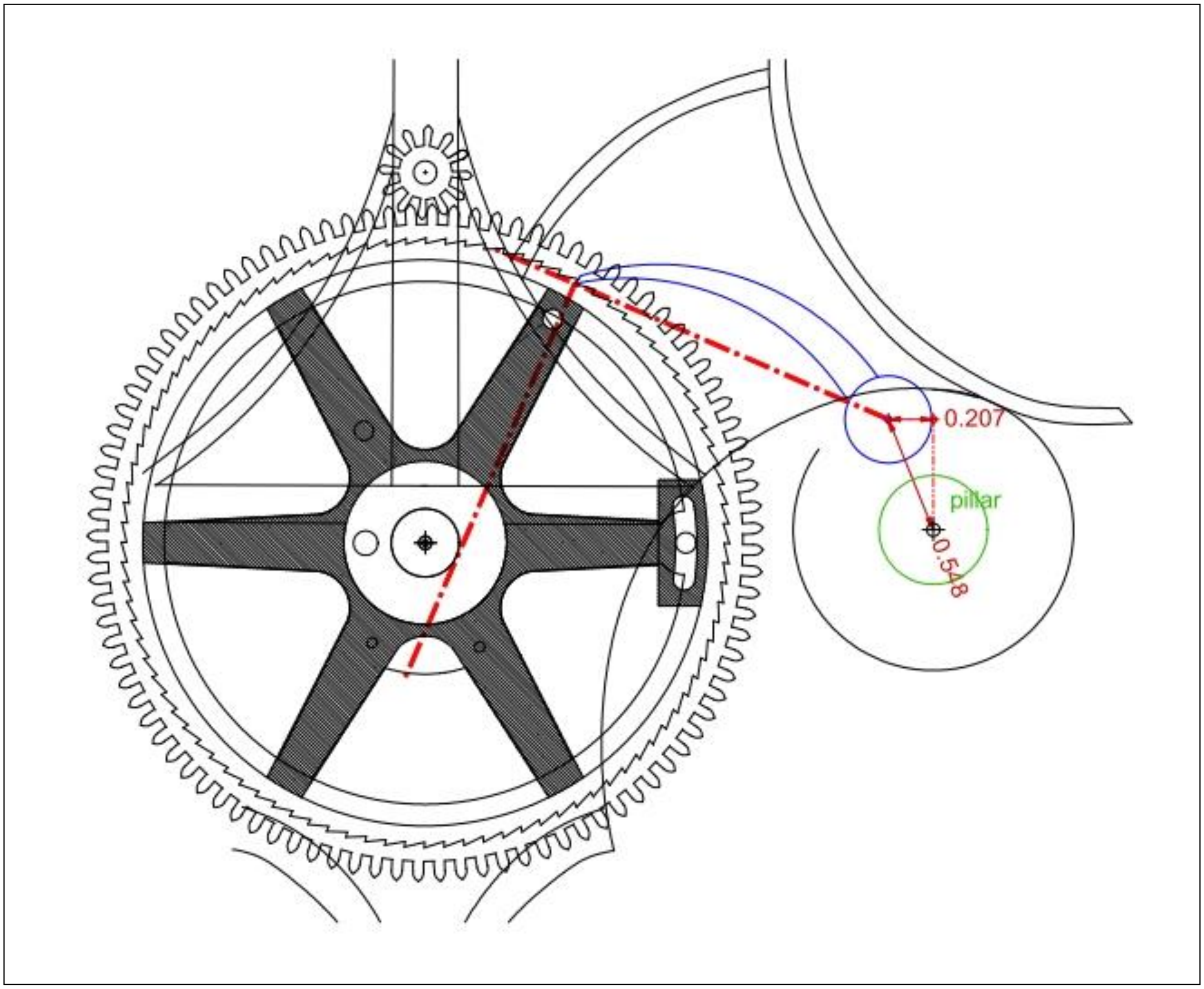


Figure 137: *Drawing used to locate the maintaining pawl arbor. Dimensions are taken from the center of the pillar, represented by the green circle.*

Figure 138: *Location of the maintaining pawl arbor pivot holes. The back plate is on the left; the front plate is on the right. The pivot holes are not drilled through. The through holes shown above the pivot holes where used for reference and will serve as access holes for cutting out the inner sections with the jeweler's saw.*

The maintaining pawl can now be installed on its arbor between the plates with the fusee, maintaining wheel and great wheel in place. The pawl should drop smoothly into each ratchet tooth as the maintaining wheel is rotated counterclockwise. Verify that the pawl stays securely in the tooth when the wheel is rotated clockwise.

The pawl will be fastened to the arbor with Loctite after final polishing is complete.

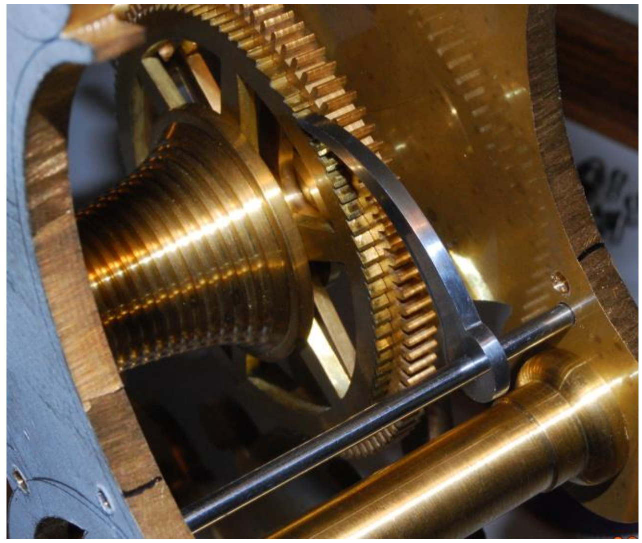


Figure 139: *Testing the maintaining pawl. The arbor should move without any binding since gravity is the only force used to keep the pawl in contact with the maintaining wheel ratchet teeth.*

A Pinwheel Skeleton Clock

7 - Motion Works

Introduction

The motion works often goes unnoticed but provides several critical functions. The most obvious purpose is to divide twelve rotations of the minute hand into 1 rotation of the hour hand. It also provides a clutch mechanism that allows the hands to be moved to set the time without disrupting the time train. And in this clock, it also divides 4 rotations of the third wheel into one rotation of the minute hand.

Design

This clock uses the traditional English design of developing the 12:1 gear reduction with a single set of gears coupled together with two intermediate wheels of the same tooth count. The motion works uses 0.5 module wheels and pinions to keep the size of the wheels small. An 8-leaf pinion drives a 96-tooth wheel to obtain the 12:1 reduction. The pinion and wheel have a combined pitch circle diameter (PCD) of 2.047 inches. The intermediate wheels must have the same combined PCD. Two 52-tooth wheels have a combined PCD of 2.048 inches, which is entirely sufficient. It is also convenient that 52 is divisible by 4 and can be used to reduce the drive train as required. Unfortunately, the resulting 13-leaf pinion is rather nonstandard but only a minor inconvenience.

A side view CAD drawing helps to understand how the parts fit together. From this drawing, each component can be detailed.
When constructing the motion works, many of the dimensions depend on the fit of another part. The order of construction provided here will provide the parts in the order needed to build the next.

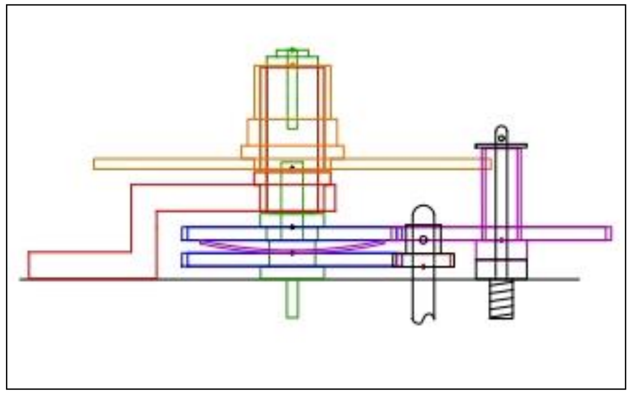


Figure 140: *Assembly drawing of the motion works. Components are color-coded by function. One of the intermediate wheels and 8-leaf pinion are not shown. There are two intermediate wheels shown, separated by a spring (purple curved object) which serves as the clutch.*

Hour Pipe

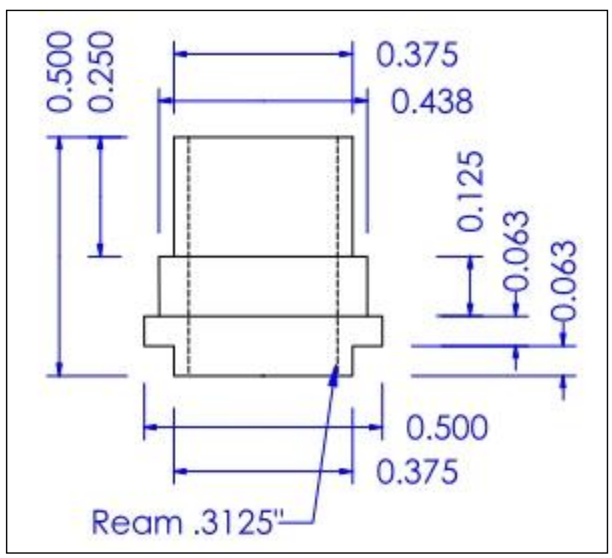


Figure 141: *Construction drawing for the hour pipe.*

The hour pipe and wheel are shown in orange in Figure 140. As the name implies, this pipe will carry the hour hand. Start with 1-inch length of ½″ diameter brass rod centered in the 4-jaw chuck with a ¾″ length exposed. Face the end and make light cleanup pass for a length of ½″. Reduce the diameter to .438″ for a length of 3/8″, then reduce the diameter to .375″ for a length of ¼″. Clean out the corners with a graver or sharp-edge file.

Center and then step drill to 19/64″ to a depth just over ½″. Bore the inside to .313″. A reamer can also be used, but boring will ensure the inside is concentric with the outside. Cut the bottom shoulder to a diameter of .375″ with a parting tool and finish the surfaces that will be exposed (.500″ and .438″ diameter sections) to a 600-grit finish. Finally, part off the pipe to a total length of .500″.

Figure 142: *A graver is used to provide clean, square corners. If these inside corners are left rounded from the lathe tool, binding of the mating part will occur.*

Bridge Pipe

Machining of this part is very similar to the hour pipe with a few exceptions. The hole through the center will likely need to be reamed unless a very small boring bar is available, so care should be taken to ensure the drill and reamer run straight. The upper portion of the pipe should be machined for a nice slip fit inside the hour pipe.

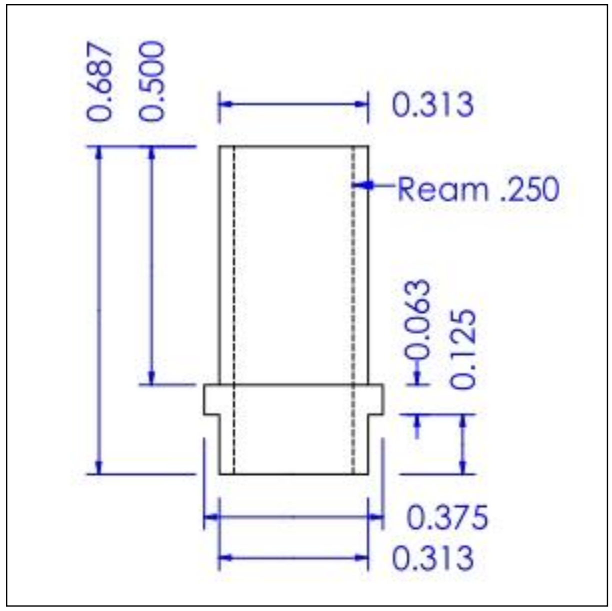


Figure 143: *Construction drawing for the bridge pipe. Material is 3/8" brass rod.*

Minute Pipe

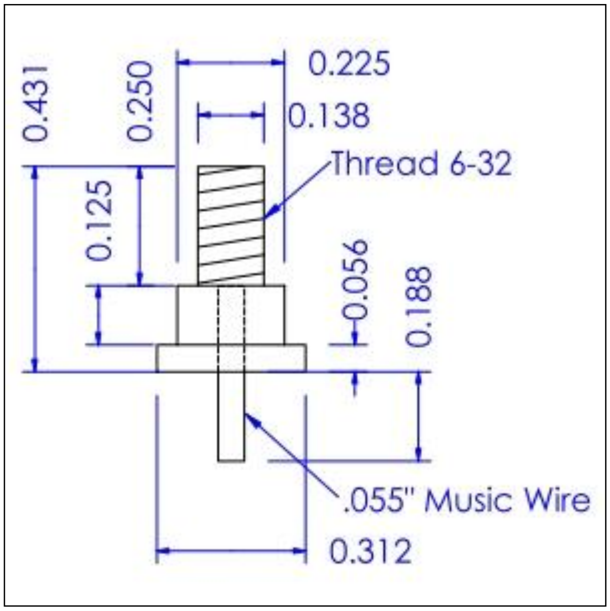


Figure 144: *Construction drawing for the lower section of the minute pipe.*

The minute pipe is made up of two sections, one brass and the other steel. Steel is used to reduce the potential for wear from the clutch and to provide additional strength to support a small pivot wire. This construction technique may be a bit unorthodox, but it allows the components to be easily installed and removed from the clock plate without having to bother with friction fits or set screws. The lower section is made slightly over size first and then brought to its final dimensions when mated to the upper section. A 1″ length of 3/8″ mild steel rod is faced and then reduced to the diameters shown in Figure 144 **except** the larger shoulder is machined to .322″ and the smaller shoulder is machined to .235″. Thread the smallest diameter #6-32. Reverse the die and chase the thread all the way to the shoulder. Part off to a total length of .431″. This part will be machined to its final dimensions after the upper section is complete.

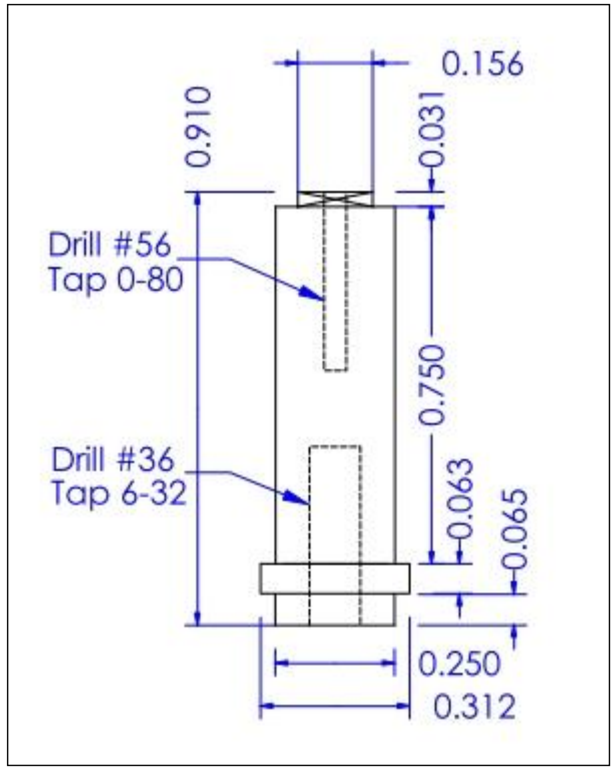


Figure 145: *Construction drawing for the upper section of the minute pipe. Begin with a 1.25" length of 3/8" brass rod.*

The upper portion of the minute pipe is machined for a nice slip fit inside the bridge pipe. The end is drilled #56 approximately 3/8″ deep and tapped #0-80. Flats are milled at the end where the minute hand will be mounted. The flats should measure .156″ across.

Reverse the part and mount it in a ¼″ collet. Face the end to provide the total length of .910″ for the part. Drill #36 approximately 3/8″ deep and tap #6-32.

Screw the lower section into upper section still mounted in the lathe. Tighten with soft jaw pliers and make sure the faces make good contact. It may be necessary to chamfer the threaded hole of the upper section to accommodate any partially completed threads on the lower section. Face the lower section, removing only enough material to make it run true. Take light cuts to bring the larger steel shoulder to its final diameter of .312″. Use a parting tool to true up the inner shoulder to .225″. Drill #55, (.052″) to a depth of .18″. Sand both steel shoulders and face to a 600-grit finish or better.

Slightly taper the end of a ½″ length of .055″ music wire until it fits approximately .1″ into the hole with finger pressure. Tap the wire into final position with a small hammer. Loctite can be used if the drill made the hole oversized. Trim the wire to .188″ length and verify the wire runs straight. Sand and polish the wire to 1500-grit finish or better as this will be a rotating pivot. It is not necessary to burnish the wire since the pressure on the motion works is negligible.

Figure 146: *From left to right are the hour, bridge and minute pipes along with a side view of the bridge.*

This completes the work on the pipes. Very little of these parts will be visible after final assembly and the surfaces that do show will be polished at a later time.

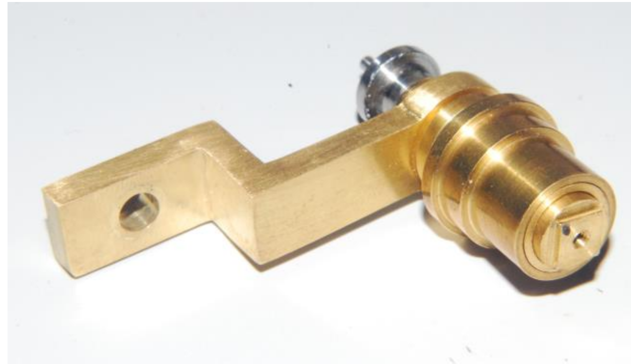


Figure 147: *The pipes are temporarily assembled to show how they stack up. Note the minute pipe extends slightly past the hour and bridge pipes so the hands will clear each other as they rotate.*

Bridge

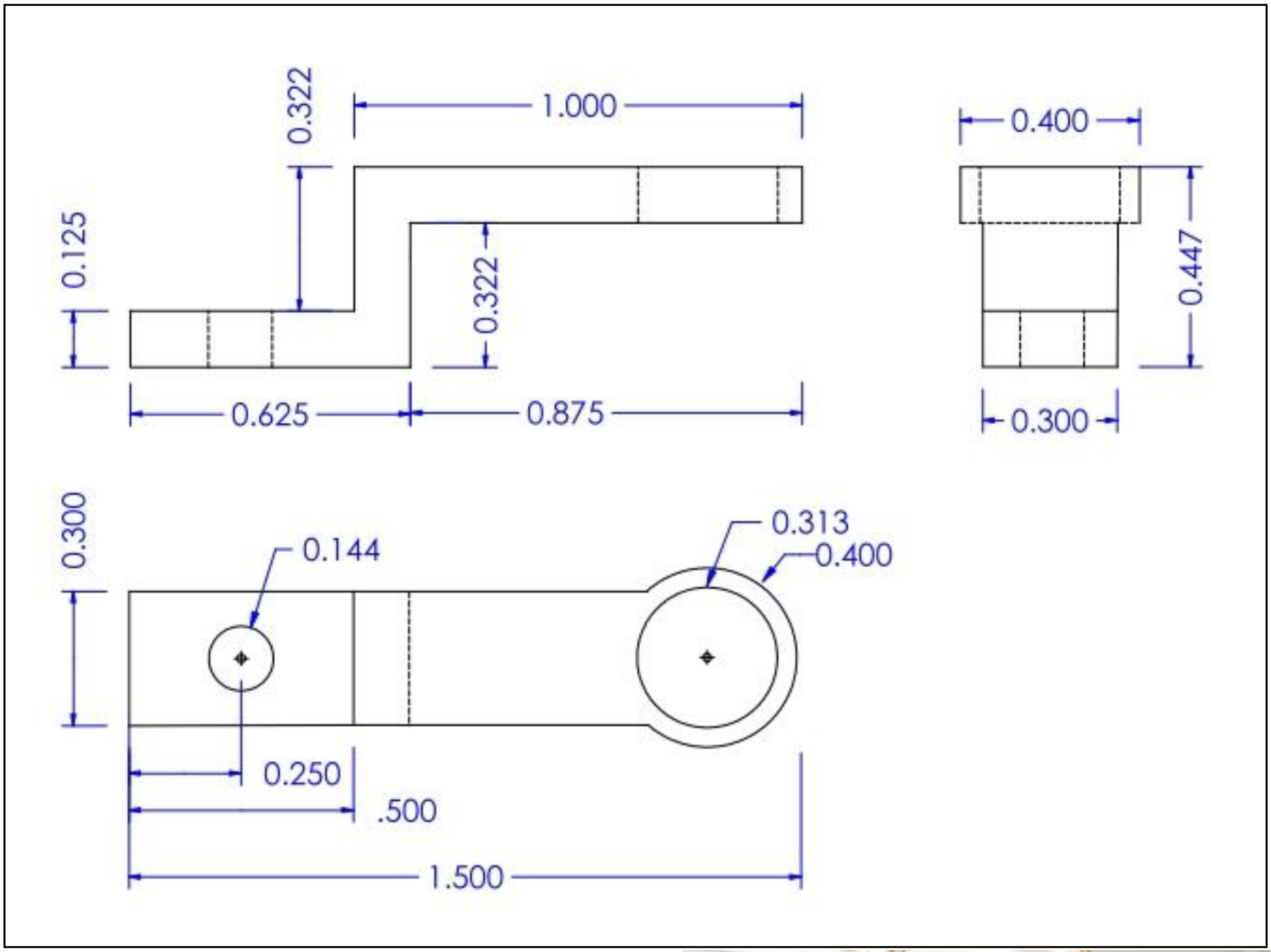


Figure 148: *Construction drawing for the bridge.*

At the beginning of this document, I stated that a Taig lathe was used as the primary tool for constructing this clock. However, a Benchmaster milling machine has since been added to the shop and this is a prefect application for its use. For those who do not have a milling machine, the bridge can easily be sawn and filed by hand or milled on the lathe.

Figure 149: *This Benchmaster mill was built in the 1950's and recently restored by the author. It also converts to a horizontal mill. Although considered a small mill, at 260 pounds, it is massive compared to the Taig lathe.*

The material for the bridge is ½″ square brass bar. Although less than 2″ is required, the material list calls out a 3″ length. This provides extra material to hold the part during machining.

The brass bar is clamped in the milling vise and a pass is taken across the end to square it up. Multiple passes are then made until the thickness is reduced to 1/8″ for a length of 7/8″. The stock is extended slightly and a .053″ cut is taken across the top to reduce the high of the bridge to .447″ as shown in Figure 148.

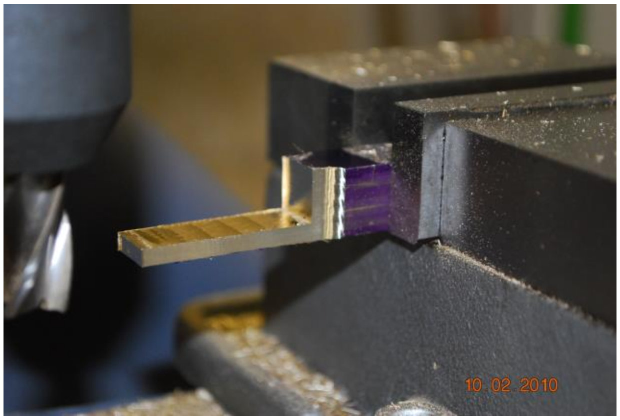


Figure 150: *Milling the long arm of the bridge. Several passes are used to remove the material rather than a single heavy cut due to the amount of overhang.*

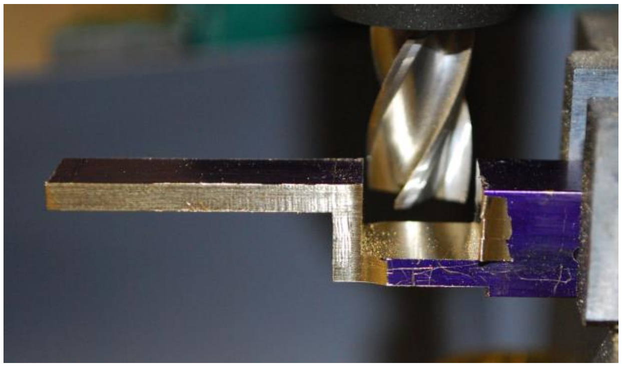


Figure 151: *Milling the short arm of the bridge. Several shallow cuts at the full width of the ½" cutter are made until the short arm is .125" thick.*

The stock is then turned upside down and several cuts are taken until the thickness of the short arm is .125″ for a length of ½″ as shown in Figure 151. Turn the stock once again and take a .1″ deep cut down each side to reduce its width to .3″ except for the last ½″ of the long arm. The bridge is then removed from the stock with a jeweler's saw and the rounded end of the long arm is filed to shape.

A .144″ diameter hole is drilled in the short arm with a #27 drill bit to pass a 6-32 screw. This screw was made in the previous section as it is the same as the fuse iron mount screw. The .3125″ hole in the long arm should be reamed for a close fit of the bridge pipe. The bridge is filed all over and sanded to a 600-grit finish. It is now time to move on to the wheels and pinions.

Hour Wheel

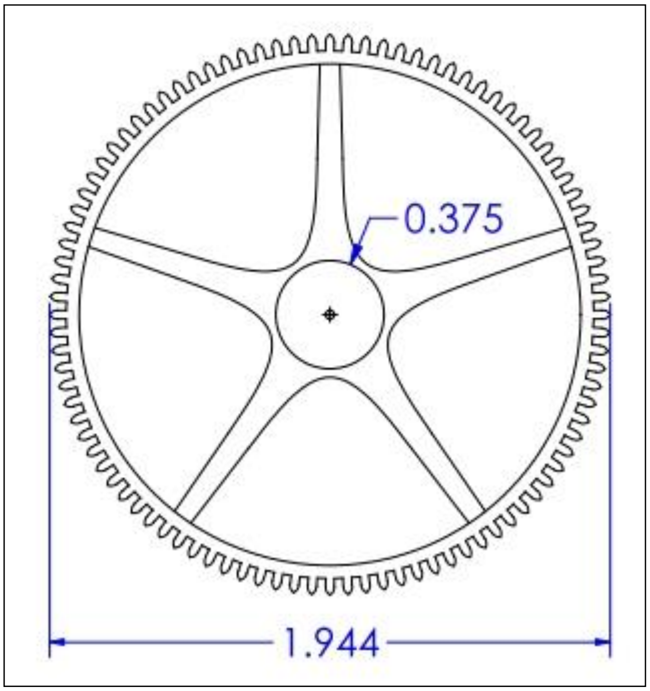


Figure 152: *Construction drawing of the hour wheel. Material is 1/16" thick leaded brass.*

Construction of the 96-tooth hour wheel is identical to the time train wheels except the teeth are .5 module. The center hole is bored as shown in Figure 153 for a tight fit on the hour hub. The wheel will be fastened to the pipe with Loctite after final polishing.

***Figure 153:** Boring the center hub of the hour wheel. This method described in J.M. Huckabee's book "Top 300 Trade Secrets of a Master Clockmaker," uses a block of wood in which an insert is trepanned into the face. Since the face and edge are cut in place, they run perfectly true. The wheel is a friction fit around the edge and light cuts are taken while boring the center hole to the required size.*

Intermediate Wheels

The intermediate wheels can all be cut at the same time. The initial center hole of all three wheels should be .191″ to fit the intermediate pinion. One wheel is then bored to .225″ to fit the lower minute pipe and the other wheel is bored to .250″ to fit the upper minute pipe. The wheels on the upper minute pipe and intermediate pinion will be fastened with Loctite after polishing. The wheel for the lower minute pipe will be a slip fit to allow it to rotate as part of the clutch. The intermediate wheels are not crossed out. However, the wheel mounted to the intermediate pinion and minute pipe wheel will be visible behind the dial so they are given a concave surface to add visual appeal.

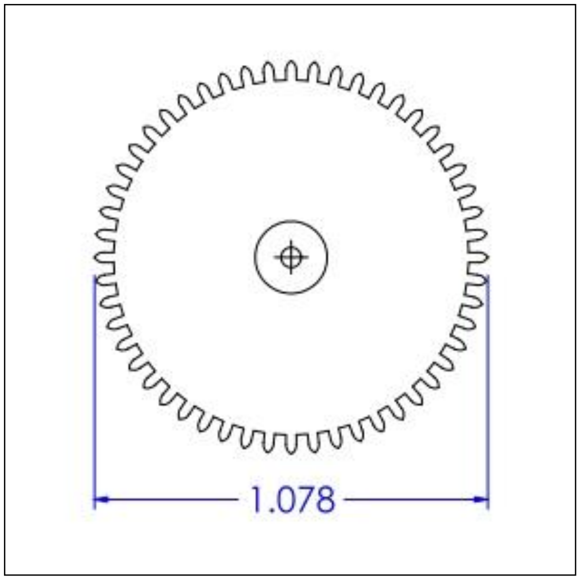


***Figure 154:** Construction drawing of the intermediate wheels. Three wheels are required and each has a different hub diameter. These wheels are not crossed out. Material is 1/16" thick leaded brass.*

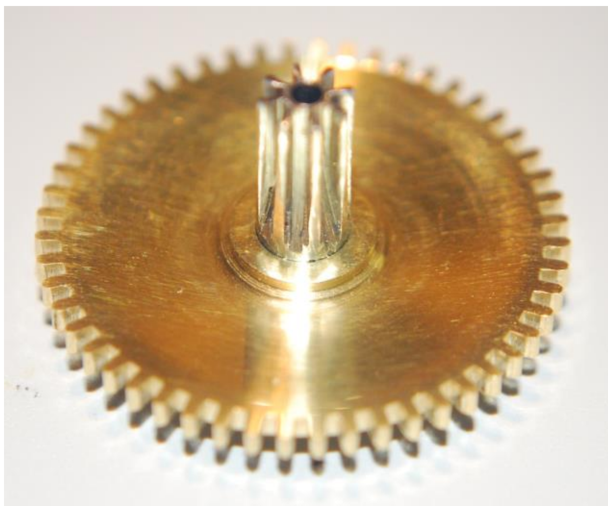


***Figure 155:** The intermediate wheel and pinion.*

Spring

The canon spring fits between the two minute wheels and provides just enough friction to keep the wheels from slipping yet allows the minute hand to easily turn when setting the time. A piece of .015″ thick brass is hammered to work-harden it and make it springy. The part is marked out and drilled before cutting the outside shape to allow extra material to clamp while drilling.

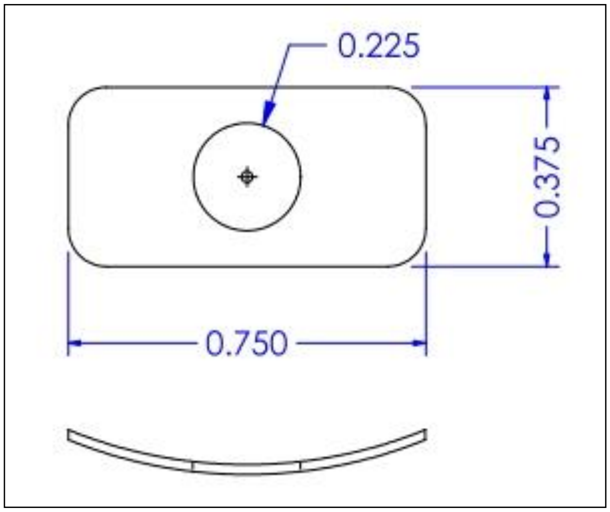


Figure 156: *Construction drawing of the canon spring. The spring is made from .015" sheet brass.*

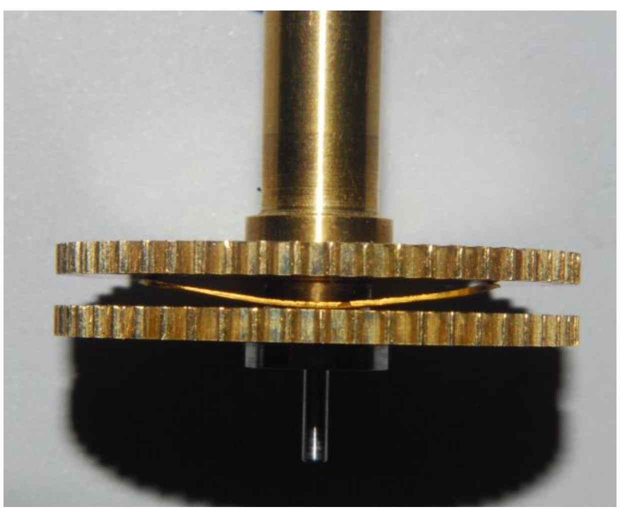


Figure 157: *The canon spring installed between the minute pipe wheels.*

The hole is drilled #2 and then filed for a slip fit on the lower section of the minute pipe. The outline is then cut with tin snips and filed to its final shape. Smooth all surfaces of the spring with sand paper and then bend the curve as shown in Figure 156.
Install the spring on the arbor between the minute pipe wheels as shown in Figure 157 and adjust the curve of the spring so the lower wheel slips easily.

Drive Pinion

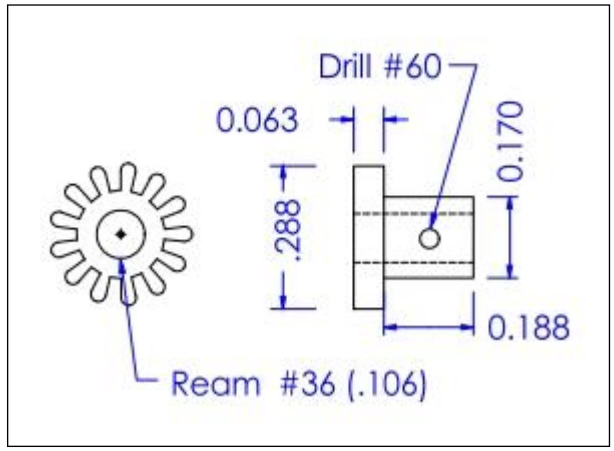


Figure 158: *Construction drawing for the drive pinion.*

The drive pinion is made from a 1″ length of 3/8″ brass rod. Reduce the outside diameter of the rod to .288″ and cut 13 teeth with a fly cutter. Cutter dimensions for a 13-tooth pinion are not commonly found but a cutter for a 12-tooth pinion will work just fine. The teeth should be 1/16″ thick to match the intermediate wheels. Center drill and ream the center hole to .106″ for a slip fit on the third wheel arbor. Reduce the diameter of the hub section to .170″ for a length of .188″ and then cross-drill a #60 (.040″) hole through the hub for a taper pin that will be used to fasten the drive pinion to the arbor.
Polish the hub and face of the pinion to a 600-grit finish and part off to a length of .250″. The pinion will be fitted to the arbor in a later step.

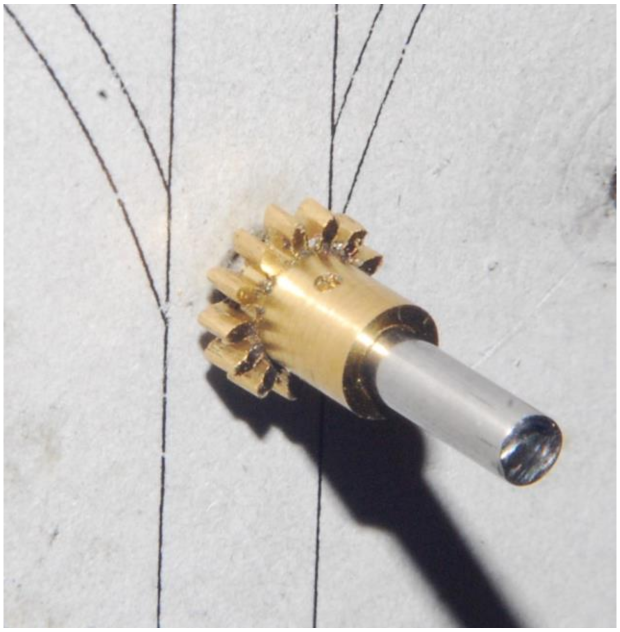


Figure 159: *Drive pinion temporarily installed on the 3rd wheel arbor. The arbor will be trimmed to length after the pin location has been marked and drilled.*

Intermediate Pinion

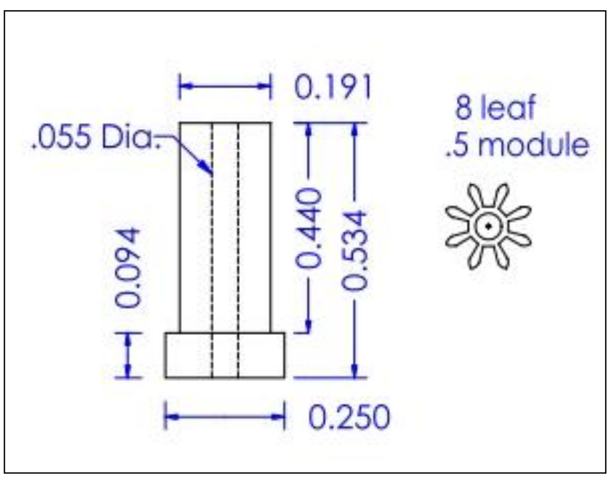


Figure 160: *Construction drawing of the intermediate pinion.*

The intermediate pinion is made from ¼″ mild steel rod. Install a 1″ length in a collet with approximately ¾″ protruding. Face the end and take a light cleanup pass across the diameter. Reduce the diameter to .191″ for a length of .440″.

A tiny .5 module fly cutter will not likely survive cutting a steel pinion even when using mild steel, and a multi-tooth cutter takes quite a bit of time to make. Instead, a rather unorthodox method is used to cut the intermediate pinion teeth. Similar to the time train pinions, 8 slots are cut to a depth of .054″ with a .025″ thick slitting saw. The saw is advanced 3/8″ after it first contacts the edge of the pinion. The teeth are then brought to their final shape using the same Cratex abrasive wheels that were used to polish the time train pinions. Only light pressure is needed to shape the teeth as the Cratex wheels cut the mild steel very easily.

After the teeth are formed, drill the center hole to a diameter of .055″. Sand the exposed surfaces to a 600-grit finish and part off the pinion to a length of .534″ as shown in Figure 160. The finished pinion is shown in Figure 167.

Intermediate Arbor

The intermediate arbor is made from two pieces that will simplify several aspects of construction.

The base is made from a section of 3/8″ mild steel. After facing the end, reduce the diameter to .112″ for a length of .188″ and thread #4-40. Reverse the die and chase the threads all the way to the shoulder. A graver may also be used to clean out the corner to allow the shoulder to sit flat when the arbor is installed on the plate. Drill the .055″ center hole approximately 3/8″ deep.

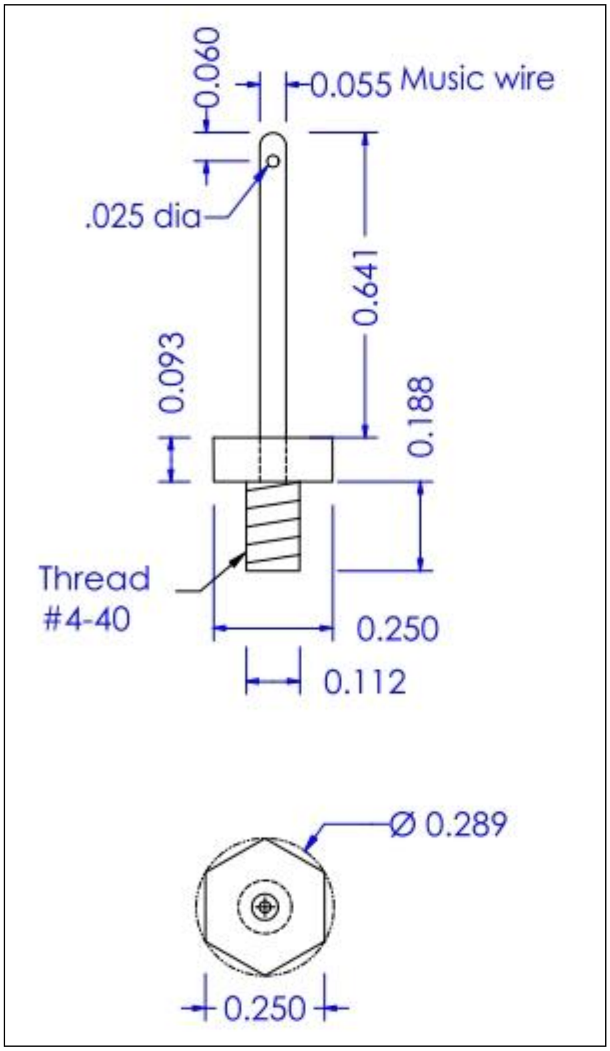


Figure 161: *Construction drawing of the intermediate arbor.*

The shoulder is machined to a hex shape so the arbor can be installed on the plate with a standard ¼″ socket or wrench. This is accomplished using the same setup used to cut the winding arbors for the fusee and mainspring.

The arbor shoulder diameter is reduced to .289″ for approximately 1/8″. The flats are then cut using the setup shown in Figure 162. Verify that the distance across the flats is .250″.

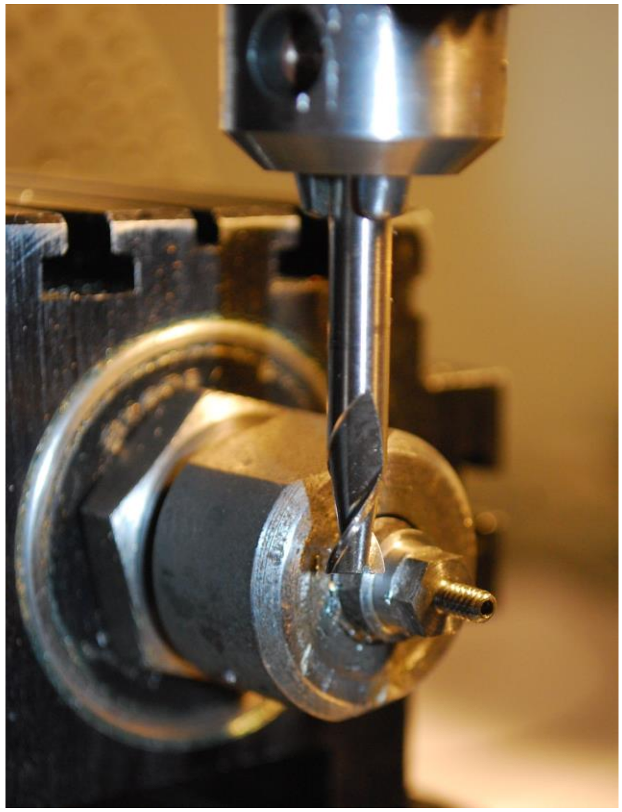


Figure 162: *Milling the flats on the intermediate arbor. An index plate mounted on the other end of the headstock provides the 6 divisions required. Note a drill chuck is used to hold the end mill since the collet assembly was in use holding the work piece.*

Part off the arbor so the hex shoulder is approximately 1/8″ thick. This is greater than the .093″ dimension shown in Figure 161 to allow the height of the intermediate wheel to be adjusted later.
The sides of the hex shoulder are sanded and polished to remove the tooling marks from the end mill. This can be done by hand, but it is much easier with the setup shown in Figure 163.

Music wire is used for the intermediate arbor shaft. Drill rod can also be used if the required diameter is available. A 1.25″ length is chucked in the lathe and the end is rounded with a Dremel grinding wheel while the wire is slowly rotated. Approximately 1″ of the wire is then polished to a 1500-grit or better finish.

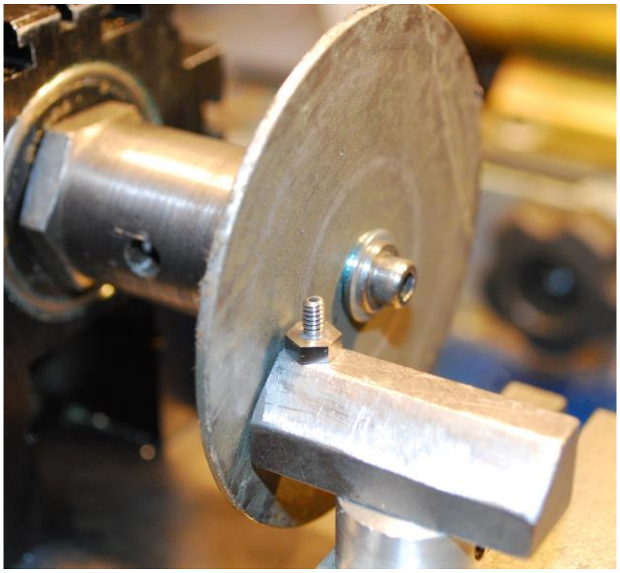


Figure 163: *A disk with 400-grit sandpaper is mounted in the lathe for polishing the hex head of the intermediate arbor. A steady rest holds the part at center height while the part is applied to the wheel by hand.*

Remove the wire from the lathe and cross-drill a .025″ hole approximately .060″ from the rounded end. It will be necessary to use a carbide drill bit to penetrate the music wire and carbide bits in this size break very easily. A micro-sized drill press is invaluable when drilling holes this small. Do not trim the wire to length yet.

Washer

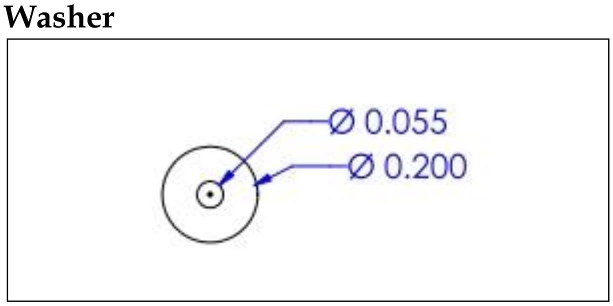


Figure 164: *Construction drawing for the intermediate arbor washer. The thickness is .015″*

A washer is required between the taper pin and the intermediate pinion. A short length of ¼″ brass rod is placed in a collet and the center drilled to .055″ to a depth of approximately 1/8″. Reduce the outside diameter to .2″ for a short distance and then part off the washer to a thickness of .015″. Sand the washer to a 600-grit finish.

A taper pin is required that will fit the .025″ cross-hole of the music wire shaft. The pin can be made from mild steel wire ground to the shape with a Dremel cutoff wheel. A dimensioned drawing is not provided for this simple part.

Final Assembly and Adjustments

Now that all of the parts are complete, the motion works assembly can be fitted to the plate. Several adjustments and dimensions will be determined by test fitting the parts.

Determine the spacing between the third arbor and the minute pipe pivot by installing an intermediate wheel and the drive pinion in the depthing tool. Transfer this dimension to the front plate placing the minute pipe pivot between the 3rd and 4th arbors. Drill the hole undersize and broach it to its final diameter.

Next the bridge location is determined. Assemble the plates and pillars with the 3rd arbor installed. Place the drive pinion on the arbor and install the intermediate wheels and spring on the minute pipe and insert the assembly in the hole just drilled. Place the bridge pipe in the bridge and slip this assembly over the minute pipe. While holding the short arm of the bridge against the plate near the 4th arbor, verify there is a very small amount of end shake between the minute and bridge pipes. At the same time, verify the position of the bridge allows the minute pipe arbor to turn freely and the lower intermediate wheel meshes properly with the drive pinion. Transfer the location of the bridge mounting hole to the front plate. Position the drive pinion on the 3rd arbor so the teeth are the same height as the lower intermediate wheel as shown in Figure 165. Transfer the position of the drive pinion mounting hole to the 3rd arbor. Disassemble the plates and drill the 3rd arbor with a #60 bit for a taper pin. Trim the end of the arbor so it is flush with the drive pinion.

Drill the bridge mounting hole in the plate with a #36 bit and tap the hole #6-32.

To mount the intermediate arbor, determine the spacing between the wheels on the minute pipe and the intermediate wheel with the depthing tool. Transfer this measurement to the appropriate location on the front plate. Drill the hole with a #43 bit and tap it to #4-40.

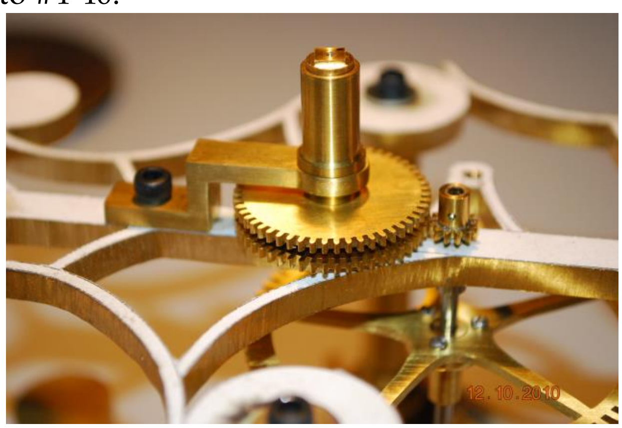


Figure 165: *This photo shows the bridge mounted to the plate and the drive pinion slipped over the 3rd arbor. The top of the clock is to the left. Note the plate has been completely cut out, but it is wise to locate the intermediate arbor first just in case it needs to be relocated for proper depthing. Also note the small arm of the bridge will require a notch where it slightly overhangs the 4th arbor pivot hole.*

Install the intermediate pinion and wheel as shown in Figure 168 to align the height of the wheels. Since the hex shoulder was initially left thick, the intermediate wheel can be lowered to the correct alignment by removing material from the top of the hex shoulder. When the wheels align, polish the top of the hex shoulder, as it will be a bearing surface.

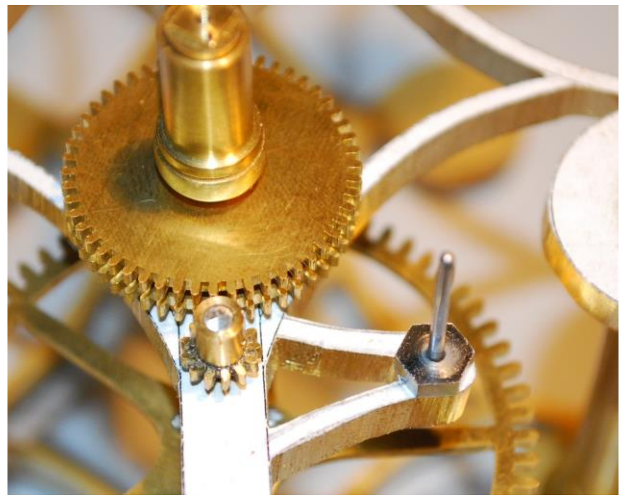


Figure 166: *Location of the intermediate arbor. The plate was cut out after the hole was drilled and tapped.*

With the hex base finished, the shaft length can now be determined. Clean the end of the shaft and hex base hole with acetone. Install the intermediate pinion, washer and taper pin on the shaft as shown in Figure 167. Apply Loctite to the end of the shaft and insert it into the hex base. After the Loctite sets, the extra length of shaft protruding through the base can be trimmed off with a Dremel cutoff wheel. Use care not to get the parts hot or the Loctite bond will be broken.

Figure 168 shows the entire motion works assembly with the exception of the hour pipe. The bridge pipe and fixed intermediate wheels will be permanently attached after final polishing is complete.

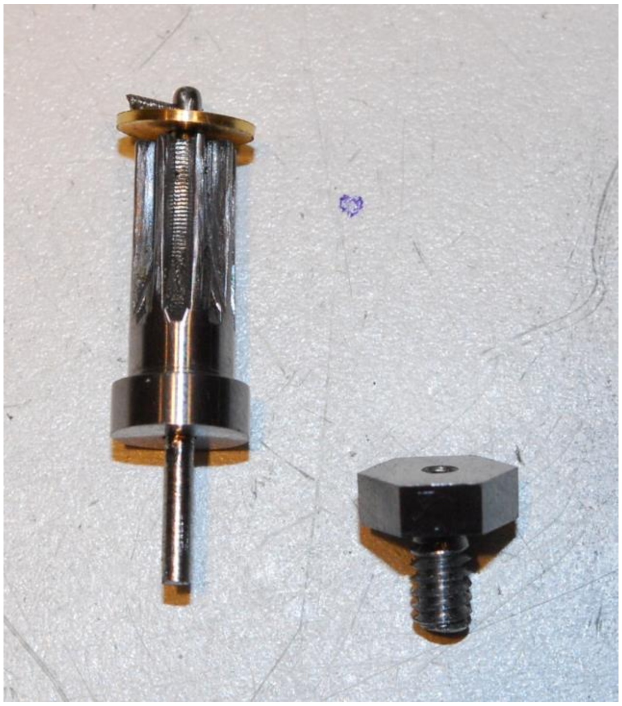


Figure 167: Determining the length of the intermediate arbor shaft.

***Figure 168:** The intermediate wheel and pinion is installed to show the layout of the motion works.*

A Pinwheel Skeleton Clock

8 - Pendulum

Introduction

This clock is designed for a half-second beat rate requiring an effective pendulum length of 9.78 inches. For proper appearances, the overall length of the pendulum will be approximately 14 inches. To achieve the correct beat rate, the pendulum assembly will be constructed with some weight in the rod and the bob weight will be adjusted to obtain the correct rate via direct measurement.

Although a simple, straight pendulum rod would serve our purpose, a more complex design similar to the original clock is chosen for visual appeal. Standard mild steel and brass are used with the components silver soldered together. Stress on the solder joints is very low, so low temperature (430 Deg F.) 3-4% silver solder is sufficiently strong and easier to work with.

Upper & Lower Sections

The upper and lower sections are constructed of 1/8” thick mild steel plate. They are easily rough cut with a jeweler’s saw and filed to their final dimensions.

One end of the upper section is cross-drilled with a #65 bit for a pin to hold the suspension spring. A .010” wide slot for the spring is then cut in the same end. A fine 2/0 jeweler’s saw blade provides the correct width of cut. The slot for the crutch pin will be located by test fitting the parts together in a later step. The lower section is drilled in one end with a #44 bit to receive the rating rod as shown in Figure 170.

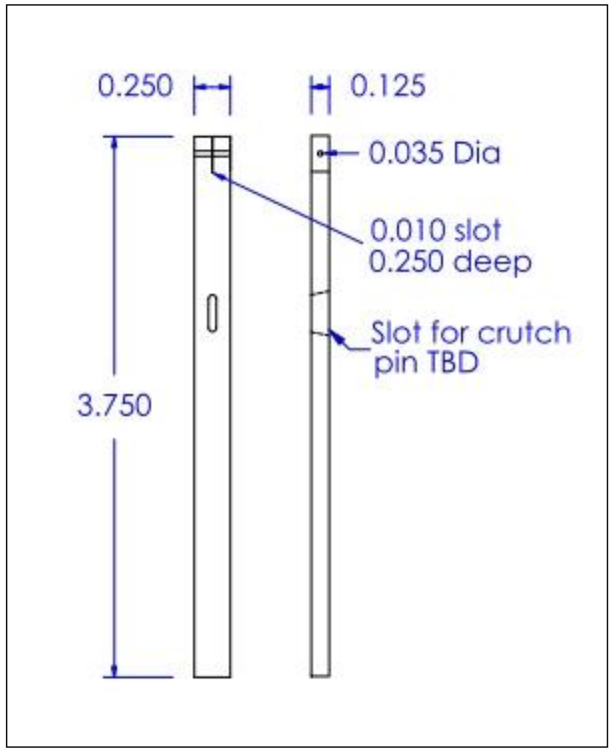


Figure 169: *Construction drawing of the upper section of the pendulum. The location of the slot for the crutch pin is determined by test fit.*

Center Sections

The center sections are shown in Figure 171. Two pieces are required. They are also made from mild steel like the previous sections, except they are 1/16” thick.

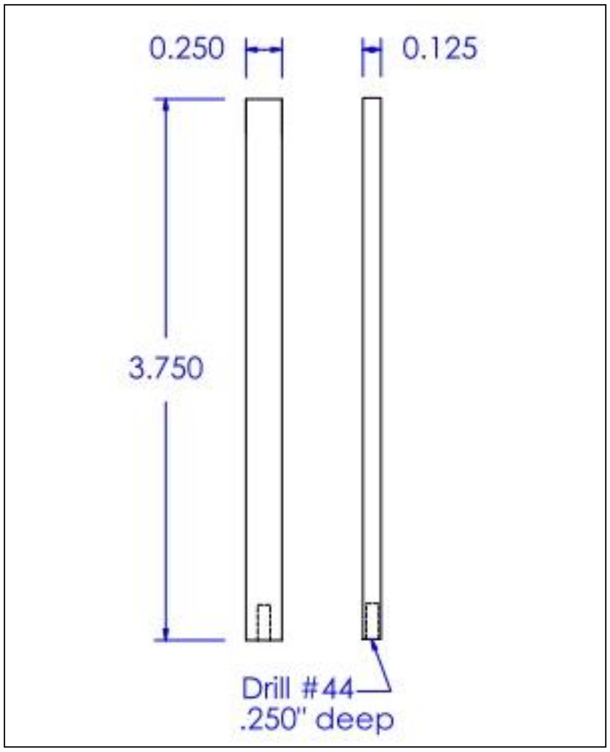


Figure 170: *Construction drawing of the lower section of the pendulum.*

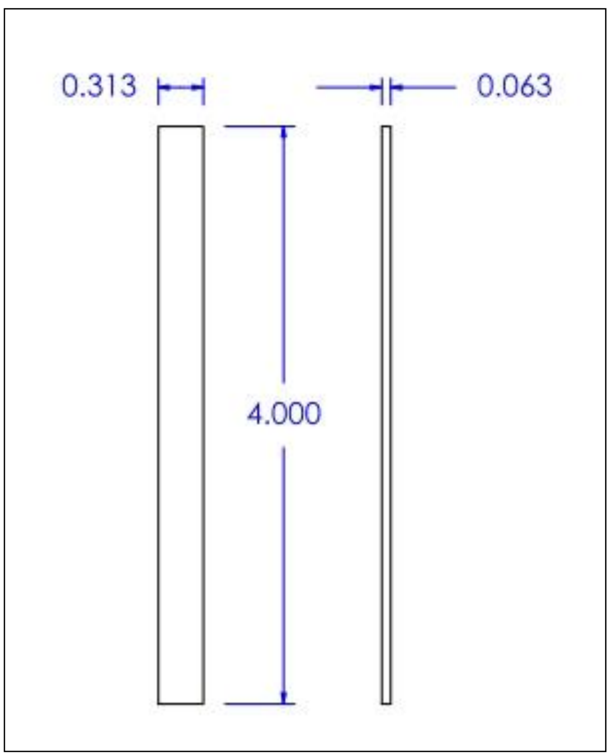


Figure 171: *Construction drawing of the center sections of the pendulum. Two pieces are required.*

Connectors

Figure 172 shows the connectors. Two of these are also required. The connectors are made from scraps of 3/16″ brass left over from the plates. Each piece is cut out with a jeweler's saw and filed to shape. A recess is milled into each connector as shown in Figure 173 to accept the upper or lower and center sections. A ¼″ end mill is used to cut the wide slot for the upper and lower sections and a 1/8″ end mill is used to cut the slot for the center sections.

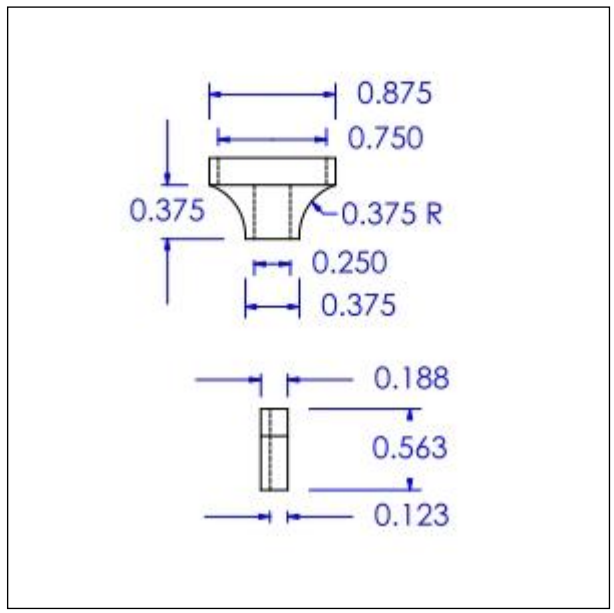


Figure 172: *Construction drawing of the connectors. The material is 3/16" thick brass.*

Figure 173: *The finished connectors. The back is milled out where the steel sections will be soldered.*

Rating Rod

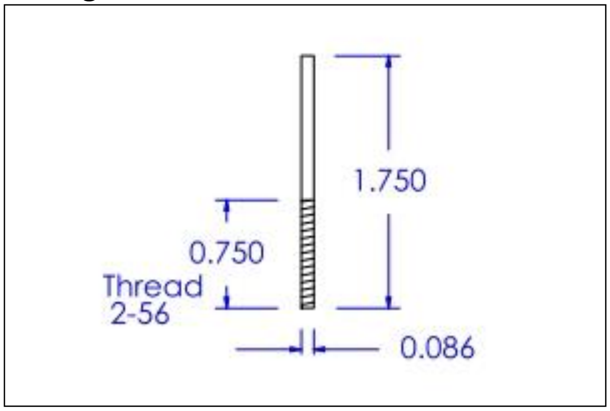


Figure 174: *Construction drawing of the rating rod. The material used is mild steel.*

A length of 1/8″ mild steel rod is reduced to .086″ diameter for the rating rod. The material is held in a collet and machined ½″ at a time close to the collet to reduce flexing. After 1.75″ of rod has been reduced, it is sanded and polished and then threaded #2-56 for a length of ¾″.

Rating Nut

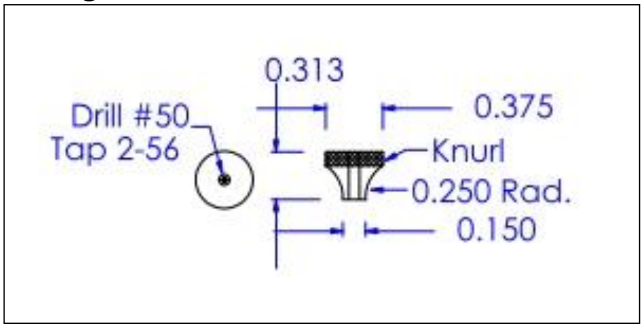


Figure 175: *Construction drawing for the rating nut. The material is brass.*

The rating nut can be made in a variety of shapes for decorative purposes. The nut shown in Figure 175 has a simple ¼″ radius and knurl. A fine knurl should be used to complement the small size of the nut. The nut is drilled with a #50 bit and tapped 2-56. The radius and face should be finished to 600-grit before parting off.

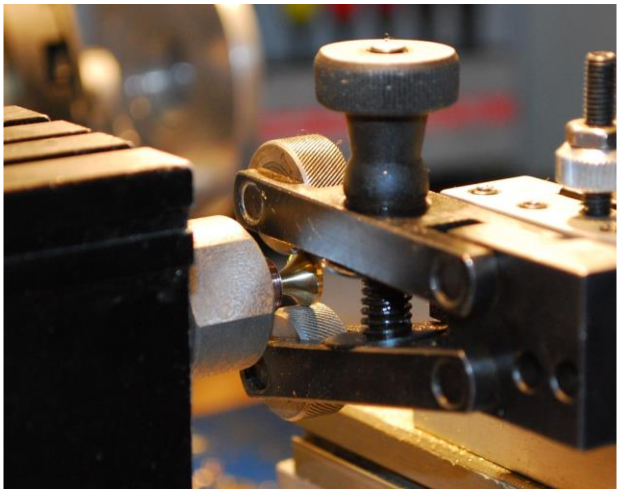


Figure 176: *The radius has been turned on the rating nut and a scissor-type tool is used to cut the knurl.*

Suspension Spring

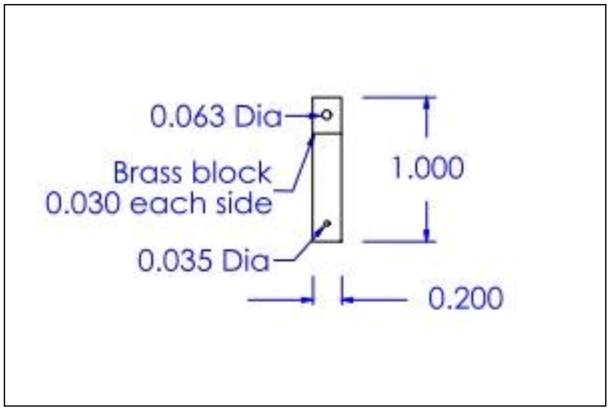


Figure 177: *Construction drawing of the suspension spring.*

The suspension spring is made from .003″ thick blue spring steel. Rather than purchase a large quantity of spring steel, this spring was simply removed from a factory-made suspension rod. Small brass squares are snipped from a .032″ thick sheet, drilled #52 and soldered to one end of the spring as shown in Figure 178. The blocks will be filed to the correct thickness to fit the slot in the suspension bracket.

Figure 178: *Soldering the brass squares to the suspension spring. A stainless steel 0-80 screw is used to align the parts. The alligator clip vise holds the assembly and also presses the parts together when the solder melts.*

The spring is trimmed to length and a new hole is punched as shown in Figure 179.

Figure 179: *The spring will be difficult to drill, but a hole can easily be punched in the thin material using a small punch and plate.*

Assembly

The completed parts are shown in Figure 180. The pockets of the connectors have rounded corners from the end mill. Rather than attempt to square them up, the corresponding corners of the center sections are rounded to fit with a file.

Silver solder is used to assemble the parts. Flux is brushed on the area to be soldered and heat is applied with a small torch like the one shown in Figure 181. Tin each piece with just enough solder to coat the surface. Try to avoid globs of solder, as these will make it more difficult to align the parts. Excess solder can be filed off after the part cools.

Figure 180: *The pendulum parts. The center sections on the left have one corner filed round to fit the slot corner left by the end mill.*

Figure 181: *Silver soldering the pendulum together. Firebricks provide a heat resistant work surface. A scrap strip of metal helps align the parts in a straight line.*

After the parts are tinned, they are placed together, aligned and joined by equally heating both parts until the solder melts. It is often helpful to push the parts together by applying pressure with a screwdriver or piece of scrap metal.

Suspension Bracket

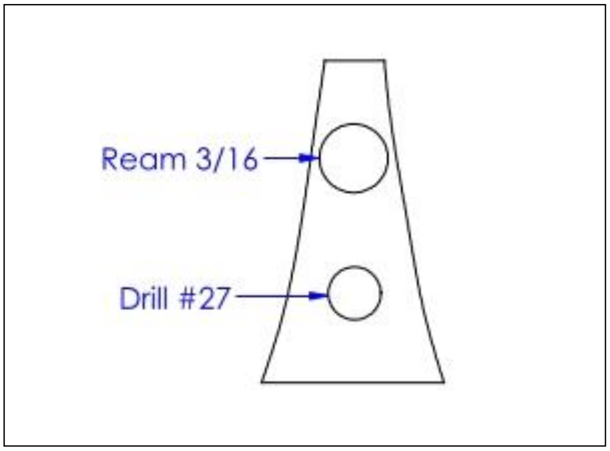


Figure 182: *Construction drawing of the suspension bracket base.*

The suspension bracket base is made from 3/16″ thick brass. Dimensions of the outline are determined by matching the base to the clock plate. The outline can be left oversize and brought to its final shape when the plates are finished. The base needs to be located so that the suspension spring flex point matches the pallet arbor. A 6-32 screw is used to fasten the base to the plate.

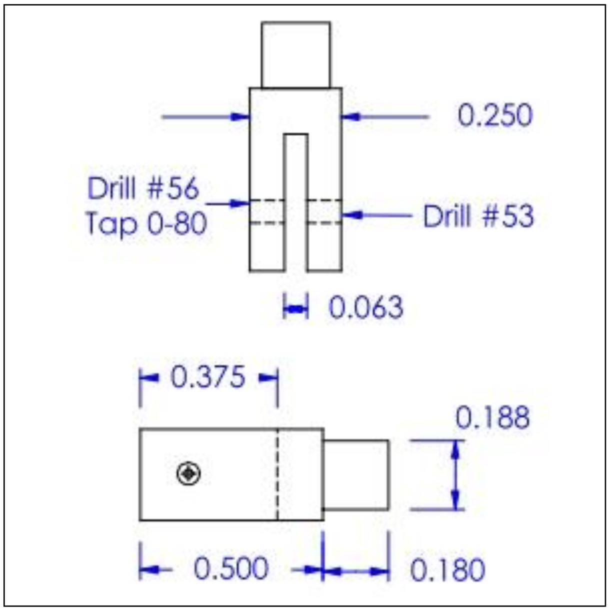


Figure 183: *Construction drawing of the suspension bracket post.*

The suspension bracket post is made from ¼″ square brass. One end is turned for a slip fit into the base that was reamed to 3/16″. The slot is cut 3/8″ deep with a slitting saw as shown in Figure 184. Scraps of brass are used to hold the post in the milling vise. The scraps are cut along with the post.

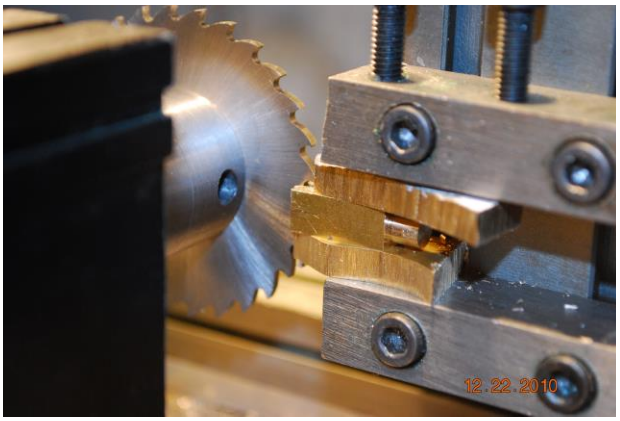


Figure 184: *Cutting the slot in the suspension bracket post. This milling vise uses screws for clamping so scraps of brass are used to provide enough surface area to securely hold the post.*

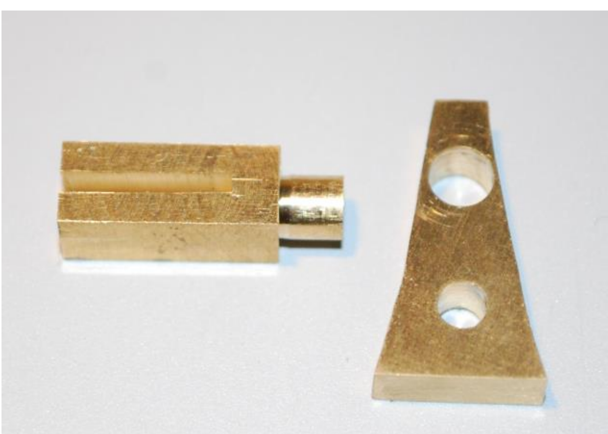


Figure 185: *The suspension bracket post and base. The holes for the spring mounting screw have not yet been drilled in the post.*

After the slot is cut, the holes are drilled for the suspension spring screw. One hole is drilled #56 and tapped 0-80 while the other hole is drilled #53 to clear the screw. The blocks of the suspension spring are now filed to reduce their thickness until the assembly just slips into the post slot. Fasten the post to the base with Loctite 609 after sanding and polishing the parts.

Bob

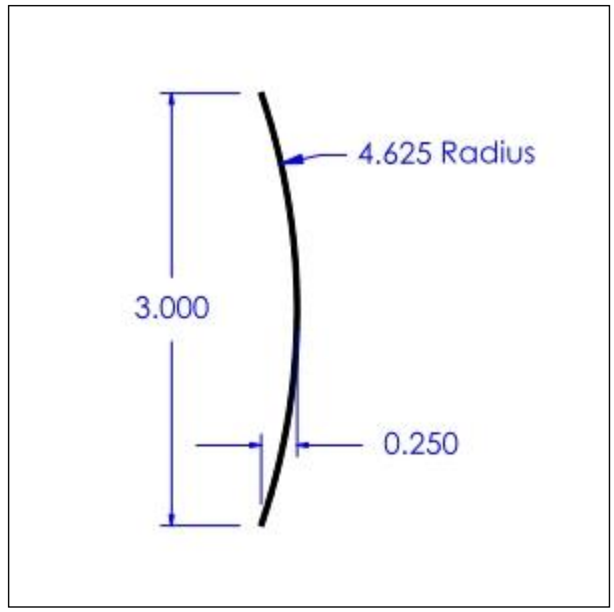


Figure 186: *Construction drawing of the bob profile. The material used is 1/32" brass sheet. The diameter shown is the approximate finished dimension.*

Most bobs are formed by spinning the brass shells on the lathe, but the little Taig is not rigid enough to perform this operation. Instead, the shells are shaped by stamping.

Two disks approximately 3 1/8″ diameter are cut from 1/32″ brass sheet with a jeweler's saw. A wood form is turned on the lathe to the diameter and radius shown in Figure 186. A ¾″ thick piece of oak or other hardwood should be used so that it will stand up to the stamping operation without deforming or splitting. The remaining parts needed as shown in Figure 187 include a piece of scrap metal the approximate size of the form, a scrap of sheetrock (also known as gypsum board or drywall) and a large hammer. The scrap metal is used to distribute the force of the hammer blow evenly across the form. The sheetrock provides a firm surface that deforms and pushes the brass around the form.

Figure 187: *The brass bob shells and tools used to form the shape. The hammer on the right weighs 10 pounds. The scrap metal disk is ½" thick aluminum.*

Figure 188: *The components stacked up for stamping. This work is done on a concrete floor.*

Figure 188 shows the metal, form and brass shell stacked on top of the sheetrock. The stack is struck very firmly with the hammer. The brass shell takes the shape of the form as the sheetrock is dented from the force. It may be necessary to anneal the brass shells and perform the stamping operation several times before the shell fully matches the shape of the form.

After both shells are shaped, the form is remounted on the lathe and the shells are held between it and a live center. Double-sided tape may help hold the shell to the form. Light cuts are taken around the edge to clean up the saw cuts and bring the shells to their final diameter of 3 inches.

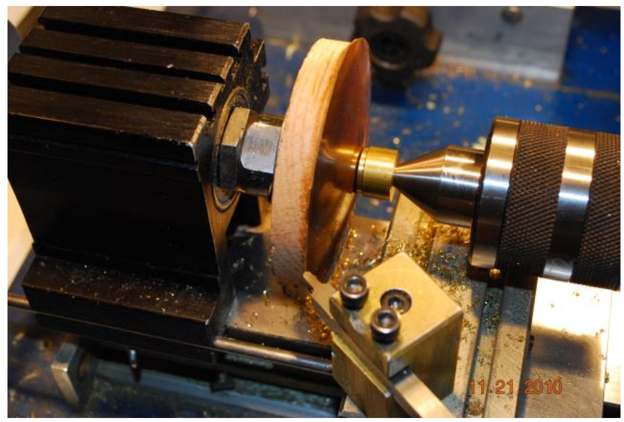


Figure 189: *Trimming the edge of a shell in the lathe. A scrap of brass is placed between the shell and live center to protect the surface.*

Rub the shells with the rounded side up on sandpaper laid flat to remove any burs. The shells are then cut to allow the lower section of the pendulum to pass through. The rating rod is temporarily inserted into the lower section and the assembly is positioned across the center of the shells as shown in Figure 190. A Dremel cutoff tool or files are used to remove only enough material to allow the shell edges to come together. Alternate working on each shell so the pendulum section is centered.

Figure 190: *Cutting the slots to allow the pendulum assembly to pass through the bob.*

Tests are required to determine if weight distribution of the pendulum assembly is correct before the shells are permanently joined. Figure 191 shows the pendulum assembly balanced on the edge of a file to locate its center of gravity. The center of oscillation will be somewhat lower than the center of gravity. The center of gravity was found to be at approximately 9.5" from the flex point of the suspension spring, which looks promising.

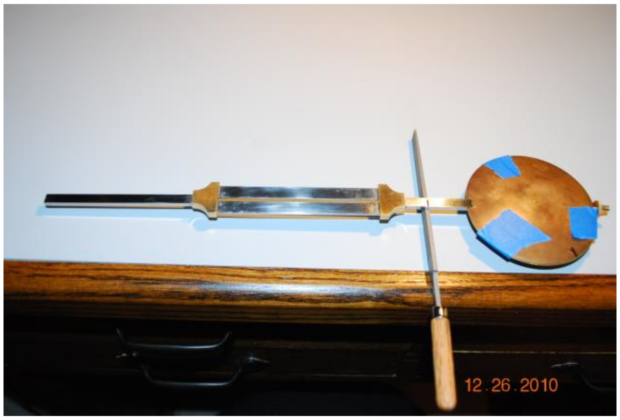


Figure 191: *Locating the pendulum center of gravity. Note the suspension spring is not shown, but should be included in this measurement. The bob is held together with tape for this test.*

As a second test, the suspension bracket and pendulum assembly are mounted to the clock frame and set in motion. The number of swings appears to be approximately 120 beats per minute, but it is difficult to tell without a precision timer. A long duration test will be necessary to determine the exact rate of the pendulum. However, these tests provide an indication that the beat rate of the pendulum will be within the required range without adding any significant weight to the bob.

Since we do not need to make any adjustments to the weight of the bob, the shells can be soldered together. The inside of each edge is fluxed and tinned with silver solder. The shells are then aligned with each other and placed on the firebrick. Figure 192 shows a scrap aluminum disk that was placed under the shells to lift the bob off of the firebrick for easier access to the edge. Another piece of scrap aluminum shown in the upper right of the figure is used to press the shells together while the edge is heated with the torch. After the solder melts, remove the heat and continue pressing the shells together until the solder solidifies. The edge is then filed to shape.

Figure 192: *Setup used to solder the bob shells together.*

Adjustable Crutch

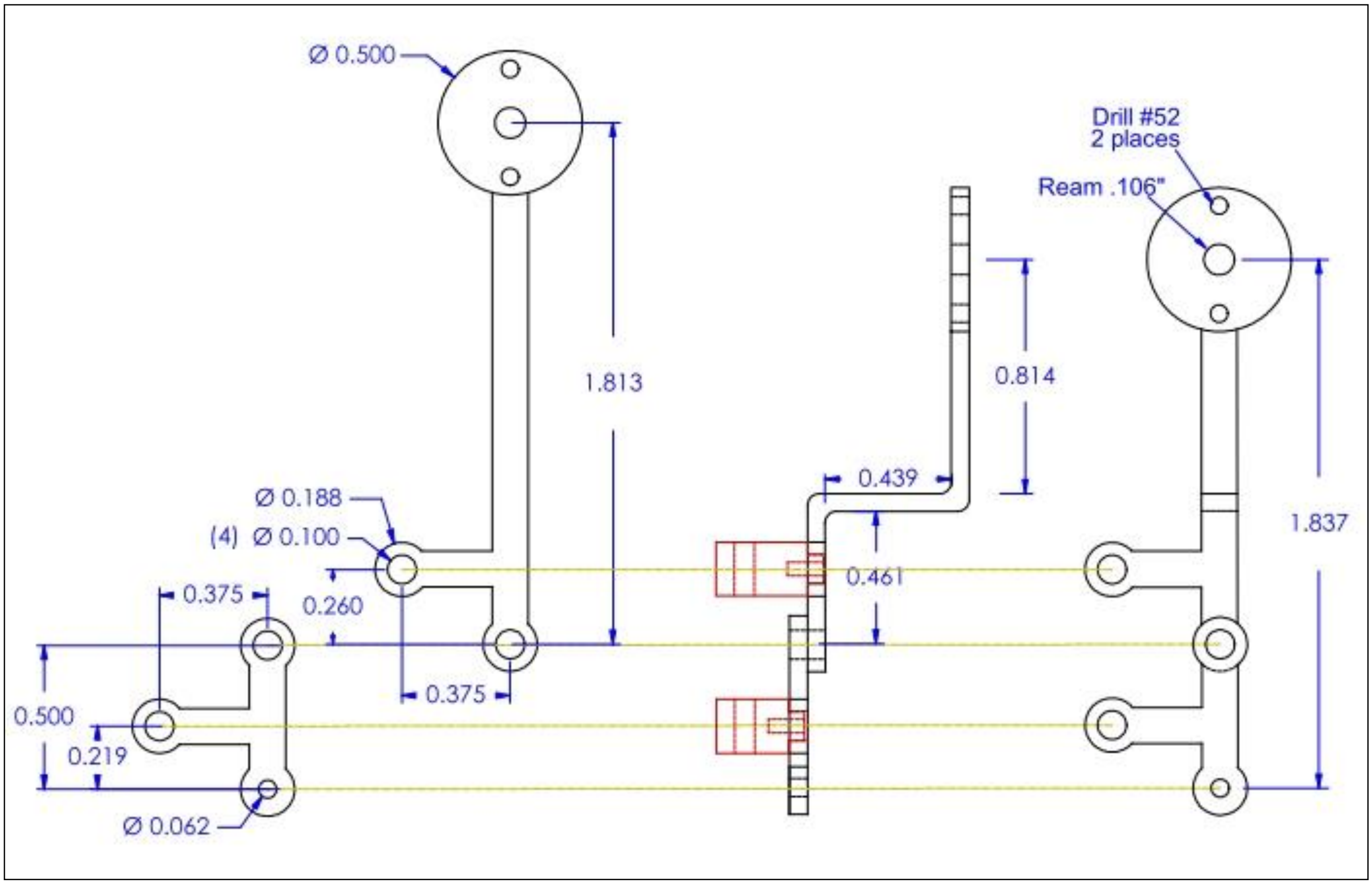


Figure 193: *Construction drawing for the adjustable crutch arms.*

Adjusting the beat of a clock is often accomplished by bending the crutch. This seems a rather crude operation so this clock will be fitted with an adjustable crutch. The collet made for the test escapement will be reused.

Figure 193 shows the arms of the crutch. They are made from 1/16″ brass. Before cutting the parts, verify that the vertical arm .814″ long will provide adequate length to allow the crutch to pass through the cutout in the rear plate with enough room to swing. Adjust this dimension and the overall length of the long arm as necessary. The four .100″ and .062″ diameter holes should be drilled undersize and broached for a slip fit of the mating component. The assembly length of 1.837″ need not be exact since the pendulum slot will be positioned to match.

The posts are turned from 3/16″ diameter brass rod. Note in Figure 194 that one post is longer than the other. The 3 washers are 1/32″ thick and are made from the same brass rod, drilled through the end and parted off to the correct thickness. The #56 holes can be drilled through to the cross hole to make tapping easier, but the 0-80 screws must not be so long that they intrude into the cross hole.

The shoulder nut is located at the pivot point of the crutch arms. It is made of mild steel to provide a bearing surface.

Figure 196 shows the knurled nut made from a piece of ¼″ brass rod. The left-hand drawing also represents the clamp nut. It is simply a 1/8″ thick piece of ¼″ rod tapped 2-56. The knurl nut and clamp nut go on each side of the long post to hold the adjusting screw in place. A drawing is not provided, but a 1.25″ length of 2-56 threaded rod is needed for the adjusting screw. The knurled nut is fastened to one end of the threaded rod with Loctite.

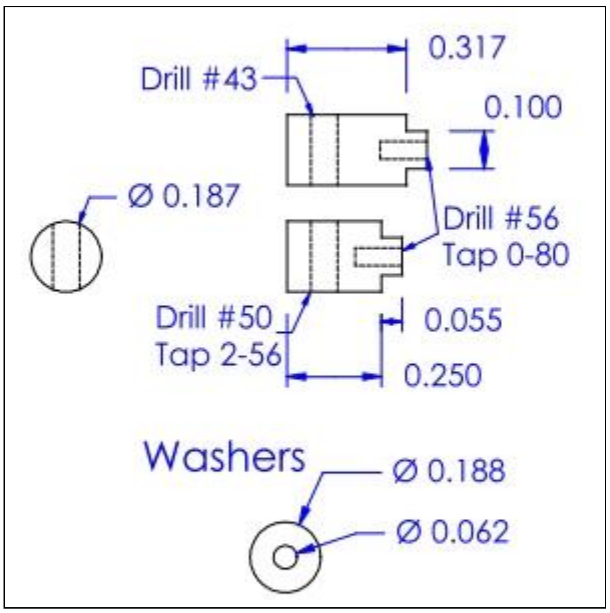


Figure 194: *Construction drawing for the posts and washers. The posts are shown in red in Figure 193. 3 washers are required.*

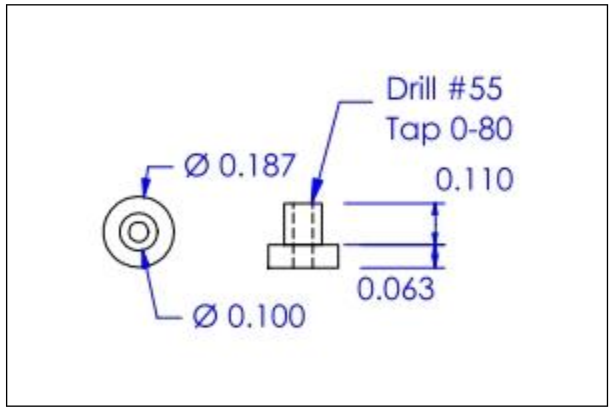


Figure 195: *Construction drawing of the shoulder nut. The material is mild steel.*

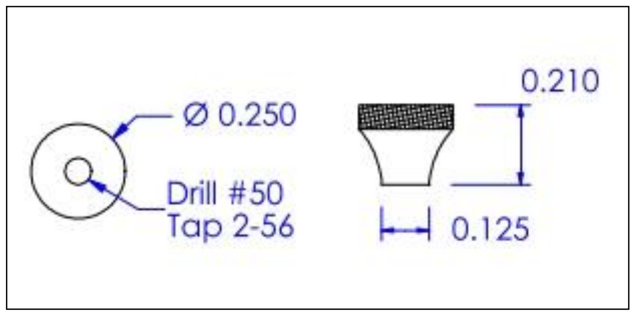


Figure 196: *Construction drawing for the knurled nut and clamp nut.*

Figure 197 shows the crutch assembly. The posts are fastened to the arms from the backside with a washer and 0-80 screw. A washer and 0-80 screw also fasten the two arms together at the pivot point with the shoulder washer. The crutch pin is .062″ music wire and will be trimmed to length after fitting the crutch to the pendulum.

The posts and adjusting screw should be free to rotate but not so loose that they wobble. Likewise, the shoulder nut must allow the arms to pivot without any unnecessary movement. This means that the screws cannot be fully tightened and will tend to work loose. Therefore, the screws will be secured with low-strength Loctite after final adjustments and polishing are complete.

The pendulum is now attached to the suspension bracket with the crutch in place so the location of the crutch pin can be transferred to the pendulum.

The slot does not need to be any longer than necessary and this one is only ¼″ in length. Each end of the slot is drilled with a #53 bit and the center section is cut out with a jeweler's saw. The slot is then opened up with a needle file until the .062″ crutch pin just slides through.

Figure 197: *The adjustable crutch assembly. The crutch pin will be trimmed to length after the assembly is test fitted to the pendulum.*

Because the section of the pendulum is rather thick, the crutch pin may bind if the pendulum twists for any reason. To reduce the chance of binding without introducing slop between the pin and slot, the slot is tapered by slightly enlarging the slot on the backside of the pendulum. This allows the pin to contact the pendulum slot at a narrow point and not bind if the pendulum twists.

Final testing of the pendulum rate can now be completed by assembling the clock and timing it over several hours. Everything will be assembled except the motion works. The fusee cable needs to be cut to length. The proper length is determined by installing the mainspring barrel and fusee in the frame. With the fusee filled with cable, there should be one full wrap remaining around the barrel. An extra inch or two of cable is added to allow for the knot at each end.

The second pinion was previously attached with Loctite 609 and low-strength Loctite can be used to fasten it to the arbor since it has no twisting force on the arbor. The third pinion and collet will need to be attached to the arbor with Loctite 609 as will the fourth pinion. These parts can be polished now before assembly. Alternately, the parts can be heated to break the Loctite bond and separated for polishing later.

A taper pin is installed in the third arbor where the motions works drive pinion will attach. The pin serves as a temporary hand for timing the pendulum. Remember this wheel should rotate 4 times per hour.

Apply clock oil to the spring barrel flanges, pivots, pallets and crutch pin. Set the pendulum bob all the way down. With the time train and pendulum assembled and all of the cable on the barrel, apply 1.4 turns of preload to the mainspring. Wind the fusee ½ turn. This will provide several hours of runtime. Set the pendulum in motion and adjust the crutch for an even beat.

Time the rotations of the third arbor. Each rotation should take approximately 15 minutes. Four samples are taken over a 1-hour period. The bob is raised to its highest position and another 4 samples are taken. If the clock loses time at the lowest bob position and gains time with the bob at its highest position, no further adjustments are needed to the pendulum.

Unfortunately, my tests indicated a loss of 1 minute 44 seconds per hour with the bob down and a loss of 18 seconds per hour with the bob all the way up. In other words, the pendulum is too long to be regulated in its current configuration. The pendulum center of oscillation needs to be raised to speed up the beat rate.

Photos of the original clock show some type of weight attached near the center of the pendulum, so the original builder may have encountered the same problem. This pendulum will be corrected in the same way.

Rate Adjustment

Two steps will be taken to add weight to the upper end of the pendulum to speed up the beat rate. First, caps will be added to the back of the brass connectors. While not adding much weight, the appearance is improved. Second, a weight assembly will be made that attaches to the center section of the pendulum. Since the center section is slotted, this weight will be adjustable with several inches of travel.

The connector caps are made from 1/16" thick brass using the same dimensions as shown in Figure 172. The caps are cut out slightly over size, silver soldered to the connectors and filed to shape. Use caution not to disturb the position of the previous solder joints.

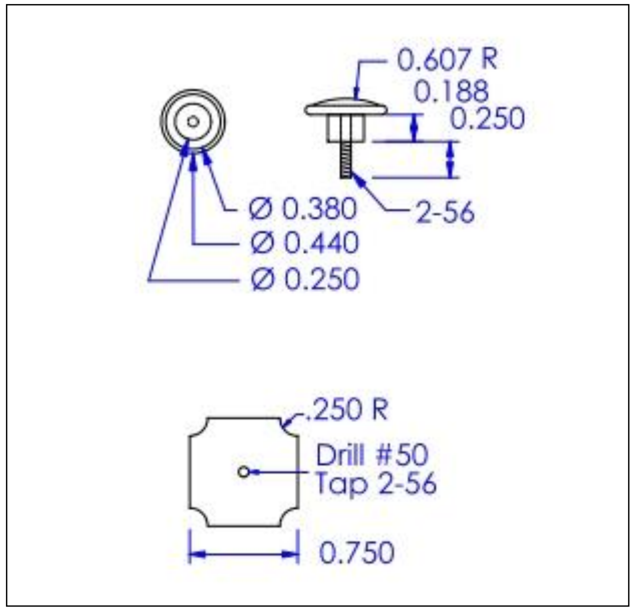


Figure 198: *Construction drawing of the rating weight and stud. The weight is made from 3/16" thick brass.*

The size of the rating weight is selected to match the width of the center section of the pendulum. It can be lengthen if necessary to provide additional weight. The shape of the weight is shown at the bottom of Figure 198. The rounded corner details serve no purpose other than decoration. Likewise, the shape of the stud can be as simple or complex as the builder desires. The top section of the stud is made from brass rod that is drilled and tapped to receive a 2-56 screw. In order to keep from drilling through the head of the stud, the brass rod is turned around and drilled and tapped from the bottom before parting off the piece as shown in Figure 199. The screw is then fastened with Loctite and cut off to the proper length.

The rating weight is installed in the center of the center section and a second set of readings are taken. The clock now loses 18 seconds per hour with the bob at its lowest setting and gains 53 seconds per hour at the highest setting. This shows that somewhere within this range of bob settings, the clock will keep accurate time. The rating weight can also be raised or lowered to adjust the beat rate.

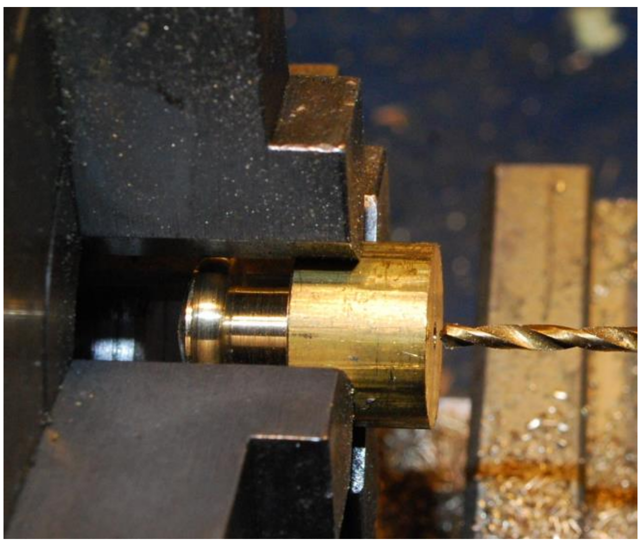


Figure 199: *Drilling the rating weight stud from the bottom leaves the top clean and attractive.*

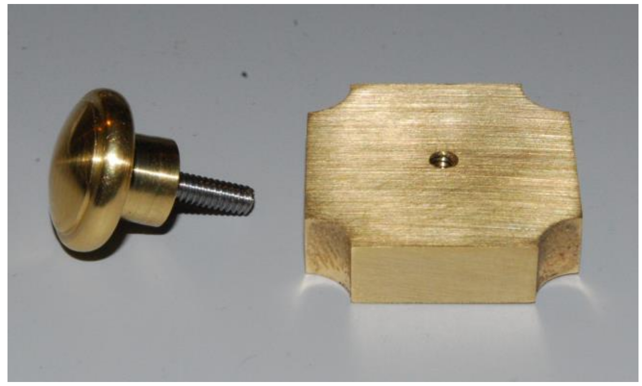


Figure 200: *The completed rating weight and stud.*

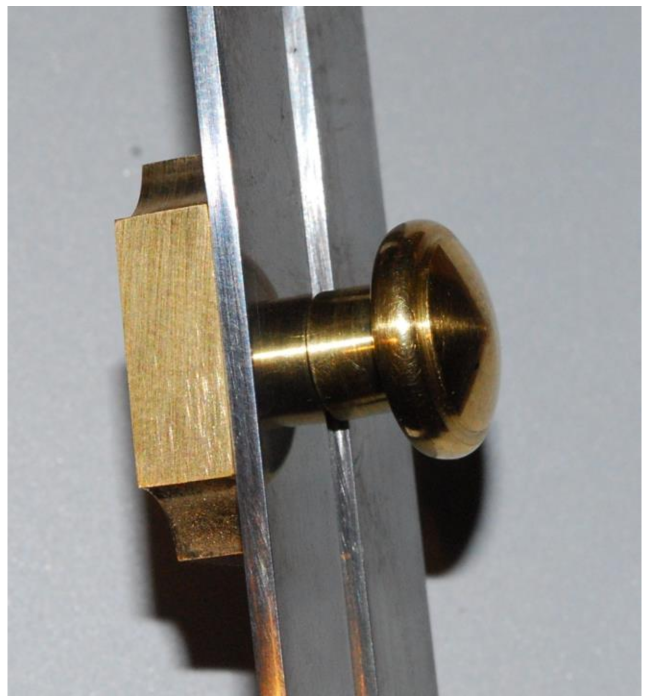


Figure 201: *The rating weight installed on the pendulum.*

A Pinwheel Skeleton Clock

9 - Dial and Dial Pan

Introduction
The dial assembly consists of a dial pan supported by 3 pillars and the dial itself. Although only a few parts are involved, they require a substantial amount of effort to produce.

Dial Pan
The dial pan shown in Figure 202 serves two purposes. It provides support for the dial and provides a decorative feature to the clock. The pan has a curved edge that adds visual depth and stiffens it against bending.

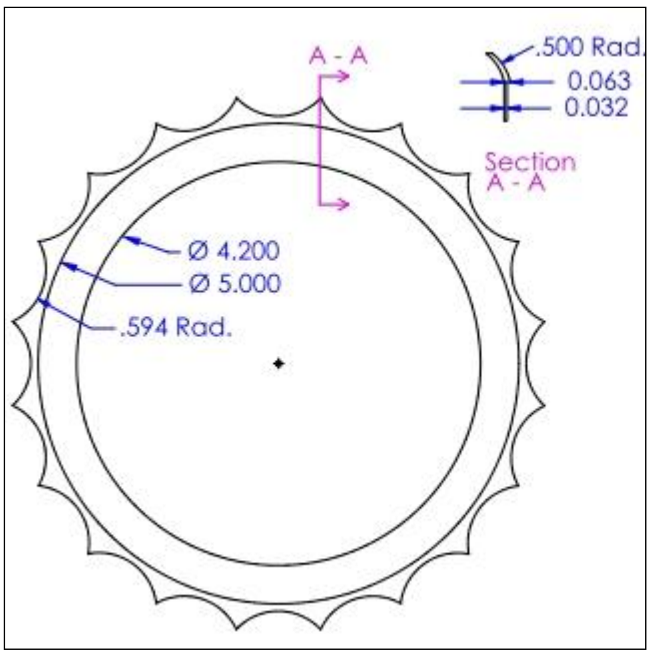


Figure 202: *Construction drawing of the dial pan. The diameter of the 1/16" thick brass plate is 5.8"*

To shape the dial pan, a plywood form consisting of two disks is constructed. Each disk is approximately 1 inch thick, built up from several layers of plywood cut slightly oversize to allow the form to be turned to its final dimension. The larger disk is mounted to the lathe faceplate, turned to a diameter of 6" and faced to provide a surface that runs true. The shoulder is rounded to a ½" radius. The smaller disk is then centered and attached to the larger disk with 4 wood screws. The screw holes are located so they fall in the cut-away portion of the dial. Figure 212 can be used as a template to locate these holes. Turn the small disk to a diameter of approximately 5".

A disk is cut from 1/16" thick brass and sandwiched between the two forms. The holes in the small form are used as a drilling jig as shown in Figure 203. The assembly is then remounted in the lathe and the brass disk is turned to a diameter of 5.8 inches.

Figure 203: *Drilling the dial pan using the form as a jig.*

Remove the entire assembly from the lathe and then remove the face plate from the larger disk. Place the assembly on a solid surface such as a concrete floor. Using a hammer and wood block as shown in Figure 205, shape the brass disk over the curved edge of the larger disk. As the brass bends it will work harden, becoming springy and difficult to bend. When this occurs, the disk will need to be removed from the jig and annealed by heating it to a dull red color. I had to anneal the brass disk twice before it would fully conform to the curved edge.

Figure 204: *Turning the dial pan diameter to size. The forms were turned to size and shape before installing the brass. Note the curve on the larger form on the left. Reference marks make it easier to reassemble the pieces.*

Figure 205: *Hammering the pan to conform to the lower section of the form.*

The scallops are cut on the mill or drill press with the configuration shown in Figure 206. A 1-3/16" hole saw is used to cut the brass. A rotary table would be the best tool. Since I do not have one, an index plate is fastened to the back of the large wood disk and bolted through the center to the milling table. The assembly is then indexed for 20 cuts. Similar to cutting wheel teeth, the first two cuts should be made shallow and the assembly advanced towards the cutter, repeating the cuts until the two scallops come to a point. The remaining scallops can then be cut.

***Figure 206:** Configuration used to cut the scallops around the edge of the dial pan. A small rod is bent to form an index pin and the straight end is clamped to the milling table. Note the lower wood disk is sacrificed during this operation.*

Remove the assembly from the mill. The index plate and small wood disk are then removed and the face plate is reinstalled on the large disk. Fasten the dial pan to the large disk and remount this assembly on the lathe. "Eyeball" the edge of the pan and adjust the disk on the face plate until it runs reasonably true. Using a dial indicator positioned approximately 2.4 inches from the center, true the face of the dial pan by adjusting the fastening screws. The face needs to run within 2-3 thousandths of true.

A section of the dial pan is now trepanned to receive the dial. The outer diameter if the trepanned area is precisely 5 inches and the inner diameter is approximately 4 inches. Very light cuts will be required to prevent chatter. The final depth should be .032" measured at the outer edge. This will allow the dial to fit flush in the recessed area. This measurement can be done visually by using a small piece of .032" brass as a gauge. Use a graver or sharp pointed tool to square the outer corner of the recessed area. Figure 207 shows the dial pan after the recessed area has been cut. Enlarge the center hole to 3/8" with a boring tool if it is not already that size and then remove the dial pan from the wood disk.

***Figure 207:** The dial pan after trepanning the recessed area for the dial. Three holes inside the recessed area will receive flat head screws for mounting the pan to the front plate.*

A compass is set to a radius of 2.41" and marks are made on the front plate from the motion works pivot to the locations shown in Figure 208. This will position the dial pan screws inside the trepanned area with clearance between the screw head and the trepanned edge. The holes are drilled in the front plate with a #50 bit and tapped 2-56.

Install the motion works bridge and hour pipe on the front plate to serve as a guide in centering the dial pan. Transfer the mounting hole locations to the dial pan and countersink them so a flat head machine screw is flush or slightly recessed. Due to the thin material in this area of the dial pan, some material may be removed from the head of the screw to obtain the clearance needed for the dial to sit flush.

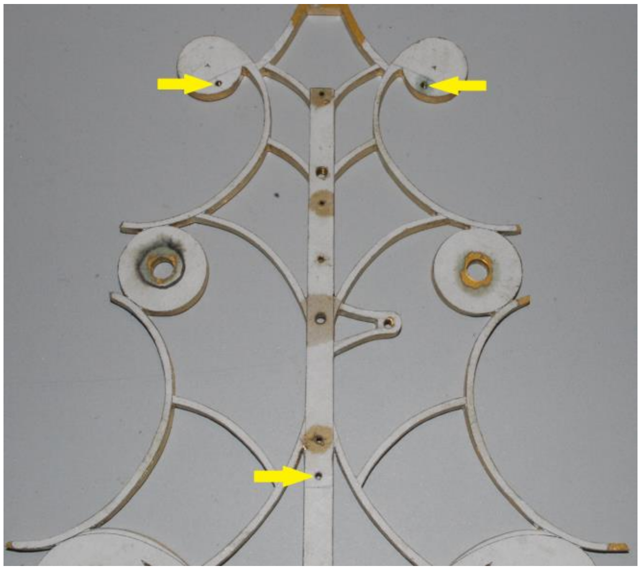


Figure 208: *Location of the dial pan mounting posts. These holes are drilled on the plate first and then transferred to the dial pan. A mark is scribed with a compass from the motion works pivot hole.*

The center of the dial pan can now be removed. Remount the pan on the large wood form on the lathe. Make a plunge cut 2 inches from the center (4 inch diameter) with a pointed lathe tool. When the cut is almost through the dial pan, stop and snap off the dial pan by hand. If the cut is made all the way through, the dial pan may be damaged when it breaks loose. Remove the sharp edge and finish with a file.

Dial Pillars

The outside shape of the dial pillars roughly matches the plate pillars. The pillars serve as spacers and are drilled through with a #42 bit to clear a 2-56 screw. It may be necessary to provide a flat area on the back of the dial pan if the pillars fall on the curved outer surface. If this occurs, a flat area is made by centering a 3/16" end mill over the hole and removing only enough material to form a complete circle around the hole as shown in Figure 211.

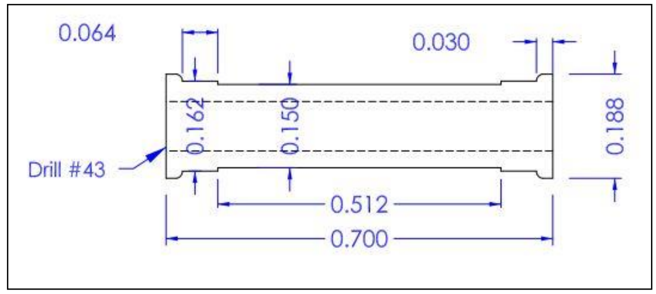


Figure 209: *Construction drawing of the 3 dial pillars. The material is brass.*

Figure 210: *The completed dial pillars.*

Figure 211: *An end mill is used to form a flat area for the dial pillar. The pan is thin here, so remove as little material as possible.*

Dial

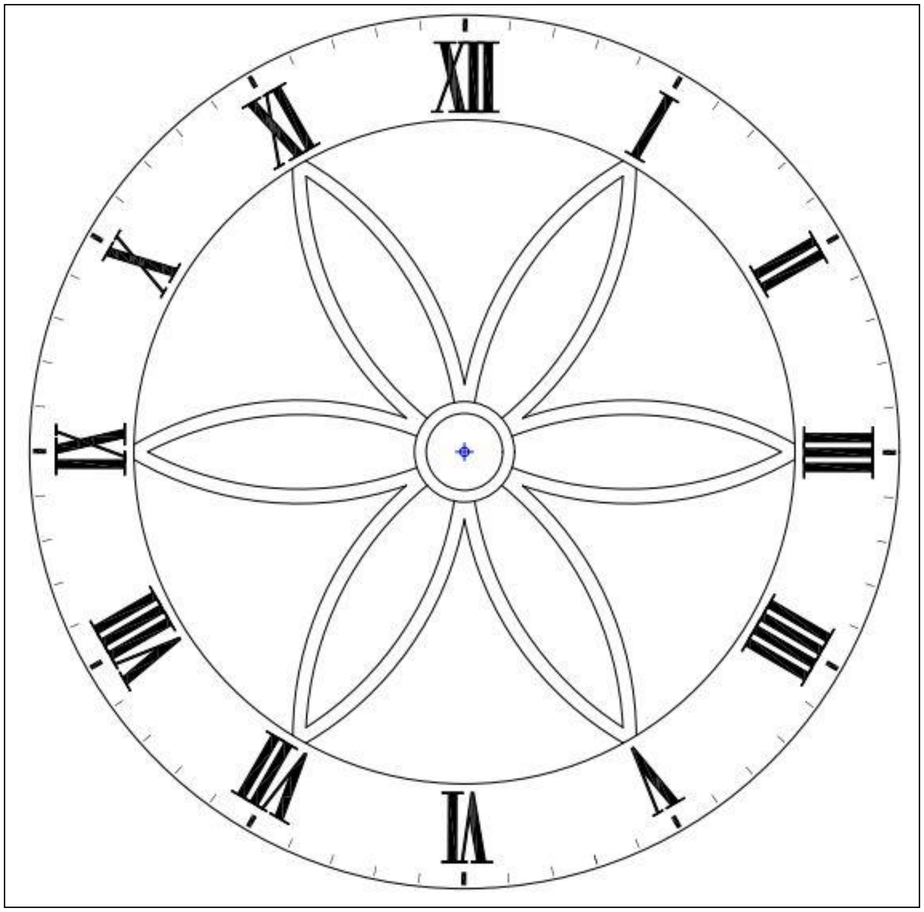


Figure 212: *Template for the dial. The dial is made from 1/32" brass. The outside diameter is 5 inches.*

The dial is made from a sheet of 1/32" brass. A disk is cut and mounted to the large wood form used to make the pan. The outside is turned to a diameter of 5 inches and the center hole is drilled and bored to .465" as shown in Figure 213. Use care when turning the outside diameter of the thin material as it may flex.

A photocopy of Figure 212 is made to scale so the outside diameter is 5 inches. The copy is then attached to the brass sheet with adhesive spray, making sure the mounting screw holes are located in an area that is cut away.

After the center sections are removed with a jeweler's saw, the edges are filed smooth and all surfaces are sanded to a 600-grit finish.

There are a number of ways to put the numbers on the dial including CNC machining, silk screens, hand painting, manual engraving and photo etching to name some of the most popular. A dial may also be purchased and adapted to fit this clock. Each has its own benefits and drawbacks so the builder should chose the method that works best for his skills and equipment. Having neither the artistic talent nor machine tools necessary for any of these techniques, I send the dial out to an engraving shop to have the numbers photo etched into the dial. This was much more economical that acquiring the materials needed to do the work myself.

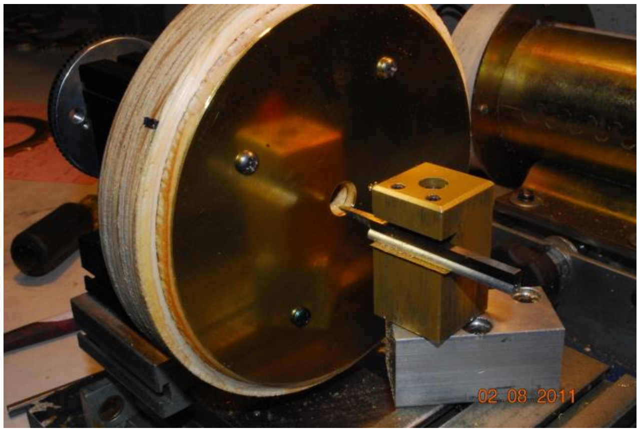


Figure 213: *Boring the center of the dial blank.*

Figure 214: *Setup used to grain the dial.*

The engraver was able to use a PDF file of the CAD drawing to generate the photoresist mask and acid etch the face. He then painted the face with black paint and sanded it, leaving paint only in the etched numbers and then lacquered the dial to protect it. It looked very good, but in hindsight, several steps should be completed by the clock builder and not the engraver. Most engraving shops make plaques and nameplates, not silvered clock dials, so their finishing techniques may create more work for you if careful instructions are not given. First, the dial should not be lacquered as it will need to be removed to allow graining and silvering. Second, the engraver used 220-grit sandpaper to remove the excess paint. Restoring the 600-grit finish required the removal of enough brass that paint was also removed from several small areas of the numbers. If you use a similar process, request that the engraver paint the dial and let you remove the excess paint with 600-grit sandpaper as part of the graining process. Four #50 mounting holes are drilled prior to graining the dial. These holes are drilled near the edge at 4 equally spaced locations as shown in Figure 215.

The dial is grained in a circular direction. The center spokes will show on the front and back, so the dial should be grained on both sides using 600-grit sandpaper. The dial is placed on the smaller top form used to make the dial pan. A scrap metal rod is placed through the center as shown in Figure 214. Another wood block with a hole at one end serves as the sanding block. The sanding block is filed to a slight curve on the working surface to prevent the edges from snagging on the dial. With a piece of 600-grit sandpaper wrapped around it, the sanding block is rotated around the rod while pushing down on the dial to create the grain. Examine the dial often to make sure the grain is consistent and all other marks are removed. Scratches will become very obvious when the dial is silvered. Remember to grain the back of the spokes and the entire front of the dial.

Wash the dial with dish soap and water after the graining is complete. Latex or similar gloves should be worn to prevent any oils and fingerprints from getting on the dial that will show up during the silvering process. Inspect the painted numbers carefully after the graining is complete and touch up any areas with a fine brush if any paint has worn through.

Silvering salts are the traditional method of coloring the dial. A small amount of salt is applied using a soft damp cloth and enough water to form a soupy paste. Rub the cloth over the dial using very light pressure in a circular pattern to work the salt over the entire surface. After about 10 minutes the dial will have a uniform dull gray color. Rinse the dial in cold water and apply the finishing powder using a light circular motion. The finishing powder will quickly turn the dull gray into a bright silver finish. Rinse the dial thoroughly and dry it with a soft cloth. Inspect the dial to ensure the silvering is even and then set it aside for a day or two and inspect it again.

The silver will become dull if left unprotected, so a coat of clear lacquer is applied to help keep the dial bright. Figure 215 shows the completed dial after being finished with Mohawk (now Behlen) brand Lacquer for Brass. This lacquer does an excellent job of protecting metal and is easy to apply. I apply one heavy coat, almost to the point of running, and then lay it flat so the lacquer self-levels to a smooth, glossy finish. Apply the lacquer in cool temperatures, around 70 degrees. This allows the lacquer to dry slower and level out, helping to prevent orange peel. Test other clear lacquers before using them on the dial. I had a terrible experience with a well-known brand that instantly developed an orange peel surface and easily flaked off the dial. The dial had to be re-sanded, grained and silvered. The gloss of the Mohawk lacquer looks nice over the grained dial. If less gloss is desired, 1500-grit sandpaper can be used with the graining setup shown in Figure 214. Very light pressure should be used to prevent sanding through the lacquer.

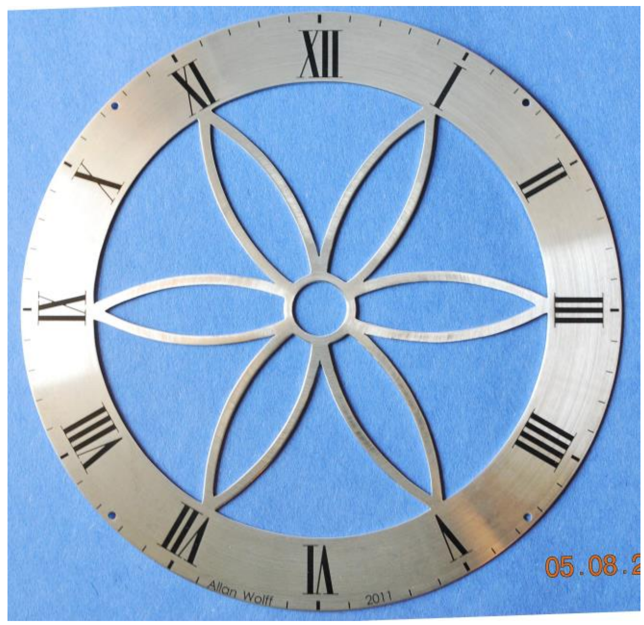


Figure 215: *The completed dial after it has been silvered and lacquered. Mounting holes for 0-80 screws are located between 1&2, 4&5, 7&8 and 10&11. The builder's name and date were also etched on the dial to add a personal touch.*

Hands

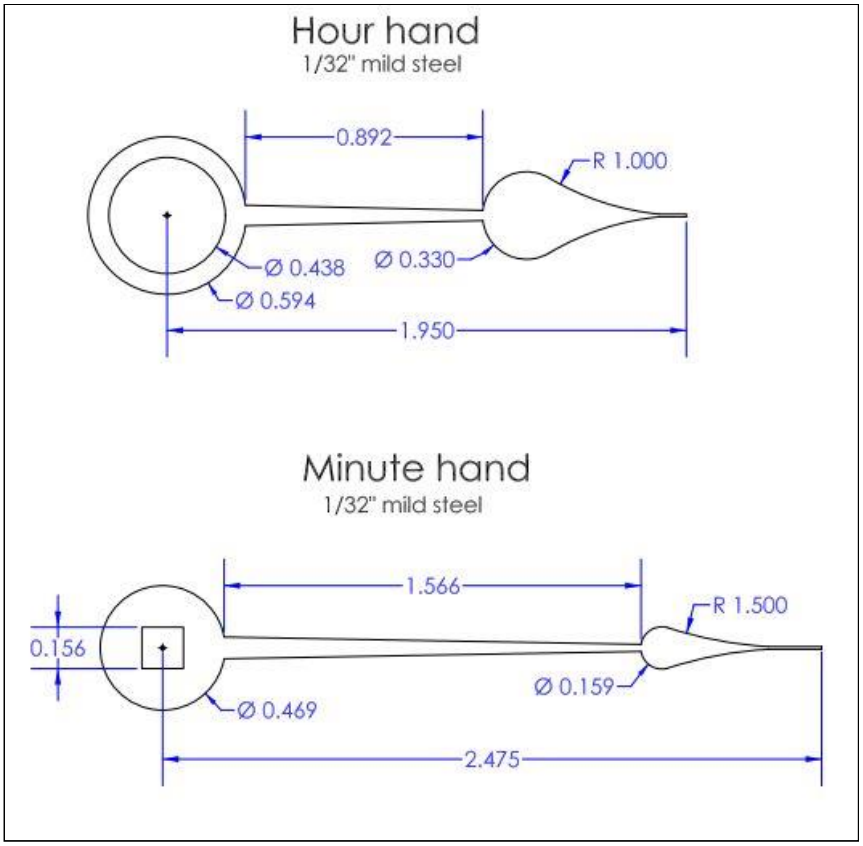


Figure 216: *Construction drawing for the hands.*

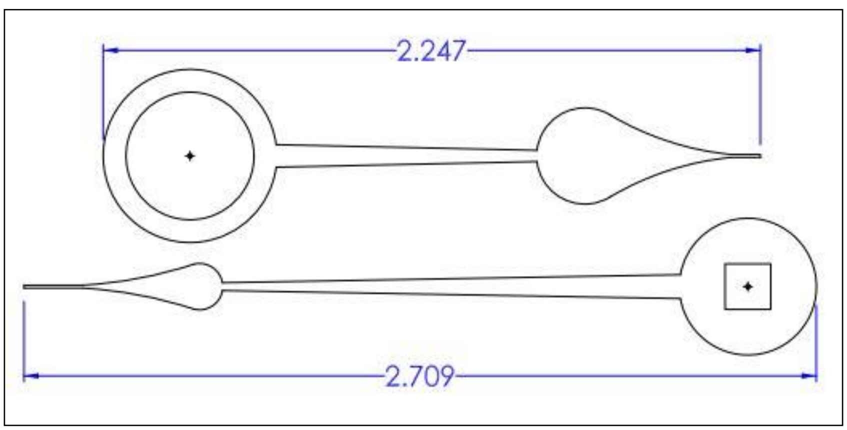


Figure 217: *Hand Template.*

A dimensioned drawing of the hour and minute hand is provided in Figure 216 but the recommended method of making the hands is to make a scale photocopy of Figure 217 and use the copy as a pattern. The pattern is glued to a sheet of 1/32″ mild steel with spray adhesive. Drill small pilot holes and cut out the hand mounting holes with a fine tooth jeweler's saw before cutting the outside shape. This will provide extra material to clamp the stock while drilling and sawing. Do not attempt to drill the large mounting hole of the hour hand since large drills will grab the thin sheet metal and ruin it. Use the jeweler's saw instead. File the insides of the mounting holes to shape. The minute hand should be test fitted to the minute pipe to ensure a good fit.

After the hands have been cut out, the edges are rounded on the top side to give them extra dimension. This is easily accomplished by clamping the hand to a 1/8″ rod as shown in Figure 218 and pulling a strip of course sandpaper over the edges. Extra care is required when working around the delicate points. A file can also be used, but the sandpaper provides a more even finish. Smooth the faces and edges with progressively finer grits of paper. Use water when using 600-grit and above paper to provide a better finish.

The hands are brought to a mirror finish with a polish such as Simichrome or extremely fine abrasive paper such as Micro Mesh. This paper is available up to 12000 grit, but I found no significant improvement between 8000 and 12000. Absolutely all scratches must be removed or they will become much more visible when the hands are blued.

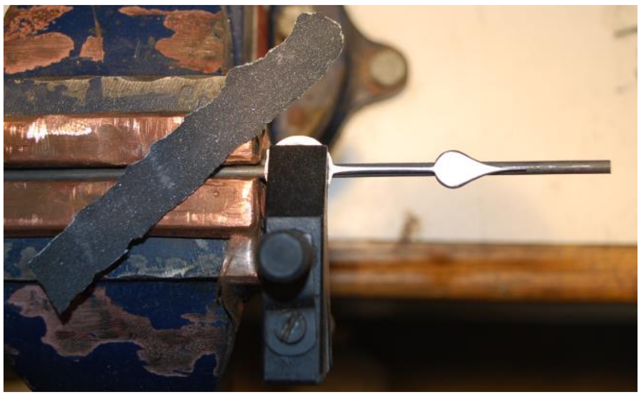


Figure 218: *The edges of the hand are rounded with a strip of sand paper. The rod provides support to prevent the hand from being bent. A small machinist's clamp holds the hand to the rod.*

Clean the hands with denatured alcohol as any contaminates will show up during the bluing process. Do not touch the hands after they have been cleaned.

A traditional method of bluing steel is to heat the part on a bed of brass filings. The part is removed when the correct color is reached. That method does not work with these hands with their broad spades and very fine points. About the time the spade reaches the correct blue color, the point and arms will have already become too hot and turned gray. An improved method is needed to achieve the desired results.

A pile of brass filings is placed in the center of a cast iron skillet. The pile should be at least 1/2" deep and large enough to easily hold the hands as shown in Figure 219. Do not place the hands on the filings yet.

Figure 219: *Brass filings heated in a cast iron skillet provide even heat distribution. The hands should be buried in the filings after the correct temperature has been reached.*

Heat the filings to 575 to 590 degrees F. This temperature corresponds to a dark blue color. Monitor the temperature with a suitable thermometer. The probe of the thermometer is inserted into the middle of the pile and a lid is placed on the skillet to help regulate the temperature as shown in Figure 220. Hold this temperature for 10-15 minutes to make sure the temperature remains steady. Patience is required as there will be quite a bit of lag due to the mass of the skillet.

Before beginning the process, make sure a bright light source is available. A halogen desk lamp provides a good white light source needed to accurately see the color changes. A pan of water should be placed nearby to cool the hands when the correct color is reached. A pair of tweezers or pliers is needed to handle the hands. Use care to prevent the hands from being scratched.

Figure 220: Preheating the brass filings.

When the temperature of the filings is stable, remove the lid and thermometer and place the hand on the brass filings with the tweezers. Move the hand in small circles while pushing down until the hand is completely buried in the filings. Leave a small portion of the hand visible where the tweezers was located to monitor the color change. The color should change in just a few minutes.

Figure 221: The finished hands. The marks on the mounting side of the minute hand will be covered by the hand washer.

When it is close to the desired color, remove the hand with the tweezers and inspect it. If it has not reached the correct color, bury it back in the filings for a bit longer. Move it to a different spot in the filings if it looks like one end is progressing faster than the other due to hot spots. The thin areas of the hand should not overheat since the filings are at the correct temperature. When the hands have a uniform dark blue color, cool them in the pan of water. Coat the hands with car wax to help prevent rust. Clear lacquer is not recommended as it tends to change the color of the bluing.

Hour Hand Collet

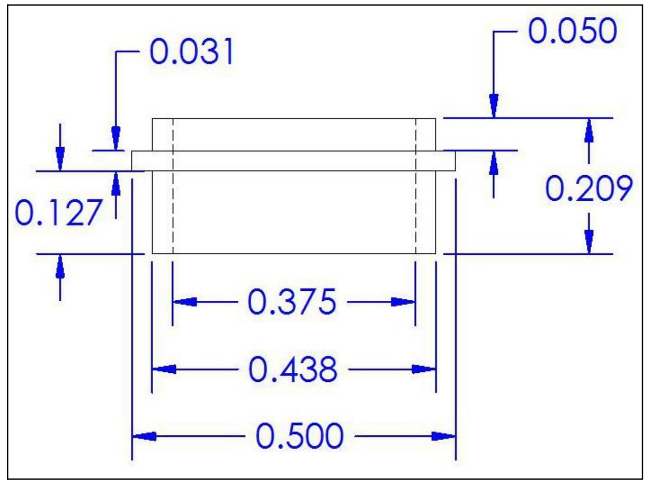


Figure 222: Construction drawing for the hour hand collet.

A collet is required to mount the hour hand with a friction fit on the hour pipe. It is machined in the same way as the motion works pipes. Slots are cut in the lower section with a jeweler's saw to allow adjustment of the friction fit. The hour hand is a tight friction fit on the upper section of the collet. If the hand is loose, the collet can be expanded slightly with a tapered punch. I prefer Loctite to fasten the hand as it provides better control in positioning the hand and can be easily removed with heat. Note that the top edge of the hour hand collet is .050″ while the hour hand thickness is only .032″. The extra material on the collet keeps the hour and minute hands separated by .020″ so the hands do not hit each other. The completed collet is shown in Figure 224.

Figure 223: *The hour hand collet is placed over a scrap rod held in the bench vise to hold it while the slots are cut.*

Figure 224: The completed hour hand collet with the hour hand installed. The hand will be permanently attached during final assembly.

Hand Washer

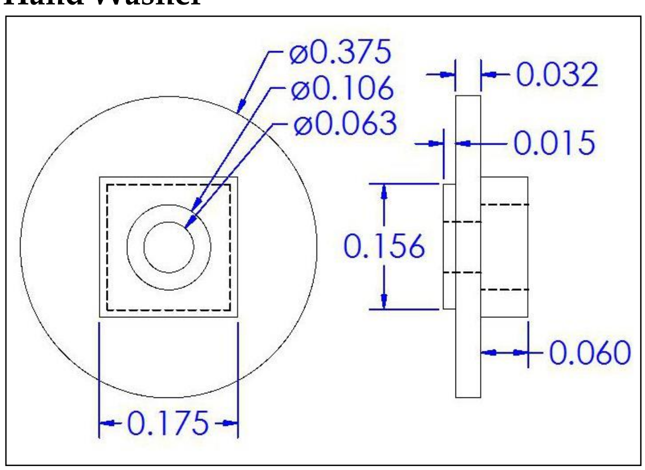


Figure 225: *Construction drawing of the hand washer. The material is mild steel.*

The hand washer is equipped with square arbors on each side. The larger arbor is the same size as the fuse winding arbor and allows the hands to be moved with the key. This provides a means of setting the time without touching the delicate hands or dial. The smaller square engages the minute hand so that it does not slip.

The washer is turned from 3/8" mild steel rod according to the dimensions in Figure 225. Complete as much machining, drilling and finishing as possible before parting off the washer. The smaller center hole is drilled first and then partially drilled through with a larger bit to provide a countersink for the mounting screw. The large arbor is then milled in the same manner as the fusee winding arbor. The small arbor is then milled by cutting through the stock as shown in Figure 226.

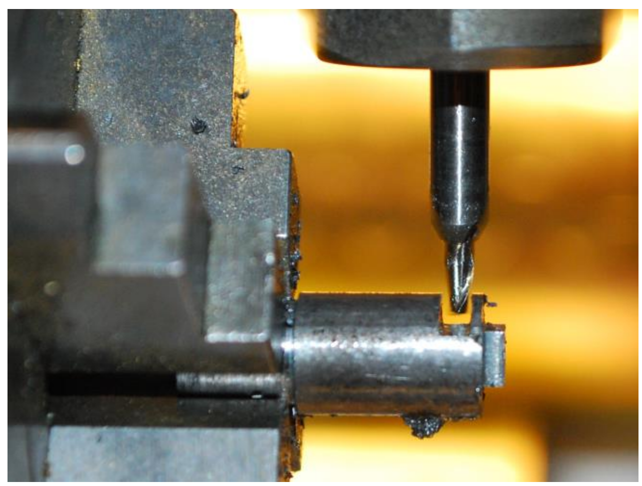


Figure 226: *Milling the second square on the hand washer. A small 3/32" end mill is used for this cut.*

While the stock is still mounted in the lathe chuck, the surface of the washer is finished to a mirror surface by sanding to 1500 grit and then polishing with Tripoli compound and a buff mounted in a Dremel tool. The washer is then parted off, leaving the required amount of the smaller square (.015”) on the washer.

The minute hand, minute pipe and hand washer are test assembled. File down the height of the squares on the minute pipe and washer so that both parts protrude half way through the minute hand. Continue test fitting until the hand is snug with the washer fastened in place with a 0-80 machine screw.

Figure 227: *The finished hand washer.*

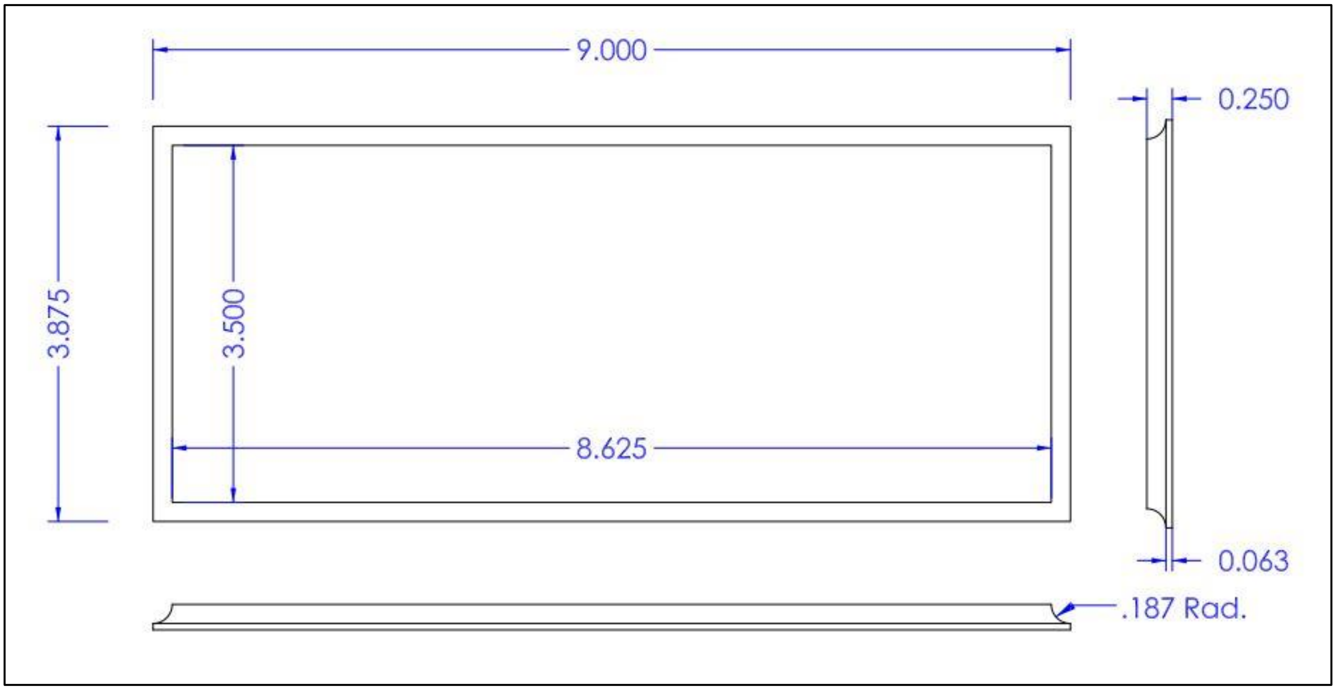


Figure 228: *Construction drawing of the base plate.*

Introduction
The clock itself is now complete and only a few "accessories" remain. Among these are the base plate, feet, key, pendulum lock and case.

Base Plate
The clock plates are secured to the base with 6-32 machine screws. The holes are located at the lowest point of each plate and drilled approximately ½" deep in the drill press as shown in Figure 229.

The clock needs to be mounted on a stable platform. A combination of wood and brass are used to provide an attractive display. The clock sits on a base plate made of ¼" thick brass. The plate is first sawn slightly oversize and the sides are then squared up and brought to their final dimensions on the mill. A decorative edge is then cut around the perimeter with a 3/8" ball end mill as shown in Figure 230.

Dimensions for the mounting screw locations are measured from the assembled plates and transferred to the base plate. The holes in the plate are drilled 5/32" which is slightly larger than necessary to clear the 6-32 screws. This provides additional clearance to allow for slight variations in alignment between the movement and the base plate. The oversize holes will be covered by the feet.

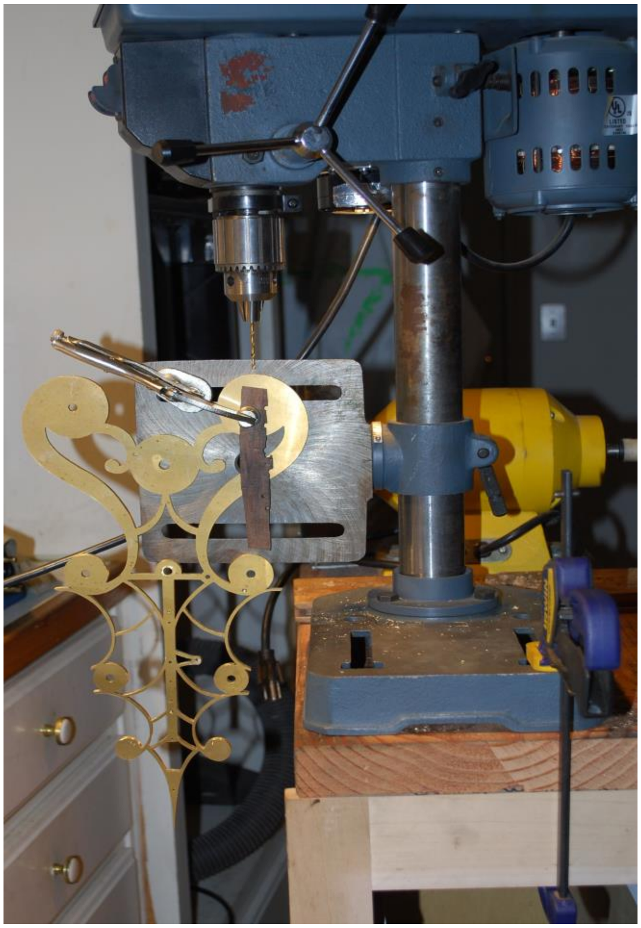


Figure 229: Drilling the mounting holes in the plates. The drill press head is turned to the left to obtain adequate clearance and the base is clamped down to prevent it from tipping over. The table is tilted 90 degrees to provide a stable clamping surface.

Figure 230: Cutting the decorative edge with a ball end mill. The clamps are repositioned without moving the plate to machine the ends.

Figure 231: The finished base plate.

Feet

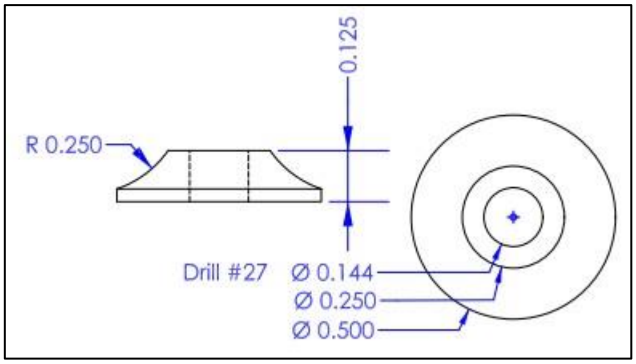


Figure 232: Construction drawing for the feet. The material is ½" brass rod.

The feet serve several purposes besides providing a little extra detail. They cover the oversize holes in the base plate and can also be varied slightly in thickness so the clock plates sit firmly on the base plate without rocking.

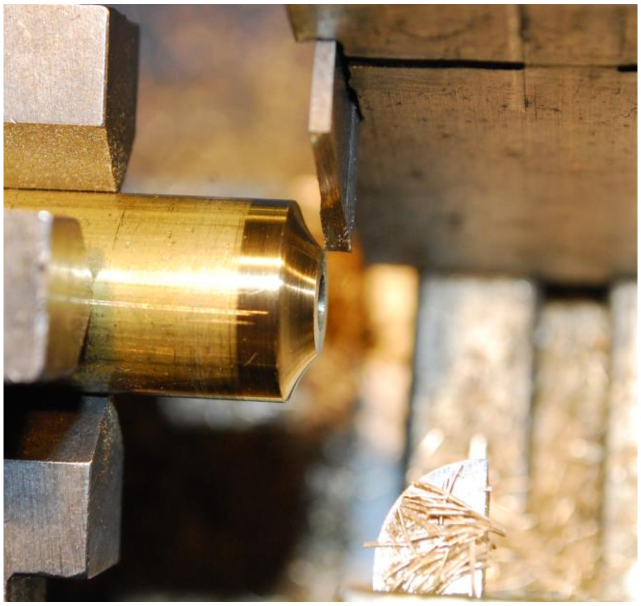


Figure 233: *A pass across the top of the foot will restore the crisp edge that was lost during sanding.*

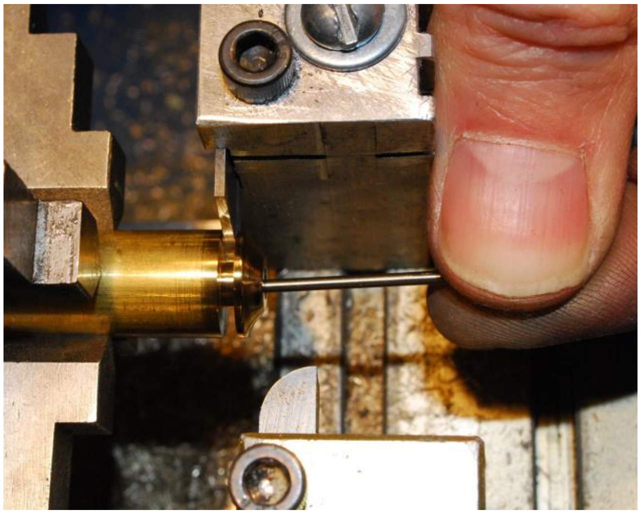


Figure 234: *Avoid scratches in the freshly finished surface by inserting pin into the center hole to catch the foot when it is parted off.*

The feet are constructed using the same methods as the plate washers. The center hole for all 4 feet is drilled first. The radius detail is then cut with a profile tool and the entire surface is sanded to 1500-grit and polished with the Dremel tool. Sanding and polishing will tend to round the top edge. A light pass across the face with the parting tool will restore the sharp edge as shown in Figure 233. The tool is then positioned to part off the foot at 1/8″ thick. Adjustments to the thickness of the feet will be made during final assembly.

Key

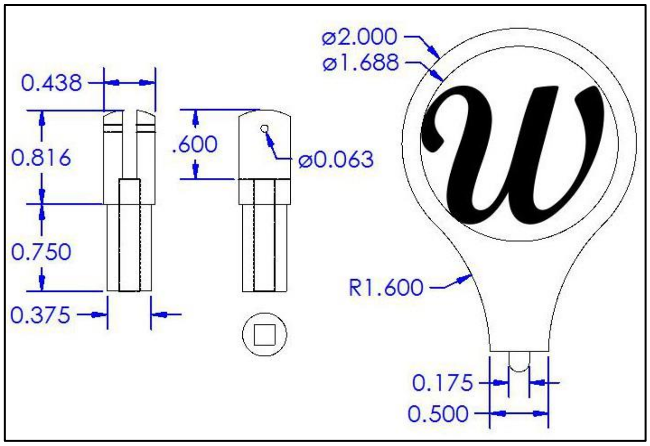


Figure 235: *Construction drawing of the key.*

I have chosen to use W.R. Smith's signet key design. It provides a personal touch and is also comfortable to use.

The head of the key is made first. The inscribed letter can be easily changed by printing the desired letter in the font of your choice with a word processor. I used "Script MT Bold" font for my "W". Some experimentation will be required to fit the letter inside the circle. The pattern is fastened with spray adhesive to an oversize sheet of 1/8″ brass and the interior is cut out with a jeweler's saw. The sheet is then mounted to a wood block in the lathe and centered. A sharp V-shaped lathe tool is used to cut a terminating circle around the letter as shown in Figure 236. This helps the letter stand out from the key head. Turn the lathe by hand while feeding the tool into the part until the desired depth is obtained. The outline of the head is cut and filed to shape followed by sanding the entire part to a 600-grit finish.

The stem is made from brass rod. The small end is machined and drilled as shown in Figure 235. The part is then reversed in the lathe and the larger end is turned to the proper diameter and length. An index plate is installed to lock the headstock while the hole is cross drilled for the retaining pin with the milling spindle.

A slitting saw is used to cut the slot for the head of the key. Figure 237 shows the 1/8″ slot being cut in two passes with a 1/16″ slitting saw. Adjust the last pass by test fitting the head of the key to ensure it fits snugly in the slot. The end of the key stem is then rounded with a profile tool in the same manner as the plate screws. Light cuts should be taken to ensure the tool does not grab on the slot.

Figure 236: *Terminating the letter with a V-shaped lathe tool. The part is mounted to a wood faceplate with screws. The lathe is turned by hand to scribe the line where the letter contacts the circle. The brass was a 3/16" thick scrap left over from the plates that was milled to 1/8" for the key head.*

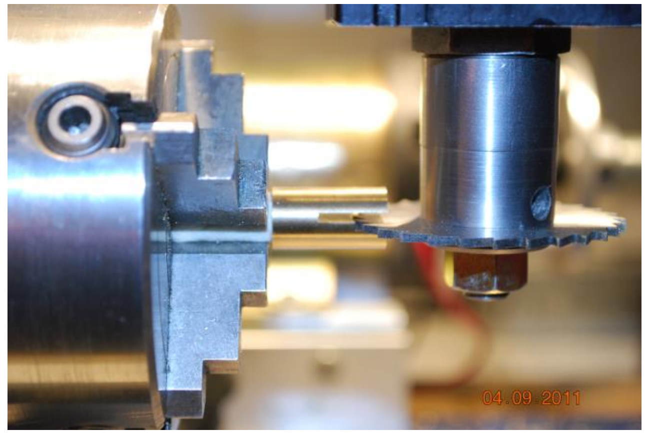


Figure 237: *Cutting the slot in the key stem. Note the smaller end is wrapped with masking tape to prevent the lathe chuck from marking the surface.*

Needle files are used to square the hole in the key stem. File and test fit the key on the fusee winding arbor until it slips on easily with minimal slop.

With the key head fully installed and centered in the stem slot, there should be no slop between the small tab of the head and the stem. If the parts are loose at this point, apply a bit of Loctite during final assembly. Drill the retaining pin hole through the head using the existing hole in the stem as a guide. A ½″ long retaining pin is made from brass and sized for a tight fit in the hole. Trim the length of the pin so it protrudes on each side by approximately 1/64″. Peen the pin with a hammer to rivet it in place. After final finishing, the pin should be nearly invisible.

Figure 238: *A pair of keys. The key on the right is from a previous project and has a steel head for a two-tone appearance.*

Pendulum Lock

When moving a pendulum clock, the pendulum should be removed or secured to prevent damage to the bob or suspension spring. I chose to make a pendulum lock that requires no tools and can be quickly installed.

The lock is basically made to fit and can easily be constructed without dimensioned drawings. It consists of a small block of wood approximately ¾" long with notches at each end to accept the pendulum and rear plate. A length of .062" diameter music wire is bent in a sigma shape to form a retaining clip. The clip is covered with heat shrink tubing to prevent scratching the plate or pendulum. Figure 240 shows how the pendulum lock is installed.

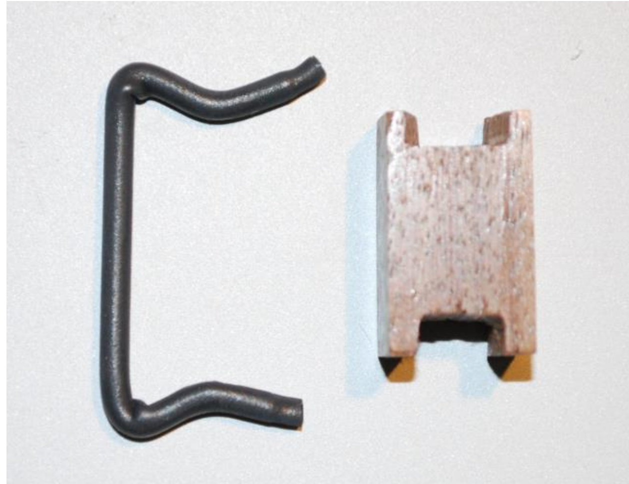


Figure 239: *Pendulum lock parts.*

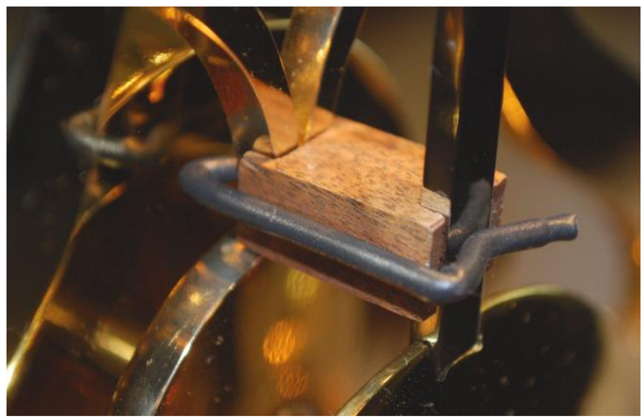


Figure 240: *This photo shows the pendulum lock installed on the clock.*

Polishing

Now that all of the parts are complete, we can move on to applying the final finish. Although a matte finish is sometimes used, I prefer to polish the brass and steel to give it a high degree of reflectivity. Polishing involves a great deal of effort to obtain a satisfactory finish. The process can be tedious and time consuming, so the builder should take advantage of any opportunity to speed up the process.

Throughout this project, each part was sanded to a 600-grit finish. It may be necessary to re-sand them to remove any marks that were picked up from handling or test assembly. The parts should then be progressively sanded to the highest grit available to reduce the amount of polishing required.

Parts that can be returned to the lathe are quickly polished by slowly rotating the part in the lathe while buffing it with a Dremel tool as shown in Figure 241.

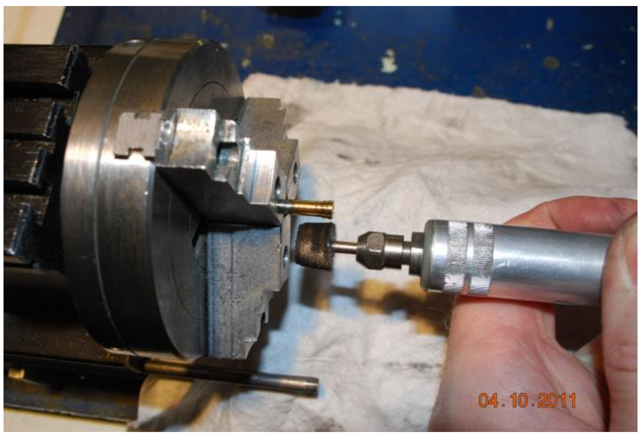


Figure 241: *Polishing a dial pillar in the lathe with a Dremel tool. A felt buff is used with Tripoli compound to quickly bring the part to a mirror finish. The chuck has aluminum jaws and holds the part without scratching.*

Other parts that are large enough to provide a safe grip may be buffed with a cloth wheel mounted on the bench grinder. This requires a great deal of caution for a number of reasons. The buffing wheel will tend to grab corners and pull the part from your hands. Corners can quickly become rounded if polished too much. Also, the parts will become hot during buffing so leather gloves should be worn.

Figure 242: *Sandpaper is wrapped around a needle file or strips of wood to finish the interior edges of the plates. The plate is shown clamped in the wooden vise of a Workmate bench.*

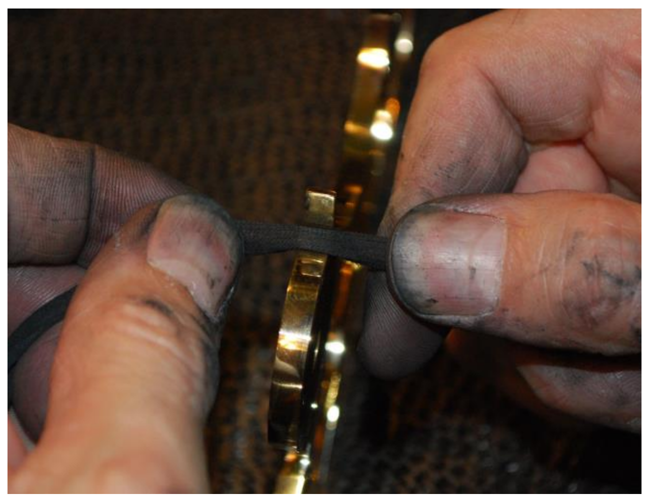


Figure 243: *A strip of cloth and Simichrome are used to polish the edges of the plates.*

I chose to polish the plates by hand due to the number of edges and corners that could be caught by the buffer. After sanding the edges and faces to a 2500-grit finish, Simichrome was used to bring the brass to a mirror finish.

A special technique is used to polish the grooves of the fusee since a buffing wheel will quickly round off the edges of the grooves. Instead, the fusee is mounted in the lathe while applying Simichrome polish with the edge of a piece of soft wood, following the groove across the fusee as it slowly rotates.

Brass will turn dark if not protected from oxidizing. Clear lacquer is the most common method of sealing brass and it was used on most of the exposed brass parts. I had significant difficulty applying lacquer to the plates. Spraying from multiple directions to cover all of the edges and corners resulted in areas of overspray. Dipping the plates in thinned lacquer also proved unsatisfactory as the corners tend to hold excess lacquer causing runs and sags. In the end, the rear plate received a somewhat adequate coat of lacquer and the front plate was protected with Renaissance wax. The waxed front plate currently looks more reflective, but time will tell which coating better protects the brass. Steel parts are polished and protected with wax to help prevent rust.

Assembly

If my count is correct, there are 128 individual parts and approximately 50 small screws that make up the clock. These parts are carefully assembled to prevent scratching the freshly polished surfaces. All bearing surfaces and holes must be free of lacquer and oiled with good quality clock oil. The pallets and crutch pin also require oil.

Remember the mainspring requires 1.5 turns of preload to establish the proper fusee tension. For the first run, the fusee should be wound only ½ turn just in case the clock needs to be disassembled to correct a problem.

Figure 244: *The individual parts before final assembly.*

Adjustments

Level the base of the clock and set the pendulum in motion. Adjust the crutch until the beat is steady and even. If the clock runs for a few hours without any problems, the fusee can be fully wound. Pay careful attention that the fusee stop engages correctly as the cable approaches the end of the fusee.

Run the clock for a full week or two before attempting to regulate the clock. This will allow the pallets and arbors to “settle in”. The pendulum weight can then be moved up or down to set the gross time keeping. The pendulum bob rating nut is used to make fine adjustments.

Case

The builder may choose to build or buy a case or large dome to protect the clock from dust and curious fingers. The variety of options is endless and the case I chose to make is shown in Figure 248. The polished brass frame holds the beveled glass and the front opens for access to wind the clock. 48 high-brightness LEDs are mounted in the recessed area of the top.

Figure 245: *Front view.*

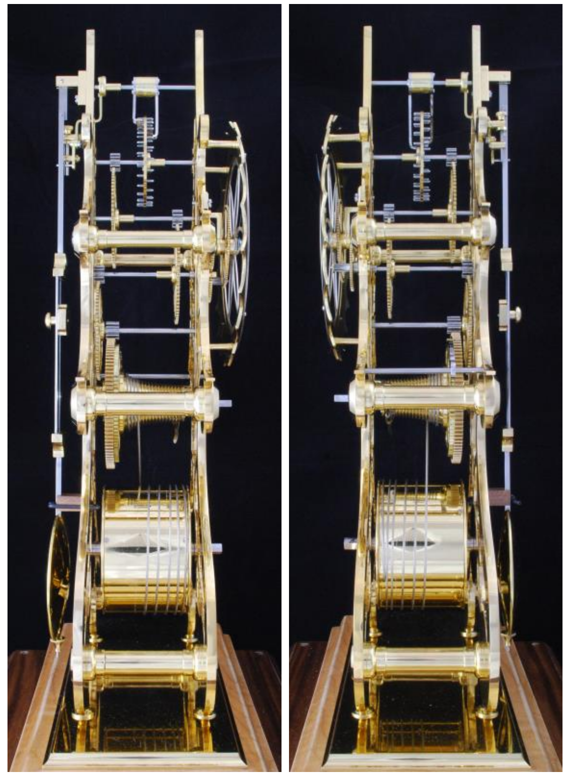
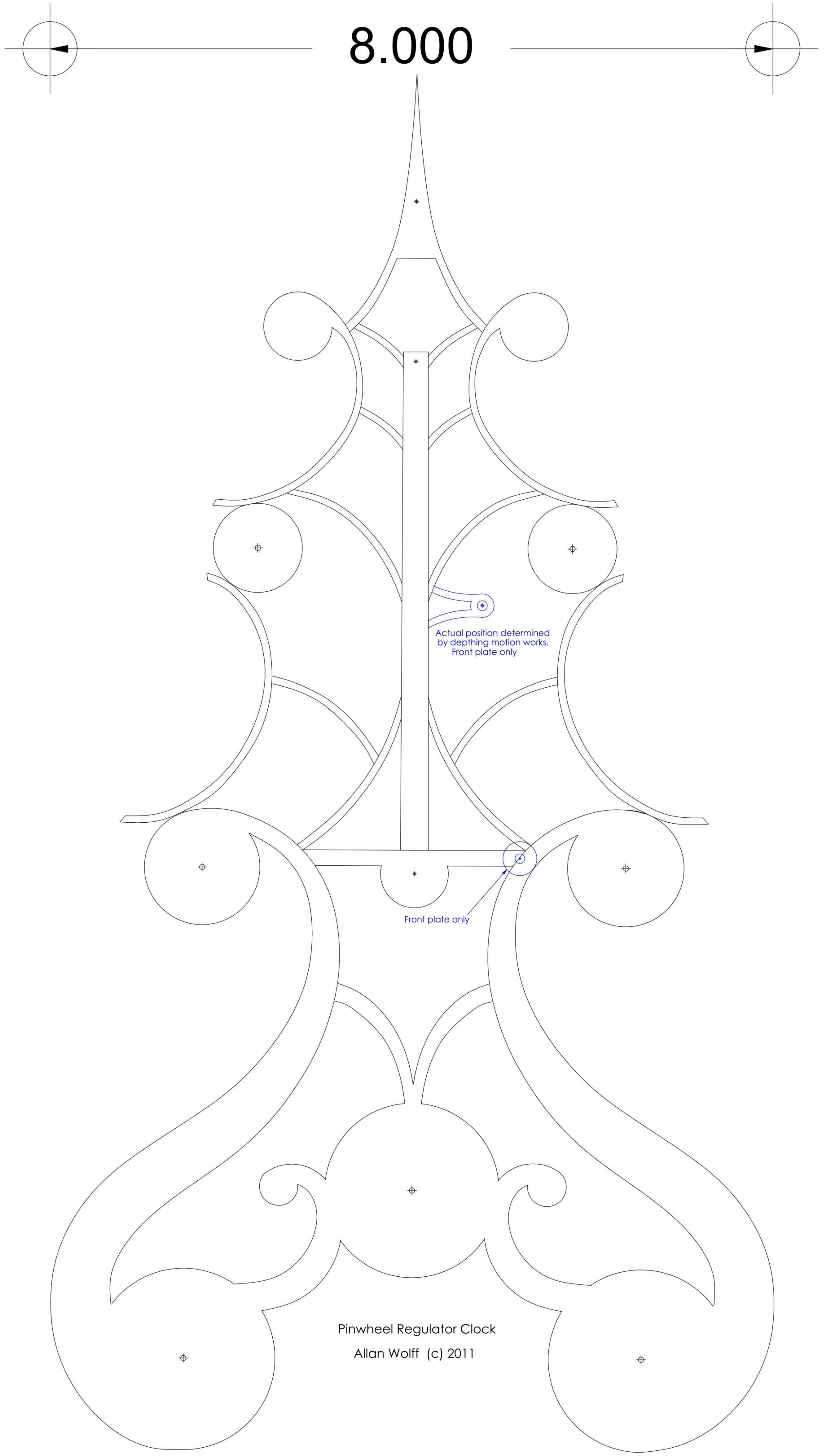


Figure 247: *Left and right side.*

Figure 246: *Rear view.*

Figure 248: *Brass & beveled glass case. The top and base were done in walnut and fiddle-back maple by Edward Wolff.*


8.000
Actual position determined
by depthing motion works.
Front plate only
Front plate only
Pinwheel Regulator Clock
Allan Wolff (c) 2011