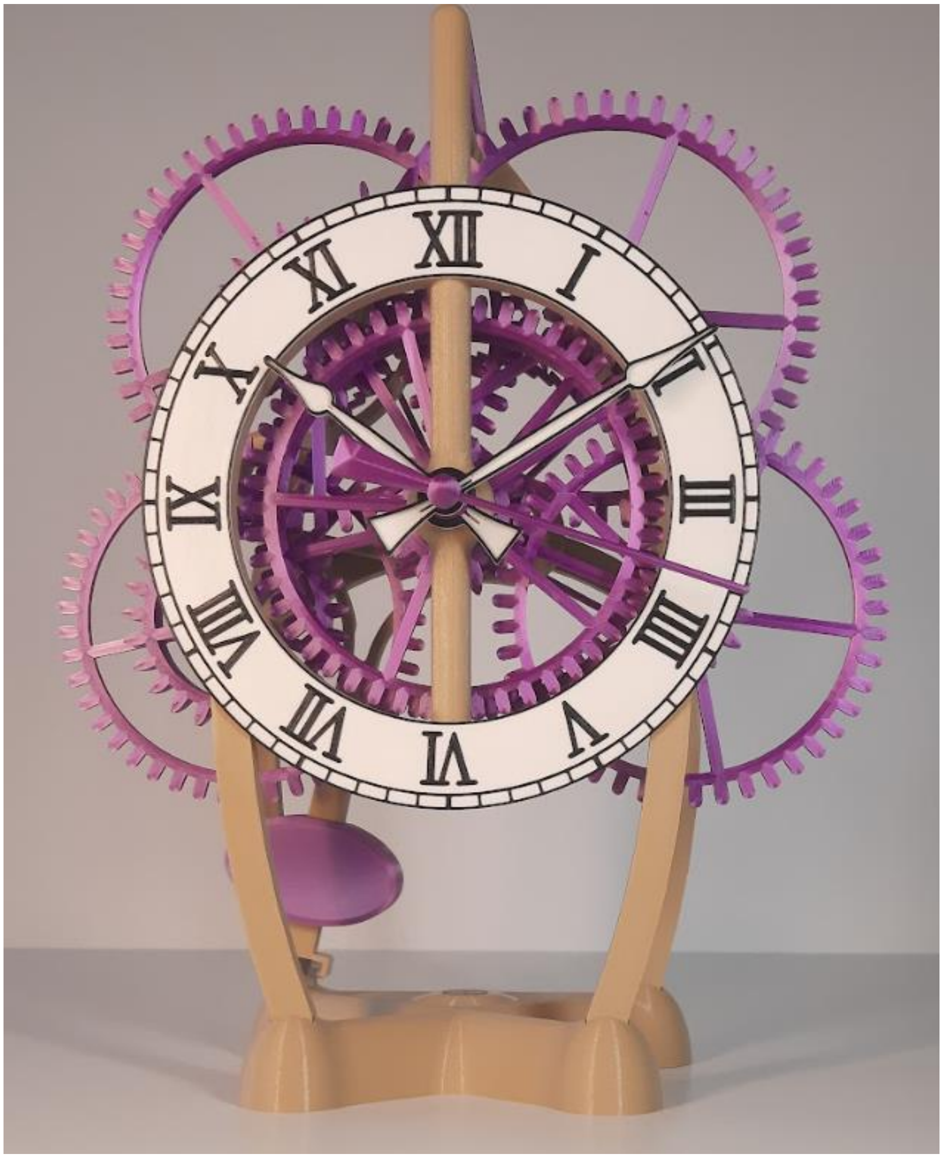

ELECTROMAGNETIC CLOCK ASSEMBLY NOTES

Instructions for building a 3D printed electromagnetic desk clock

Steve Peterson
11-Mar-2022

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Revision History

18-Feb-2022	Updated pages 30 and 32 to show 3.75” (95mm) arbor lengths. Added options on page 14 for additional front dial types.
11-Mar-2022	Fixed corrupted printed parts list table on page 14.

Description

This is my first 3D printed clock that runs on battery power. It uses a simple electromagnetic driver circuit that can be acquired for around US$4. Preliminary estimates show that it should run for more than a year on two AA batteries.

The design is loosely based on my stepper motor desk clock with an added pendulum. The second hand beats 60 times per minute, so the clock was sized to support a 10” (250mm) pendulum. This makes it larger than my stepper motor driven desk clock.

The clock shown on the front cover needs a printer similar to a Prusa MK3S (250x210mm) or an Ender 3 (220x220mm). The dial is 7.7” (195mm) in diameter and the overall size is 11.2” (284mm) wide, 13.8” (350mm) tall, and 5.9” (150mm) deep.

A design with a smaller front dial is also available that will fit on a Prusa Mini or any printer with a 180x180mm bed size. The dial was reduced to 7.0” (178mm) and the frame was re-partitioned to fit the smaller bed size. The pendulum and gears are the same so the overall size remains the same. This option is described in the appendix.

Total print time for either option is around 70 hours and about one roll of filament.

Electronics

The most important non-printed component is the electronics that drive the pendulum. The module is common on eBay and AliExpress, but rare on Amazon in the US. Prices are typically under US$4 including shipping. I ordered from different vendors and they start to trickle in about a month later. They are cheap enough that I don’t mind ordering several.

The module can be found by searching for “Quartz Pendulum Drive”. It is intended to add a pendulum to a standard battery driven clock. We will be using the circuit board, battery clips, and magnets. The plastic case is not needed.

Below is a drive module I ordered from eBay.

Quartz Pendulum Drive Unit Module General Movements Clock Repair Accessories-ca

Condition: **New**

Quantity: 1 More than 10 available / 83 sold

Price: **C $4.19**

Approximately US $3.29

Buy It Now

Add to cart

Best Offer:

Make Offer

Add to Watchlist

83 sold | 30-day returns

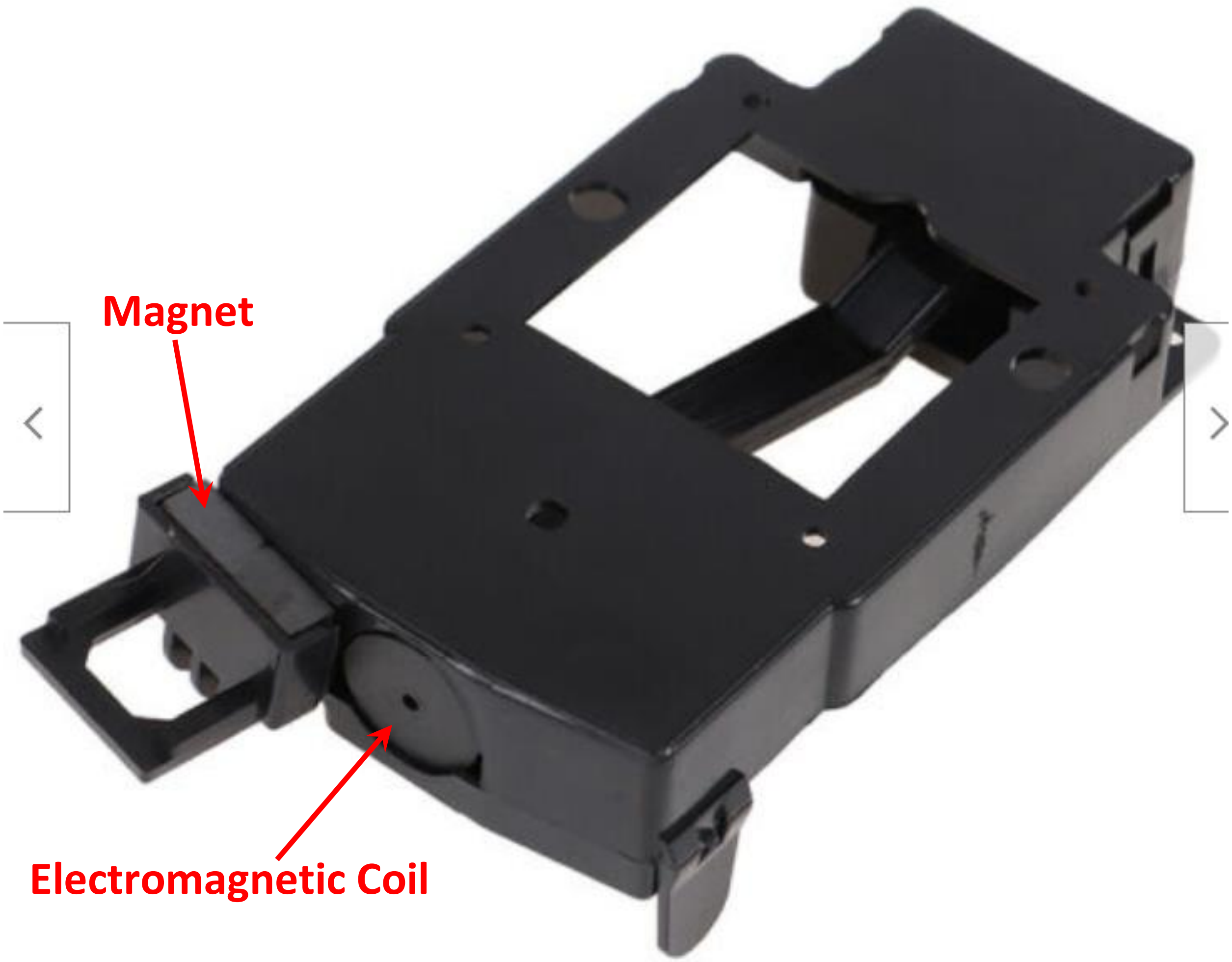
Shipping: **FREE** Economy Shipping from Greater China to worldwide | See details

International shipment of items may be subject to customs processing and additional charges.

Located in: Shanghai, China

$ Have one to sell? Sell now

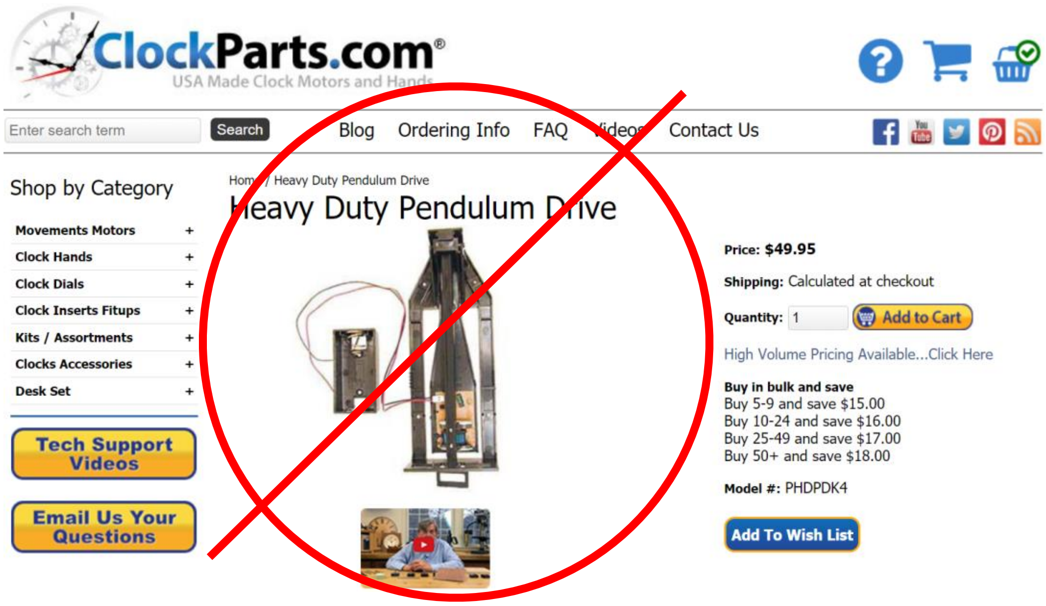
The proper pendulum drive module has two side by side magnets that pass near a small electromagnetic coil. Here is a close-up view.



Another distinguishing feature of the desired pendulum drive module is the coiled spring style battery clip. Here is another close-up view.

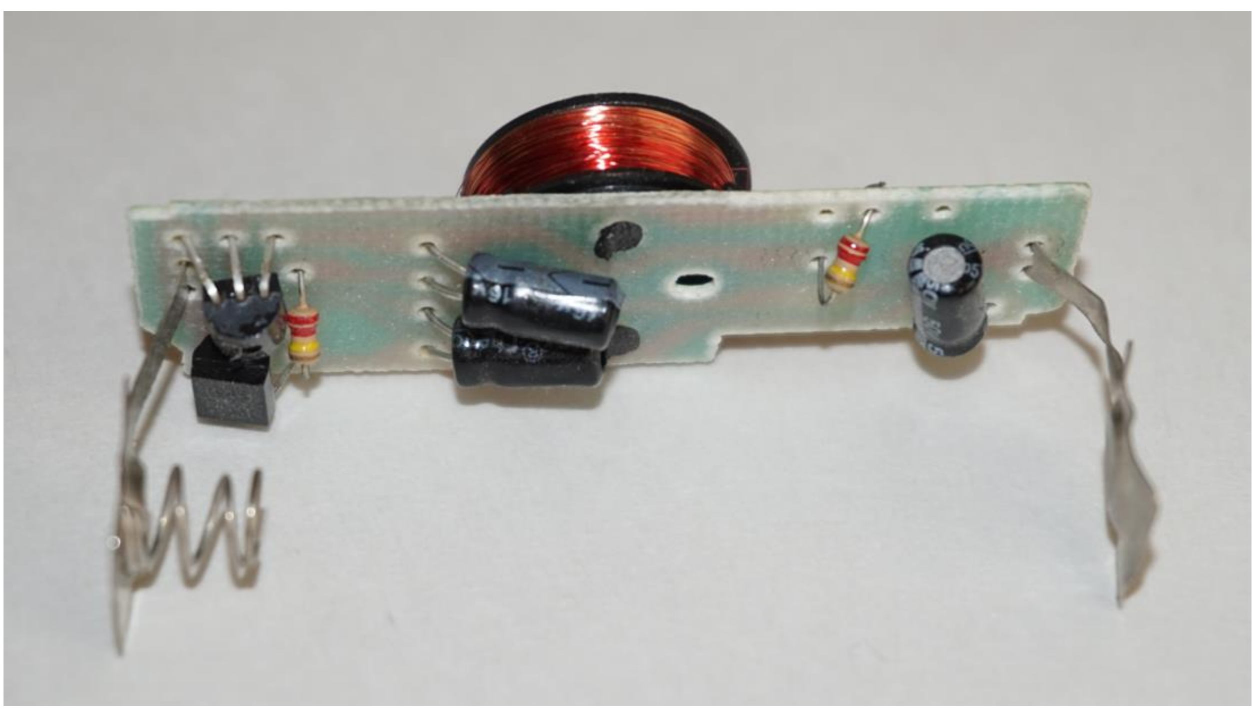
There are other pendulum drive modules with a flat blade battery clip. This is one I tested from Amazon. The internal electronics are a different size and will not fit into the clock base. The base would need to be redesigned to make it work, but the clock was designed to fit the other style.

There are also a few heavy duty pendulum drive circuits that seem very expensive so I did not try to use them.

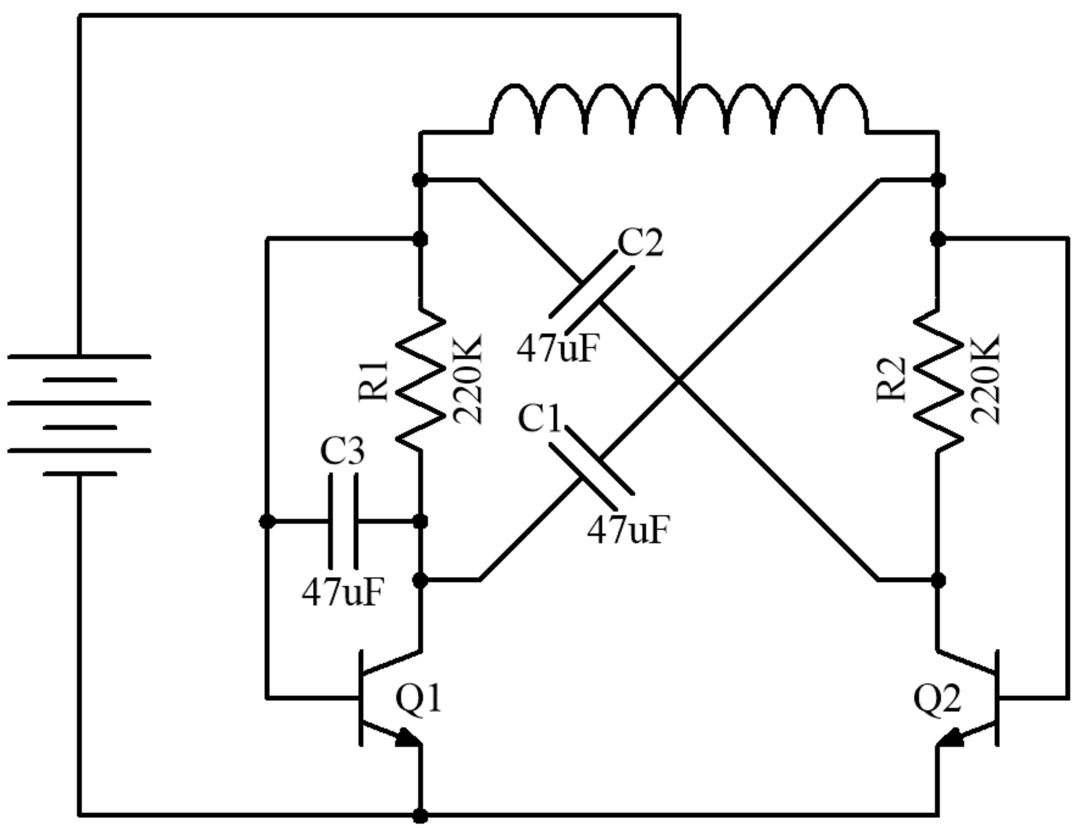


The internal circuit board of the desired pendulum drive module is shown below. It can be removed from the plastic case by spreading the tabs and pulling off the cover. One of my samples had a glued case that needed to be broken apart. This is OK. We are only interested in the electronics on the inside.

The circuit board should look like this:



The reverse engineered schematic is shown below. The magnet generates a current when it passes over the coil. Depending on the direction of the magnet motion, either Q1 or Q2 will trigger and conduct a large current through the opposite side of the coil through C1 or C2. This will push the magnet and add energy to the pendulum. The other side of the circuit will trigger when the pendulum passes in the other direction. Capacitor C3 probably helps to push the pendulum in one direction during startup.



Current was measured at about 2mA every time the circuit triggers. The total pulse width was 50ms and the pendulum has a 500ms period, so the circuit has a 10% duty cycle with an average current of about 0.2mA.

Alkaline AA batteries have around 2400mAh total capacity. The 0.2mA average current should be expected to power the clock for 12000 hours which equals 500 days. The measurements were a bit rough, but I would be quite happy with anything longer than 6 months. My first prototype is still running strong after more than a month.

Other Components

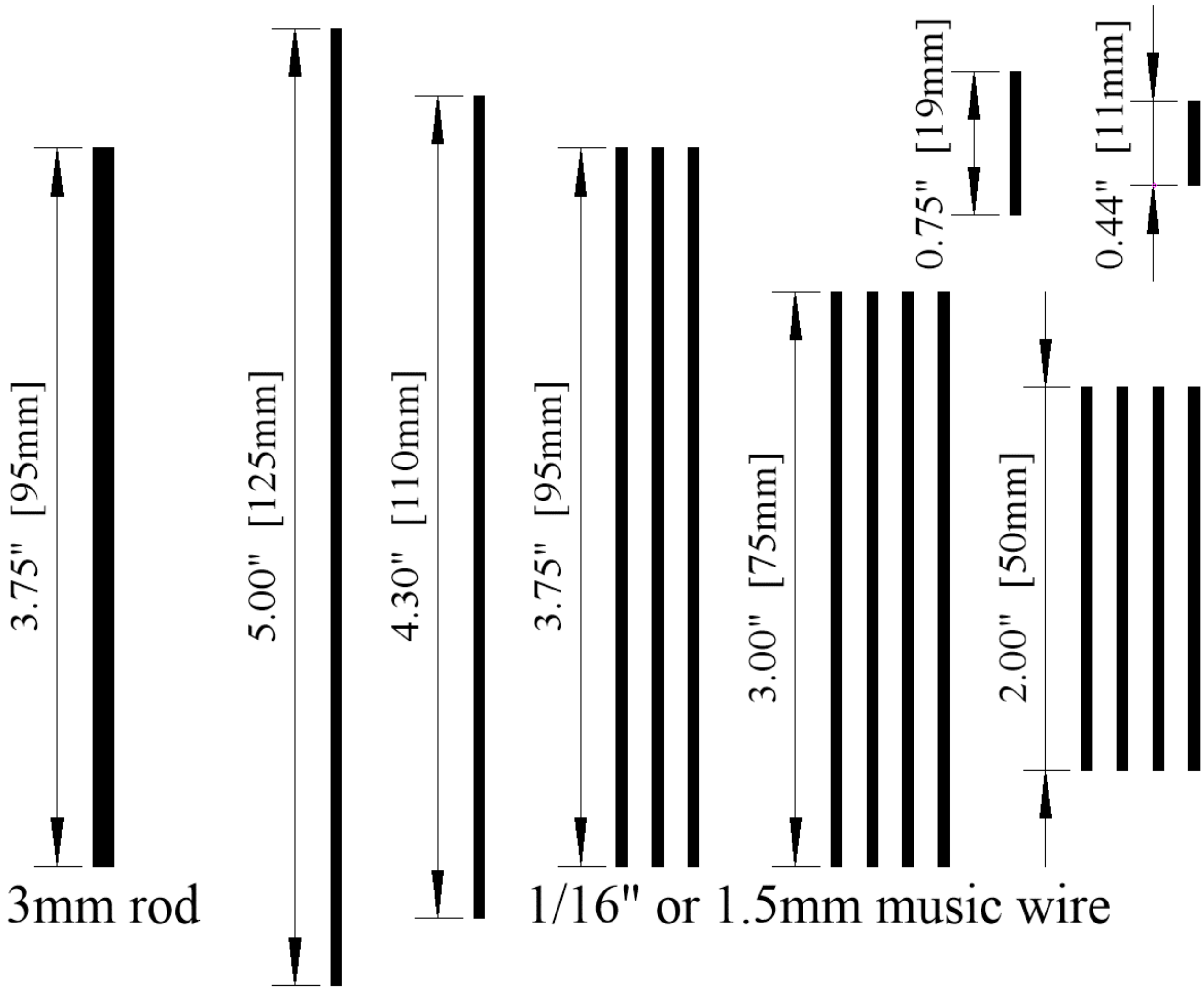
If you have built any of my other clocks, then you may already have many of the components needed to build this clock. The metric screws were in the spare parts bag from my Prusa MK3S. They may also be used in many other 3D printer brands.

This clock uses the following components. McMasterCarr part numbers are listed for some parts.

Qty	Component sizes (alternate size in parenthesis)	McMC Part No.	Notes
1	quartz pendulum drive module		Contains electronics and magnets See the previous section for a description
2	AA batteries		
6" (15cm)	fine gauge electrical wire		To extend battery clip locations
	epoxy or tape		To attach magnet to bottom of pendulum
3.75" (95mm)	3mm stainless or brass rod	1274T42	See cut metal parts list
42" (1.1m)	1.5mm (1/16”) music wire	89085K85	See cut metal parts list Either diameter can be used The option in Appendix A printed on a Prusa Mini needs 54” (1.4m)
17	#6x3/4” flat head wood screws	90031A151	Metric equivalent is M3*20 or M3.5*20 wood screws (both sizes should work) The option in Appendix A printed on a Prusa Mini needs 19 screws
1 to 5	M3*10mm (6-32*3/8") cap head screws	91292A113	Need one screw for time adjust knob, the rest are optional if printing parts that fit tight to the shafts, Phillips head is OK
1	M3*40mm (6-32*1.5") cap head screw	91292A024	For adjusting pendulum bob length, socket head is preferred, but can use Phillips head
0 or 1	M3 square nut	97258A101	For adjusting pendulum bob length, can use a printed option with a threaded fit and no square nut
2	623 bearing (3x10x4mm)	7804K128	Any quality of bearings will work, no seals are best, removable rubber seals are also good (McMasterCarr version has difficult to remove metal shields, try to find elsewhere)
1	click pen springs		Remove from a common ball point pen
24	pennies or small washers		Adds some weight to the pendulum bob

Cut Metal Parts List

The metal rods and music wire should be cut to the following sizes:



The small diameter music wire can be either 1/16” (0.0625” or 1.5875mm), 1.5mm (0.059”), or 1.6mm (0.063”). 1/16” and 1.6mm music wire are nearly identical. 1.5mm music wire may be easier to find in the metric parts of the world. The clock can be built using any of these sizes. It is best to find wire labeled as music wire or spring steel since they come in a hardened state, but softer steel rod can be used if that is all you have available. Use hardened cutters or a Dremel tool with a small cutoff disk to cut the wire. Remove any small burrs on the ends.

The pendulum support uses small ball bearings with 3mm inside diameters, so the 3mm rod diameter is important. The rod could be steel, brass, or aluminum. 1/8” rod could be used, but you would need to turn down the ends to fit into the bearings and drill the pendulum arm holes larger.

Tools

The following hand tools will be useful when building the clock:

Soldering iron

Small hand files

Screwdrivers

Allen wrenches to fit set screws

1.5mm, 1.6mm (1/16”), and 3mm drill bits

Hacksaw or Dremel with cutoff disk for cutting metal rods

Printing the Parts

Print one of each part in the table below. Most parts default to the optimal orientation with the largest surface already positioned on the build plate. Supports are not needed.

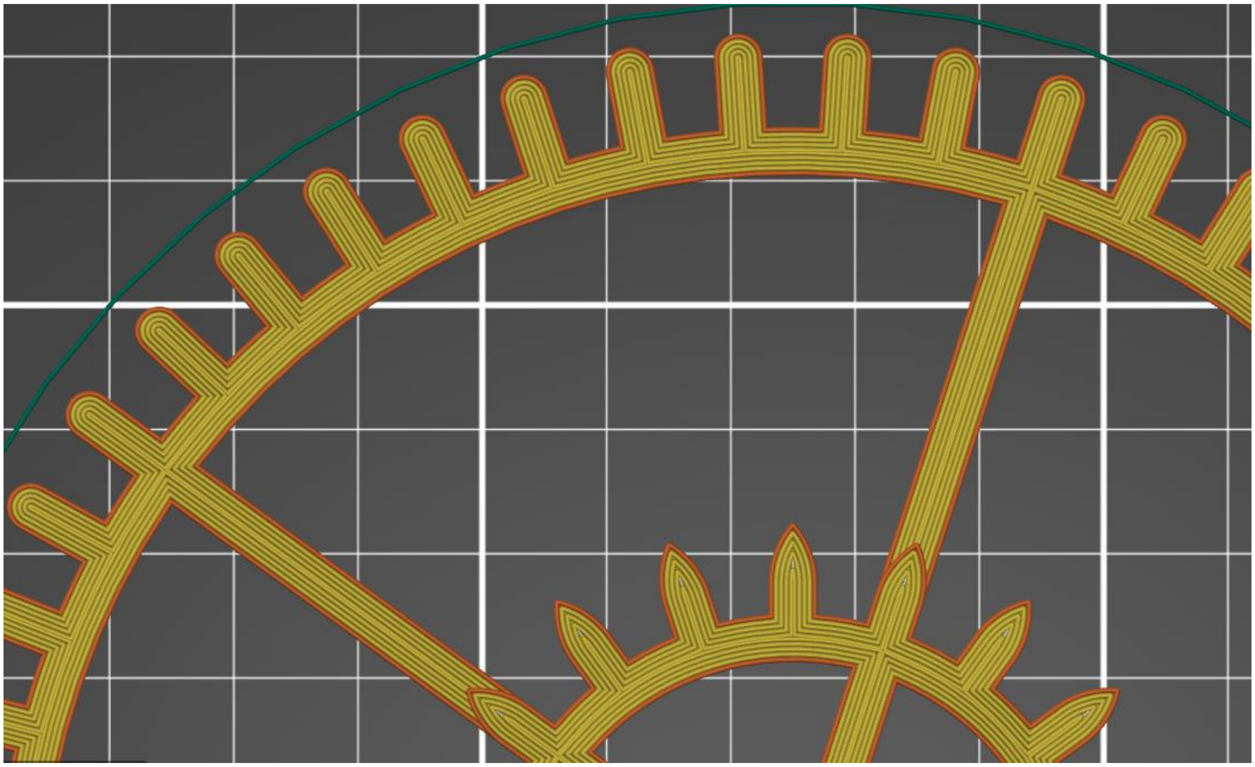
A few parts have multiple options, so select the one you prefer. The biggest choice is the front dial that can be a traditional Roman numeral dial or simple numbers. The second choice for the dial is either a simple top post (as seen on the front cover) or an arched front dial. Load the various dials into the slicer and select the option you like best. Other components have a press fit onto the shaft or set screws. The option with set screws is easier to build, but will require the additional screws. The press fit components have undersized holes that typically need to be drilled out for a close fit where the shaft can be tapped into position.

I print all parts, except when noted differently, with a 0.4mm nozzle, 0.20mm layers, 4 perimeters, 7 top layers, 6 bottom layers, 30% cubic infill, 0.12mm elephant foot compensation, and random seams. Any special parameters are listed in the table below. Specifically, the gears and a pendulum arm are designed to print best with 5 perimeters. The second hand needs to print with enough perimeters for the counter-weight to be completely solid.

The gears look best using a bold color. Gold or bronze are good. Silk PLA is also good. The clock on the cover picture was printed using purple silk PLA. The frame can be printed using a neutral color with a light colored dial and dark highlights for the numbers. The colors listed in the table are only suggestions. I use PLA exclusively, although it may be possible to use different materials.

The print times were reported in PrusaSlicer 2.3.0 in normal mode with 0.20mm layer heights. It is OK to combine multiple parts into one long print job, although many parts are so large that it is difficult to fit more than one on the build plate at a time.

The gears in this clock have a modified cycloidal tooth shape that is optimized for 3D printing. The primary optimization is to define all the key parameters with a consistent width that prints cleanly using 5 perimeters. Here is a portion of a gear showing the filament lines with minimal retractions.



The gear teeth appear reversed from a cycloidal gear used in many older clocks. The gear train in a traditional weight driven clock has large cathedral shaped gears driving round shaped pinions. Everything reverses in this clock because power is provided at the fast moving ratchet. The speed of all other gears is reduced. The inner cathedral shaped gear teeth drive the outer round shaped gears. Technically, the gear shown above could be considered to be a 20 tooth wheel with a 50 tooth pinion.

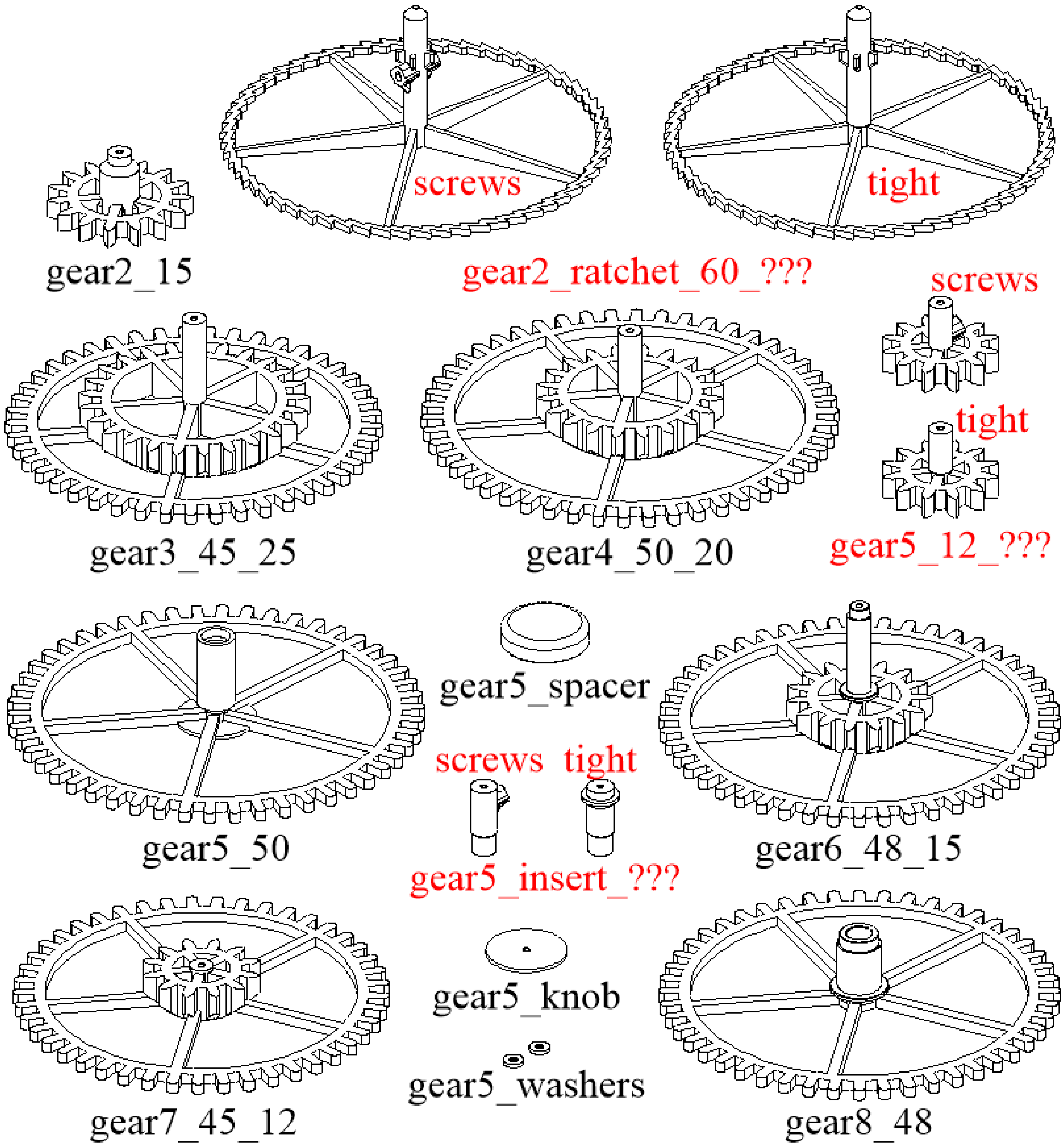
Other optimizations were done to straighten the gear tooth side walls for cleaner printing. Traditional tapered side walls would often require small dots of infill added inside every tooth. You can watch the gear get printed and the last step of each layer would be a pass around the perimeter to add a tiny bit of infill. These infill dots often result in stringing and sometimes leftover filament that shows up on the gear teeth as a rough surface. Eliminating most of these infill dots produces much better looking gears, although they sometimes still occur on the smaller inner gear teeth. It is a minor problem since the inner gears have the smallest numbers of teeth.

Adding extra perimeters to produce solid gears will use extra filament, but surprisingly no additional time. The print time with 2 perimeters is similar to the print time with 5 perimeters. Printing with 3 or 4 perimeters would take the longest.

Printed Parts List

File Name	Color	Print	Time	Filament	Notes
frame_back_bottom	tan, purple	1	5h 19m	19.88m	Add a color change at 10.4mm
frame_back_top	tan, purple	1	5h 8m	17.54m	Add a color change at 10.4mm
frame_base	tan	1	11h 5m	49.22m	
frame_base_battery_cover	tan	1	1h 15m	5.4m	Could use a brim
frame_base_battery_holder	tan	1	1h 9m	4.6m	
frame_dial_numbers	tan, ivory, purple	1	8h 56m	47.11m	print one of any style, may need to rotate to fit a square build plate Add color changes at 10.40mm and 12.20mm
frame_dial_numbers_arch	tan, ivory, purple		9h 33m	49.68m	
frame_dial_roman	tan, ivory, black		9h 6m	47.54m	
frame_dial_roman_arch	tan, ivory, black		9h 42m	50.11m	
frame_front_left	tan	1	1h 7m	4.57m	
frame_front_right	tan	1	1h 7m	4.59m	
gear2_15	purple	1	1h 10m	3.15m	5 perimeters
gear2_ratchet_60_screws	purple	1	1h 33m	4.17m	5 perimeters - print either one with a screw fit or tight friction fit
gear2_ratchet_60_tight	purple		1h 27m	4.02m	
gear3_45_25	purple	1	4h 12m	15.05m	5 perimeters
gear4_50_20	purple	1	3h 46m	13.67m	5 perimeters
gear5_12_screws	purple	1	1h 5m	2.76m	5 perimeters - print either one with a screw fit or tight friction fit
gear5_12_tight	purple		1h 4m	2.7m	
gear5_50	purple	1	2h 19m	7.97m	5 perimeters
gear5_insert_screws	purple	1	0h 26m	0.7m	5 perimeters - print either one with a screw fit or tight friction fit
gear5_insert_tight	purple		0h 25m	0.69m	
gear5_knob	purple	1	0h 22m	1.56m	
gear5_spacer	purple	1	0h 5m	0.33m	
gear5_washers	purple	1	0h 2m	0.05m	
gear6_48_15	purple	1	3h 18m	11.44m	5 perimeters
gear7_45_12	purple	1	2h 40m	9.19m	5 perimeters
gear8_48	purple	1	2h 7m	7.42m	5 perimeters
hand_hour	ivory, black	1	0h 13m	0.7m	Add a color change at 2.20mm
hand_minute	ivory, black	1	0h 15m	0.77m	Add a color change at 2.20mm
hand_second	purple	1	0h 27m	1.39m	14 perimeters so it is solid
pawl_active_arms	purple	1	0h 51m	2.66m	active pawl options
pawl_active_clips	tan	1	1h 14m	3.29m	active pawl clip options
pawl_static_arms	purple	1	0h 34m	1.61m	static pawl options
pawl_static_clip	tan	1	0h 19m	0.76m	
pendulum_arm_bottom	tan	1	2h 5m	7.9m	5 perimeters
pendulum_arm_spacer	tan	1	0h 14m	0.37m	
pendulum_arm_top	tan	1	3h 7m	9.14m	5 perimeters
pendulum_bob_back_nut	purple	1	0h 31m	2.04m	print either one to use a square nut or tight threaded fit on the screw
pendulum_bob_back_tight	purple		0h 31m	2.06m	
pendulum_bob_front	purple	1	2h 17m	7.56m	
pendulum_shims	tan	1	0h 10m	0.29m	
	Total	**34**	**70h27m**	**425.65m**	

Here is a diagram showing the gears used in the clock. The optional parts that can be printed using screws or tight friction fit are shown in red text. Only one version needs to be printed.



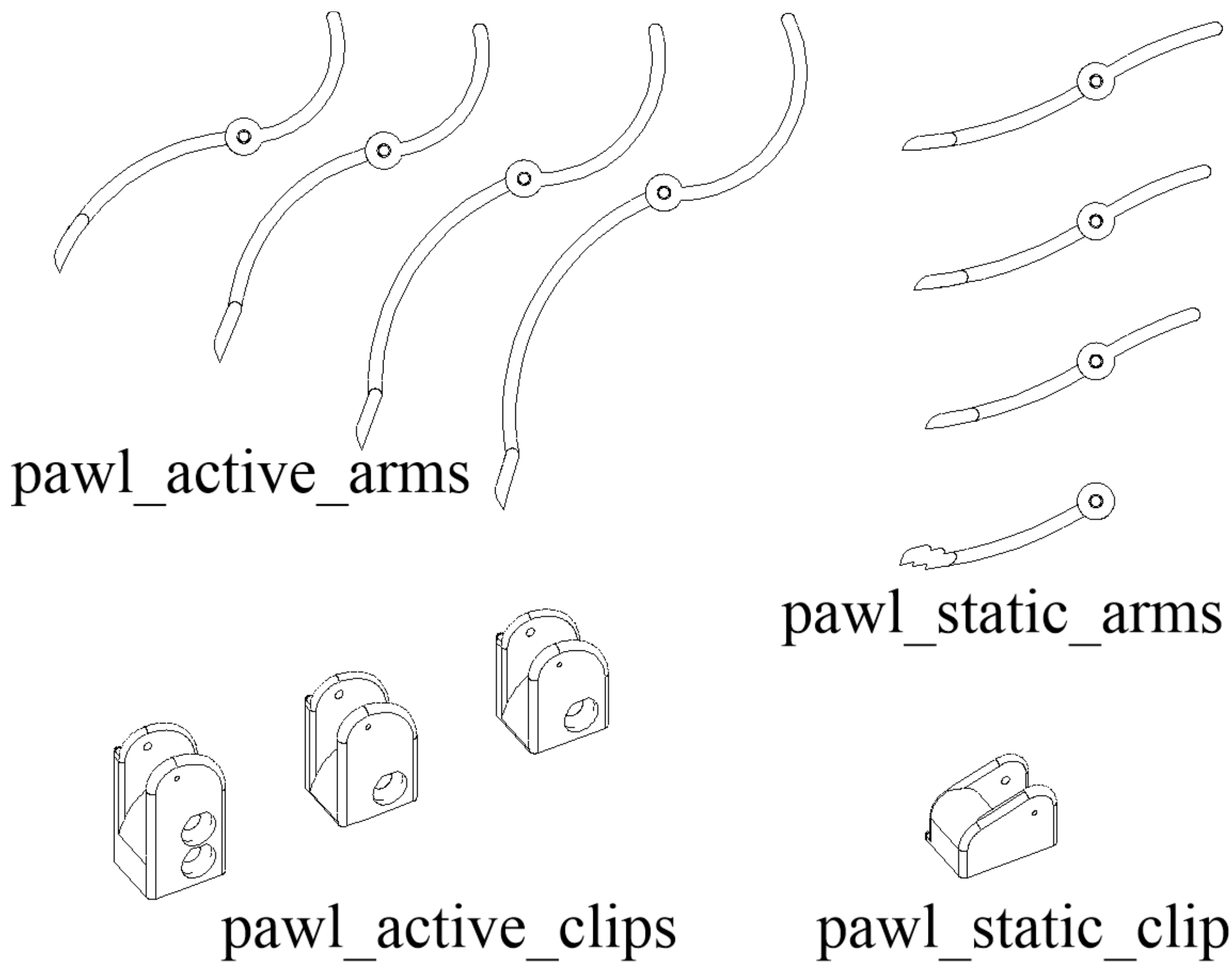
The movement of the ratchet can be fine-tuned using various size pawls as shown below.

The pawl_active_arms come in different lengths to support a range of pendulum amplitudes. They are counter-balanced to minimize noise and friction.

The pawl_active_clips attach the active pawls to the pendulum. Most of the adjustment can be done using the largest clip. The two shorter clips are needed for very large pendulum amplitudes when the clip needs to be attached very high on the pendulum arm.

The pawl_static_arms come in different lengths to adjust for various active pawl lengths and positions. The static pawl with three teeth can be used to help identify the best “normal” static pawl.

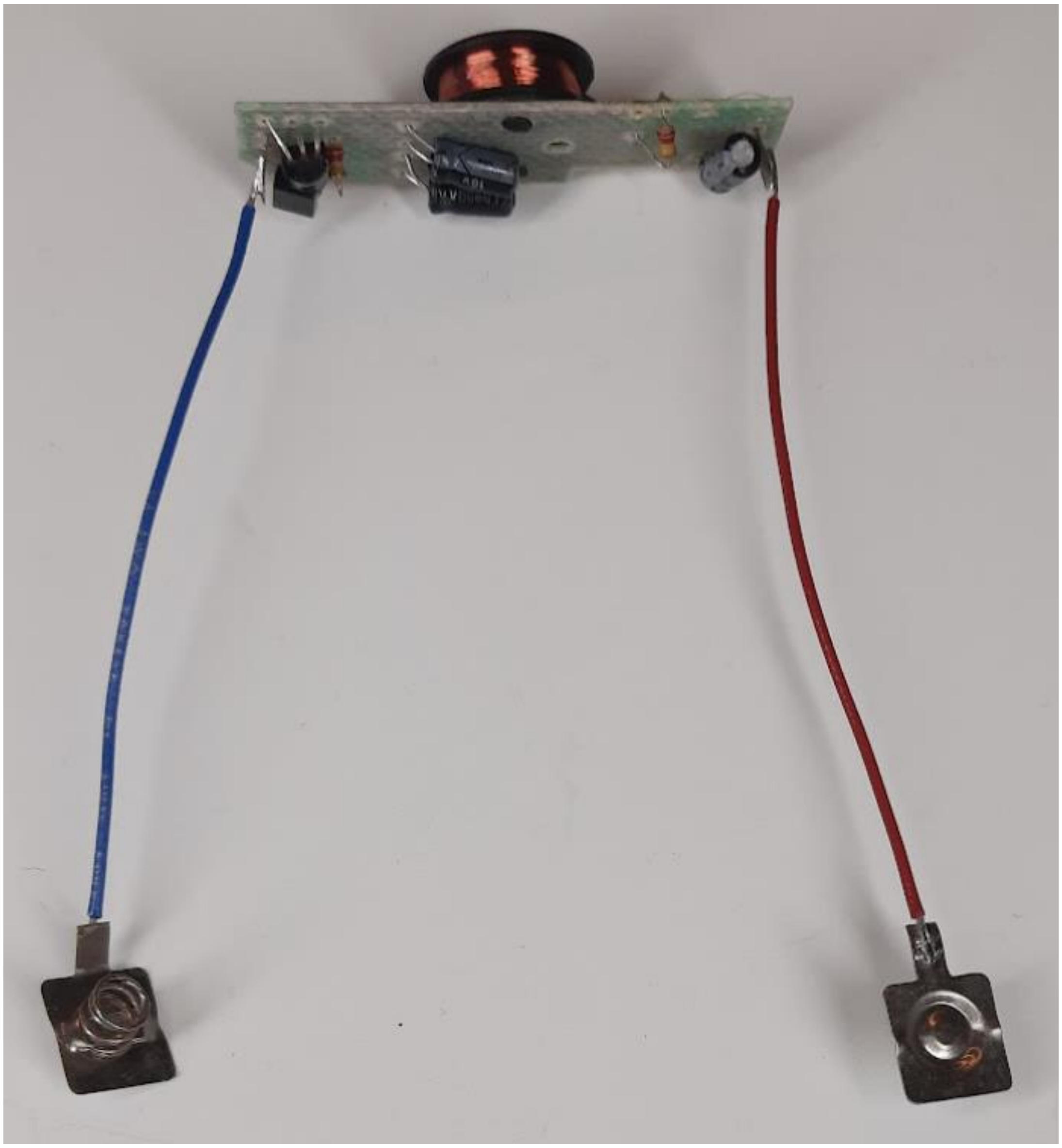
There is only one pawl_static_clip.



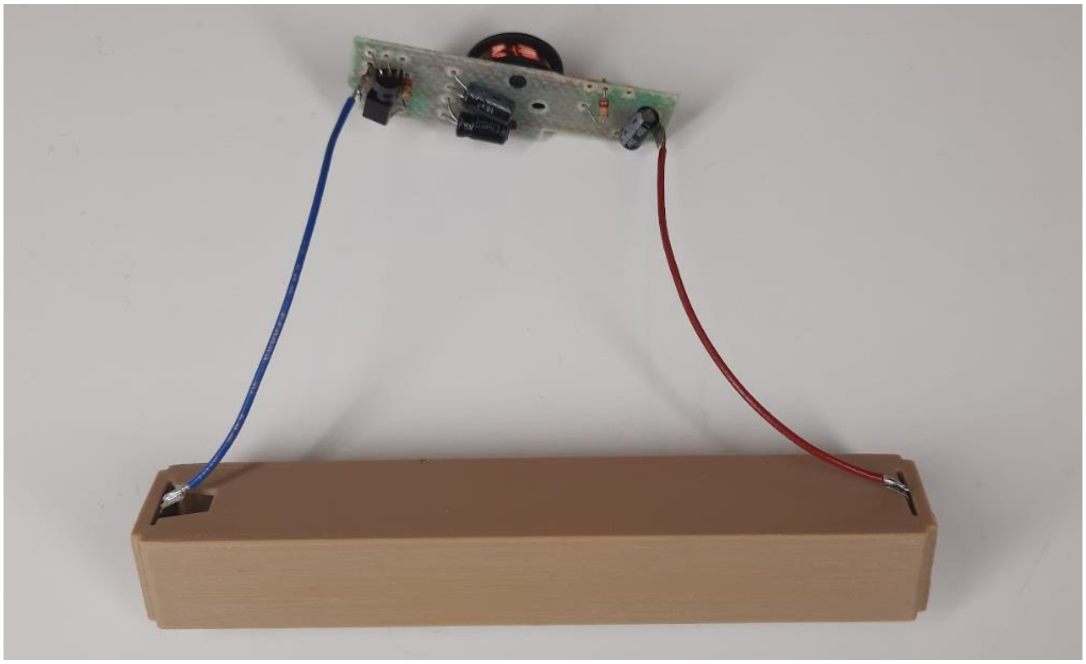
Pendulum Driver Battery Connection

The clock operates using a readily available pendulum driver module that normally impulses a free swinging pendulum. The ratchet takes energy from the pendulum, so extra energy is added by using a second battery. The battery terminal clips need to be extended to span two AA batteries.

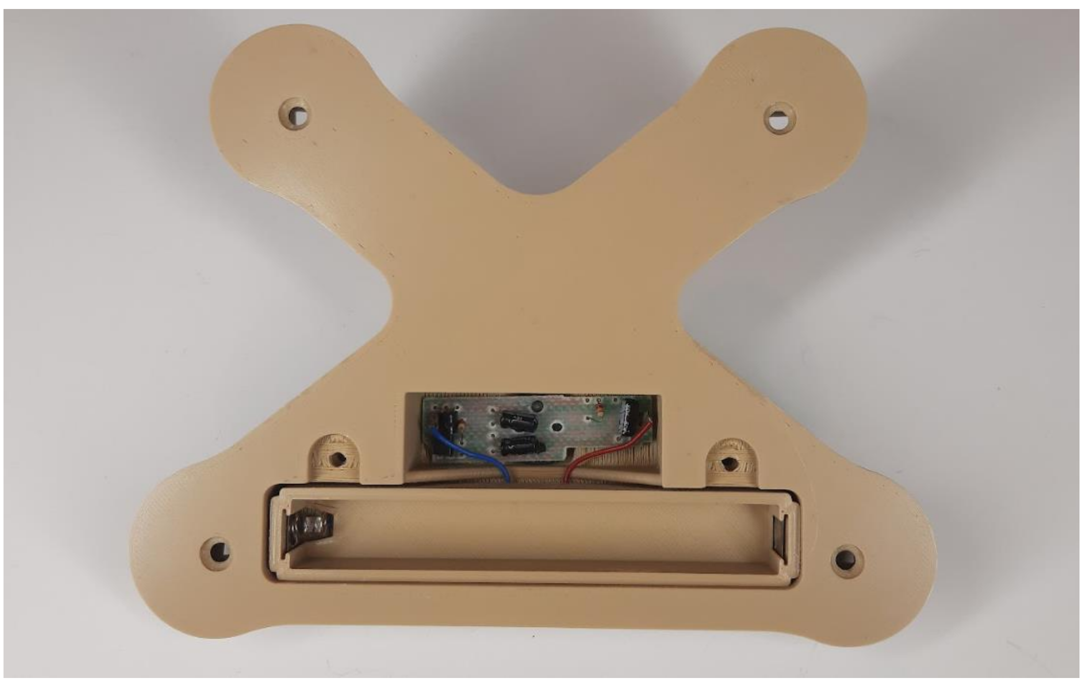
1) Cut two pieces of fine gauge electrical wire about 3" (75mm) long and strip the ends. The current is low enough that anything between 20 gauge and 30 gauge wire should work.
2) Cut the tabs of the battery terminals near the center of the narrow portion. This will leave a small tab on both ends with enough length to solder the wire.
3) Solder the wire between the circuit board and the battery terminals. Make sure to keep the negative terminal with the coiled spring connected to the side closest to the transistors.



4) Insert the battery terminals into the battery holder. There is room on one side for the coiled spring to fit.



5) Add the completed module into the base as shown below so the tabs on the battery cover will fit properly. Position the wires to the side as shown in the diagram.



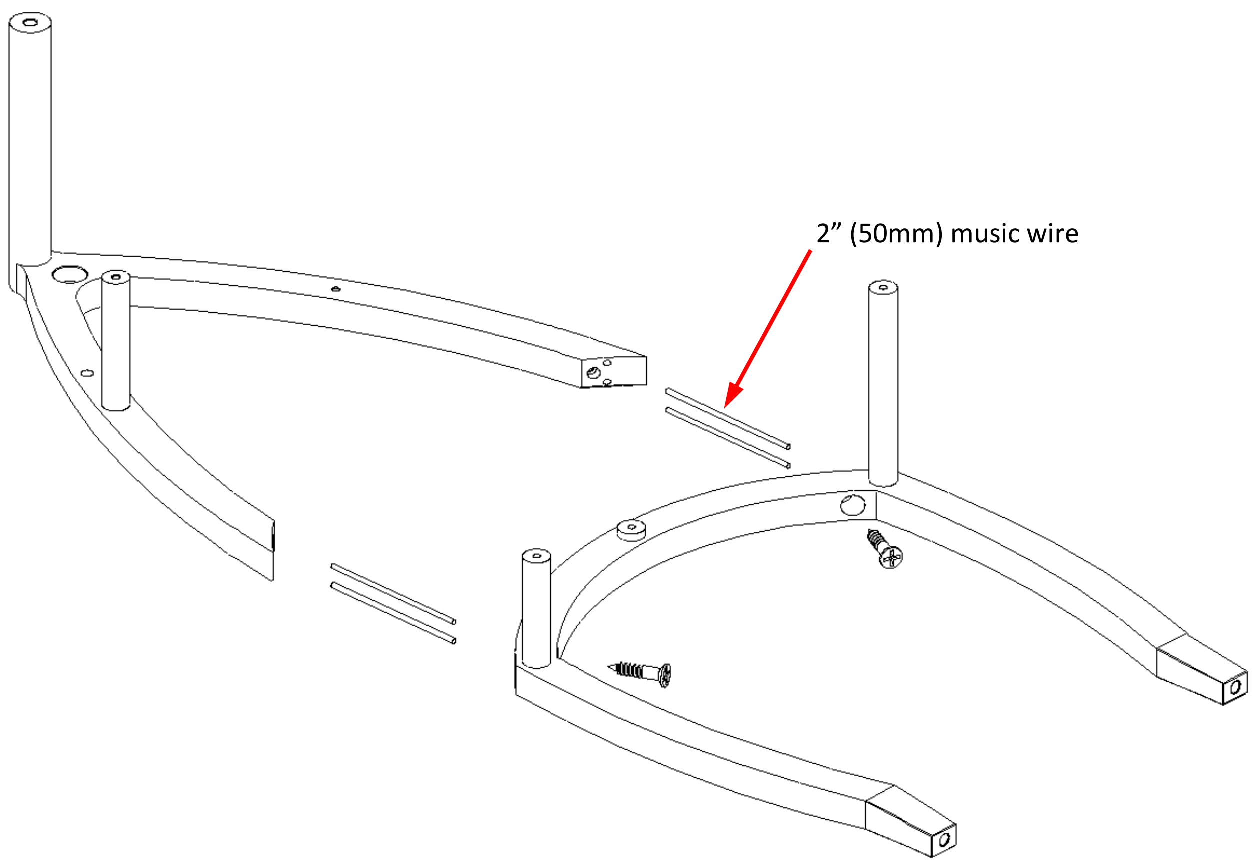
6) Add two AA batteries into the holder and add the battery cover using two #6x3/4" wood screws. These common size wood screws are used throughout the clock. The metric equivalent size is either M3x20mm or M3.5x20mm. Both sizes should work. M3 will be slightly loose and M3.5 may be snug, but should still fit.

Printed Part Pre-Assembly

Back Frame

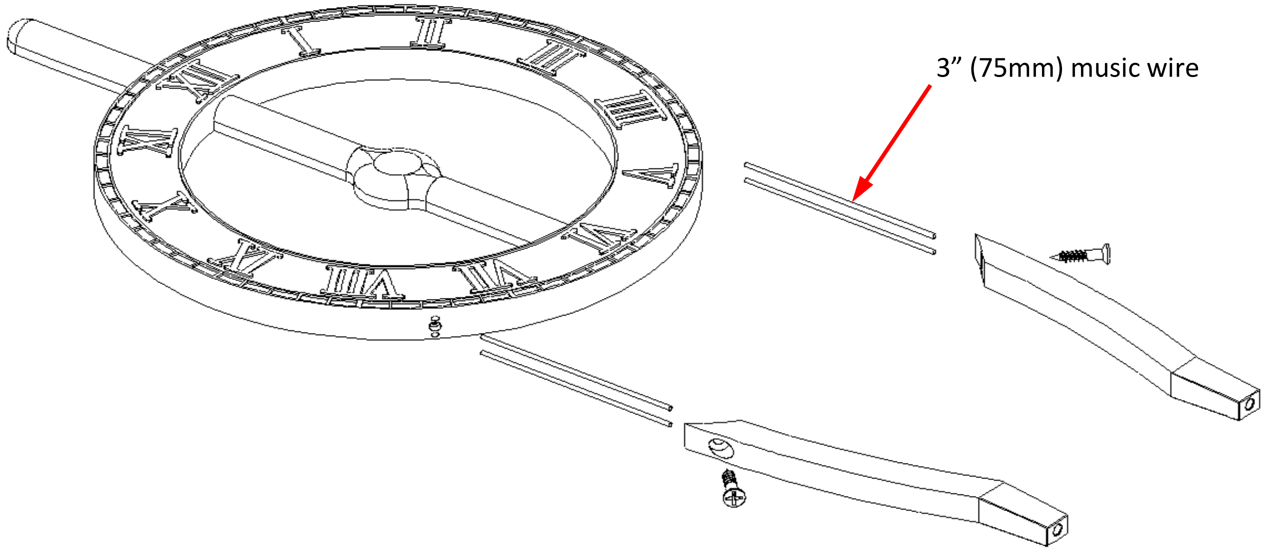
The back frame has two components that use four 2” (50mm) alignment pins and two screws to create a clock that is larger than the standard 3D printer bed size. The alignment holes are tight and may need to be drilled out to fit the pins.

Add the four alignment pins and push the pieces together. Two screws hold everything together. Check that the back is flat.



Front Frame

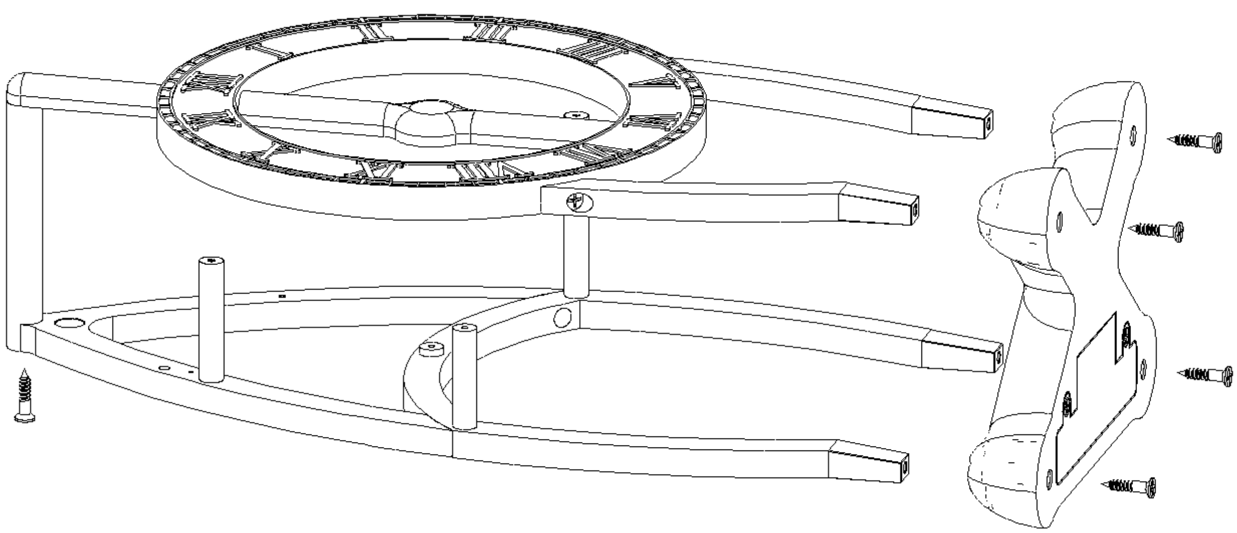
The front frame has three components and goes together similar to the back frame. There is room for 3” (75mm) long alignment rods. The taper on the front legs should be towards the front, so the back side of the front frame is completely flat.



Test Fit the Frame

Add the front and back frames into the base. There are four screws on the bottom of the clock and one screw at the top inside a deep pocket. The frame fits into the base using tapered pins that go together very easily.

Check that the frame is parallel along the entire height. The center portion should be approximately the same depth as the top and bottom. It is OK if there is a slight warp along the height as long as all parts are warped by a similar amount. Everything prints in the same orientation, so if parts warp when they cool, they might warp in the same direction.



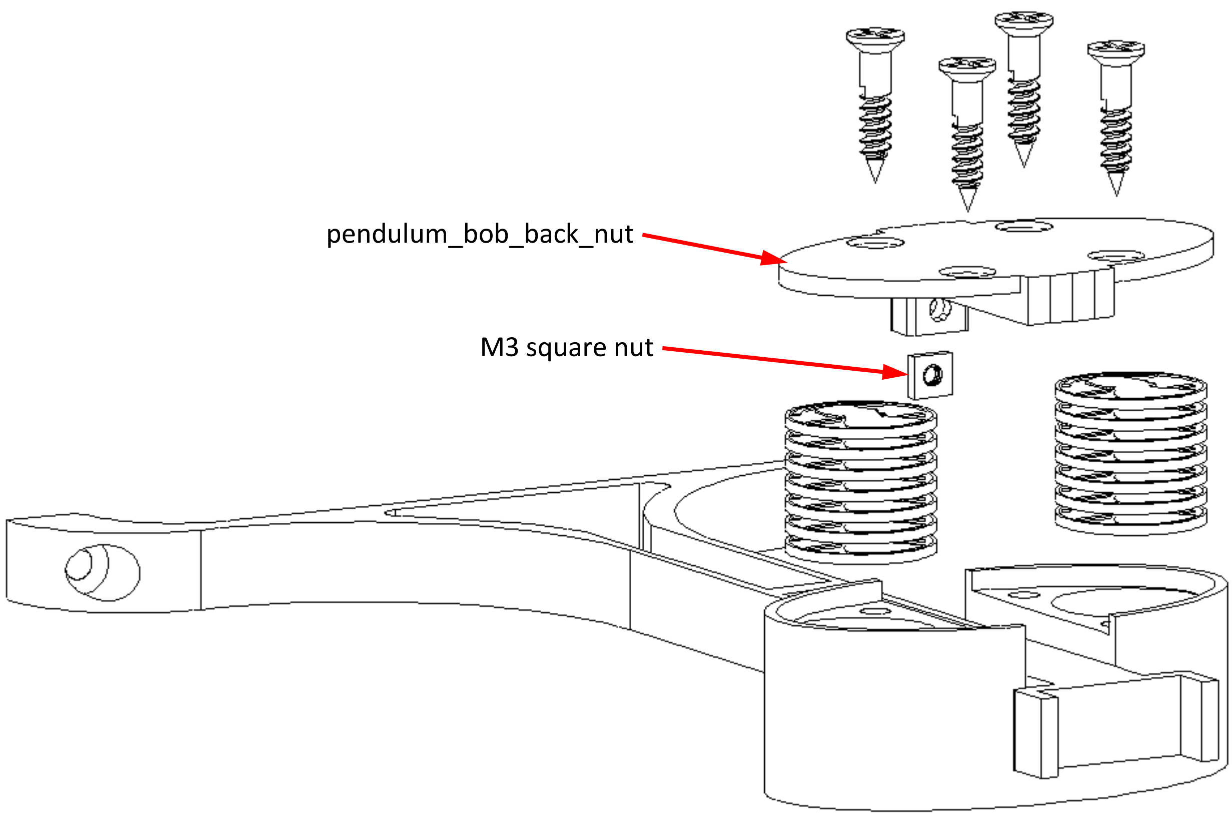
Pendulum Bob

The pendulum bob is a two piece shell filled with small weights to give the pendulum some momentum. The holes are sized to fit US pennies, but it should also fit 1 or 2 cent Euro coins. Anything metal that fits in the holes will work. You could use washers, large nuts, BBs, lead shot, etc. The total amount of weight is not critical as long as it is reasonably dense.

Add a 3mm square nut into the pendulum bob back piece if you are using the pendulum_bob_back_nut option, or pre-thread the M3*40mm (6-32*1.5") screw into the pendulum_bob_back_tight option.

You may want to pre-thread the bob back to prevent it from splitting if you use the tight option. Clamp it with a hand clamp to apply some pressure along the layer lines. Thread the screw into the hole using gentle pressure. Back it out after a few turns if needed.

Place the pendulum bob around the lower pendulum arm and add four #6*3/4” wood screws. The nut (or “tight”) portion of the bob should be towards the top to receive the M3*40mm (6-32*1.5”) screw. This should allow for a reasonable range of pendulum length adjustment. Make sure the bob easily slides up and down the pendulum arm.

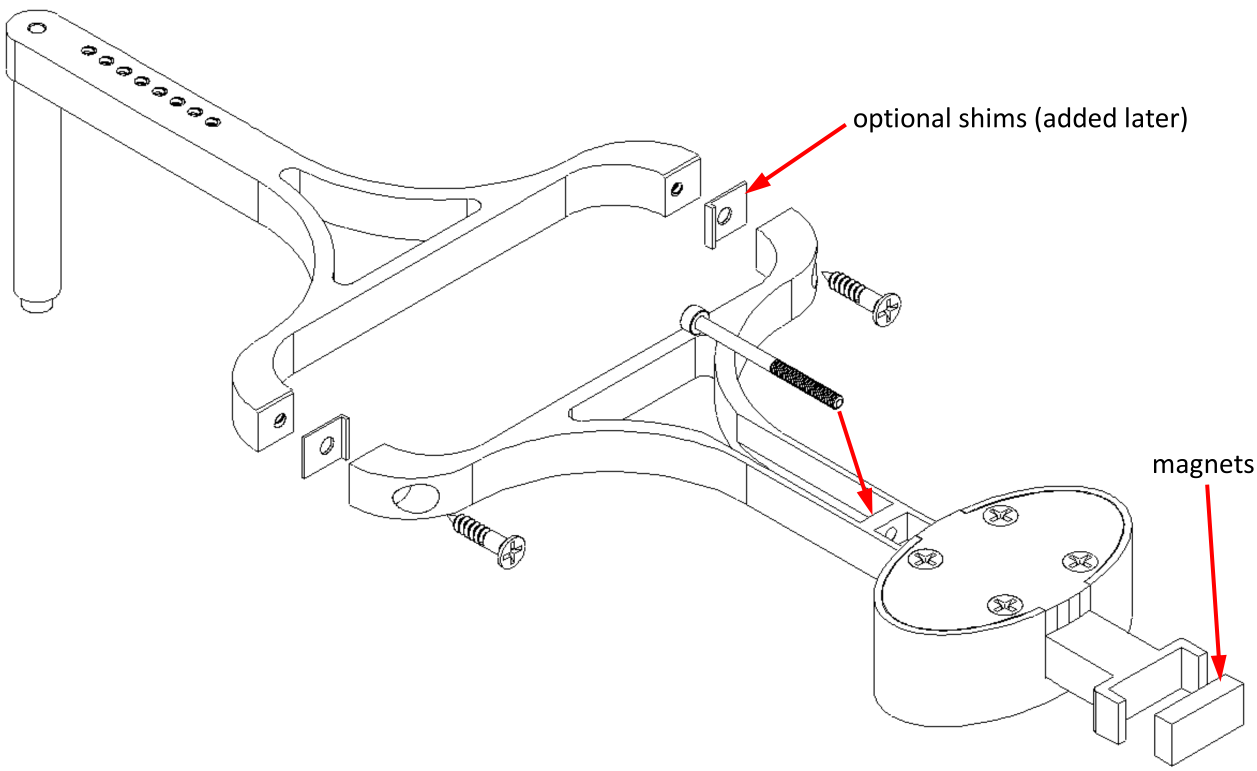


Pendulum

The magnets need to be removed from the clock driver module to be glued into the pendulum arm. Pry the plastic parts away from the magnets in the pendulum driver. It is OK to break the plastic when removing the magnets. We are only interested in the magnets.

The magnets need to be glued or taped to the bottom of the pendulum arm. I don't think the orientation matters. I usually just wrap thin strips of Scotch tape around the ends of the magnet and lower pendulum arm. Silicone glue or epoxy should also work.

Attach the both pendulum arm halves together using two #6x3/4" wood screws. Notice the orientation of the lower portion to allow access to the pendulum length adjustment from the back of the clock.



Bearing Cleaning

All of my 3D printed clocks use small ball bearings to support the pendulum. They have amazingly low friction to give great run times for weight driven clocks. The secret is to remove the rubber seals to remove the thick factory grease. The loads in the clock are so small that they will not wear out even if they are used dry. This clock uses the same bearings as my weight driven clocks. I am not sure if they need the factory grease removed. It is a small step, so I continue to do it.

Open (unshielded) 623 bearings would be easiest to use, but hardest to find. Rubber sealed bearings are a very good option. Pry out the rubber seal using a small pin or safety pin. Soak the bearings in solvent that will dissolve the grease. I use mineral spirits. Alcohol used to clean the print bed may also work.

You can add a drop of dry Teflon lube or very light oil to help protect the bearings from rust. This step would not be needed if you have stainless steel or ceramic bearings. I use cheap bearings, so I add a drop of Teflon lube to each bearing. They should spin freely for several seconds after cleaning.

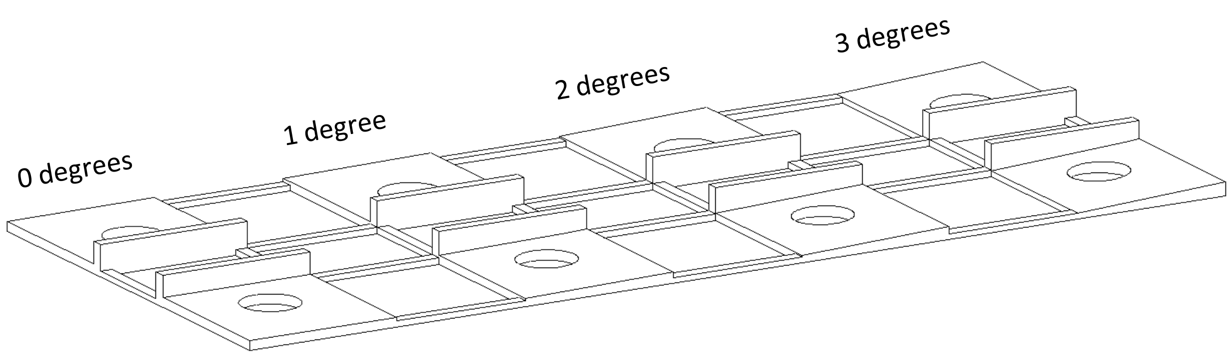
Pendulum Alignment

This is a great time to test the fit of the pendulum arm into the frame. It is easiest to adjust things without all the other gears in the way. If you already added the electronics into the base, then you can test it as well.

Insert the 3mm rod into the pendulum arm. The hole may need to be drilled out slightly to accept the 3mm rod. Add the pendulum arm spacer to the shaft with the narrow end towards the bearing. Insert the pendulum arm into the back frame with a bearing on both ends of the rod. Add the front frame and the clock base.

The pendulum should start swinging on its own if the electronics are working. A small oscillation will build up to a full amplitude swing. It may swing with enough energy for the pendulum to bump into the end stops. The amplitude will settle down a bit when the ratchet load is added.

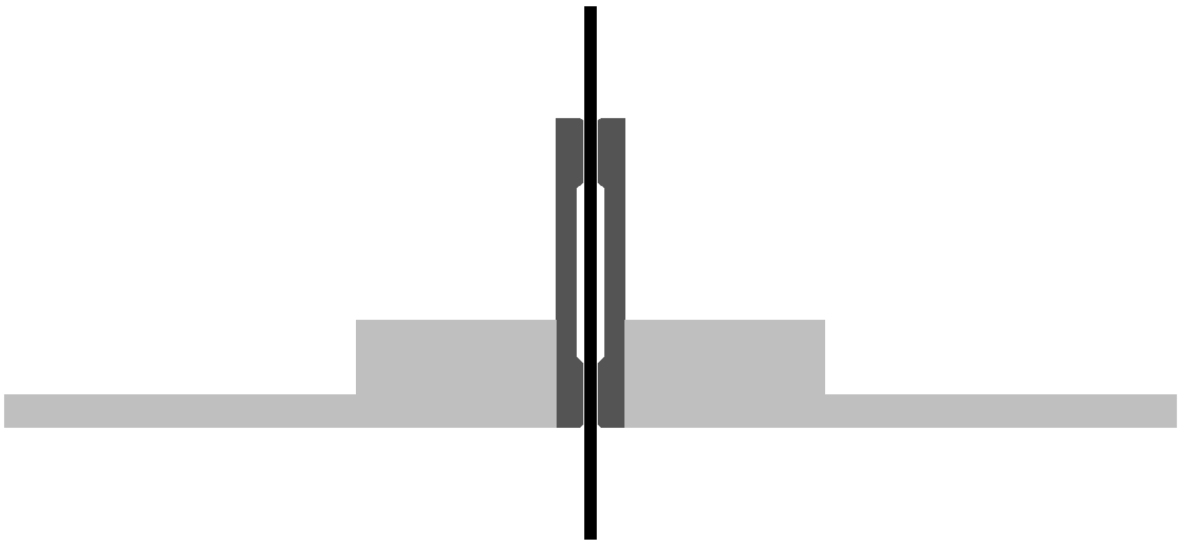
Look at the side profile to check the alignment of the magnets above the coil. The magnets should be reasonably close to the coil for the clock to work best. Shims are provided to help center the magnets directly above the coil. The average thickness is 0.025" (0.6mm) with varying amounts of tilt ranging from 0 degrees to 3 degrees. Cut apart the shim sheet to separate a pair of shims for your clock.



The shims can be printed with a 50% Z scale factor and 0.1mm layer heights needed to prevent the pendulum arm from becoming too long.

Component Pre-Assembly

Printed holes usually end up smaller than expected and different for every printer. They may need to be drilled out to fit. This is most important for the gears and arbor holes in the frame. Make sure that the gears fit loosely over their arbors. Drill the holes out with the appropriate size drill bit if needed. A 1.6mm drill bit works great to open up a 1.5mm hole. Most gears are designed so only the ends of each shaft needs to be drilled as shown below.



If you are using the tight press fit option for some of the gears, then they may also need to be drilled out. It usually works to put a 1.5mm drill bit in a hand vice and slowly turn the drill bit into the hole one time. Do not dwell or make a second pass. This should leave the hole with just enough grip to hold on to the shafts.

If you are using the gear options with screws to clamp onto the arbors, then it helps to pre-thread the screws into their holes. The holes are tighter along the sides to help prevent the component from breaking along the layer lines, but it is still a risk. Clamp the part to apply some pressure along the length of the shaft. Insert the screw into the hole as straight as possible. Slowly turn the screw into the hole. Back the screw out every few turns, just like you are tapping a hole. If it feels too tight, then drill the hole slightly and try again.

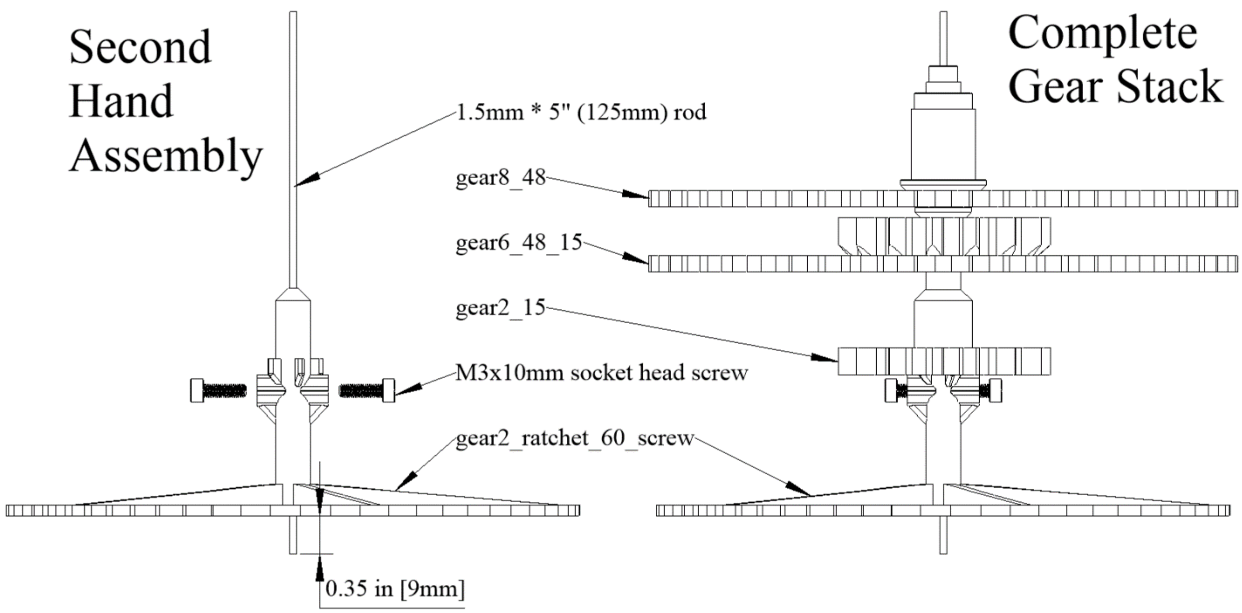
Also check that the minute hand gear fits into the hour hand gear and the hour hand gear fits into the front frame. Several gears pass through the center of the dial and it cannot be too sloppy. The shafts may need a small amount of sanding or filing to smooth off any rough layer lines. Wrap some sandpaper around the shafts to clean them up. The insides of the shafts can be cleaned up with a small round file. They should go together and turn freely.

Ratchet Assembly

The second hand ratchet needs to be attached to an arbor that passes through the dial to drive the second hand. There are two options to attach the arbor, a tight press fit, or a screw clamp. The screw option uses two screws to keep the weight balanced. Any unbalanced weight can cause the ratchet to slow down on one portion of the rotation and double count on the other portion.

The press fit option starts with gear2_ratchet_60_tight and the 5” (125mm) music wire rod. You may need to drill out the ratchet center holes to be close to the rod diameter. It usually works to hand drill very slowly using a drill bit of the same diameter as the music wire. Make one pass into the hole and pull the drill bit out. This should leave a rough enough inner surface to hold the wire. Gently tap the wire into the ratchet with about 0.35” (9mm) sticking out the bottom.

The screw option is easier to build since the ratchet hole sizes are less critical. The ratchet uses two screws to stay symmetrically balanced. It doesn’t need to be very tight, just strong enough to hold. Drill out the ratchet center holes if needed. Insert the wire into the ratchet sticking out 0.35” (9mm) below the ratchet. Add two M3x10mm screws and gently tighten them to the shaft. Do not over-tighten them or you risk splitting the ratchet along layer lines.



Center Gear Stack Test

This is a great time to test for friction in the ratchet and center gear stack. Any frame warp will be largest near the center of the clock. The ratchet will have too much friction if the frame pinches on the center gear stack, so that should be tested now.

Take the frame apart and remove the pendulum arm. Add the ratchet assembly into the back frame. Add gear2_15 onto the spline above the ratchet. This two part ratchet and pinion combination allows the pendulum to be removed from the clock without taking it apart.

Add gear6_48_15, gear8_48, front frame, and base. Secure everything using the 5 screws. Stand the clock up and spin the ratchet. It should spin with minimal resistance. Any excess friction needs to be removed. Make sure gear2_15 is positioned all the way onto the spline. You could also try to gently bend the frame near the alignment pins. Remove the frame from the base when bending it so you don't apply any pressure to the top support post. At a minimum, remove the top screw so the support post does not break. The last resort is to remove a small amount of thickness from the top of gear2_15. It is easy to use a chisel along the layer lines to remove material, but do this sparingly. Remove no more than 1-2mm. Large amounts of material removal can affect the gear alignment.

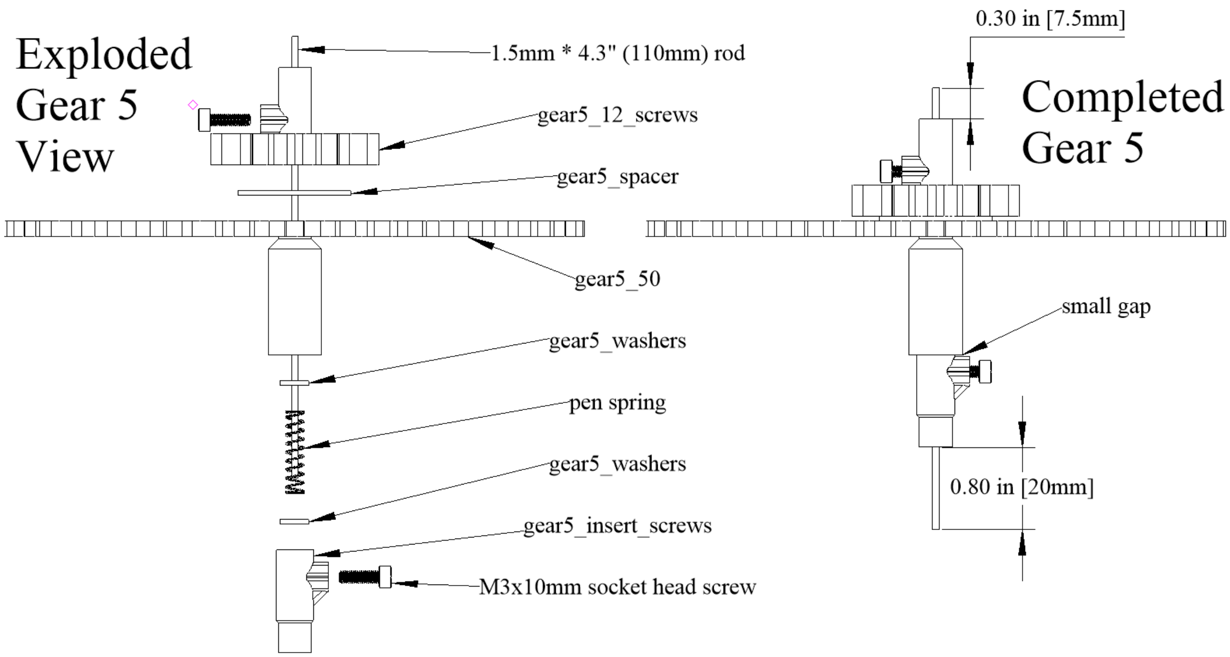
Feel free to skip ahead to the full ratchet adjustment section at this time. It will be a lot easier to see the ratchet pawls in operation without the rest of the gears in the way. The only components needed are the pendulum arm and the complete center gear stack.

Gear 5 Stack

The gear 5 stack contains a friction clutch to allow setting the time while the clock is running. Some clocks allow the time to be changed by simply rotating the minute hand. This clock has a second hand that would get in the way, so the arbor passes through the back frame and an adjustment knob will be added later. The diagram below shows the version using set screws instead of tight friction fit. The set screw option allow everything to be taken apart if needed to adjust the spring pressure.

Start by adding gear5_12_screws and a set screw near the end of the 4.3” (110mm) rod. The rod should stick out about 0.3” (7.5mm). Add the remaining components in the order shown in the diagram. Gear5_insert_screws should compress the spring slightly and leave a very tiny gap to gear5_50.

When everything is assembled, gear5_50 should rotate around the shaft when gear5_12_screws is held steady.

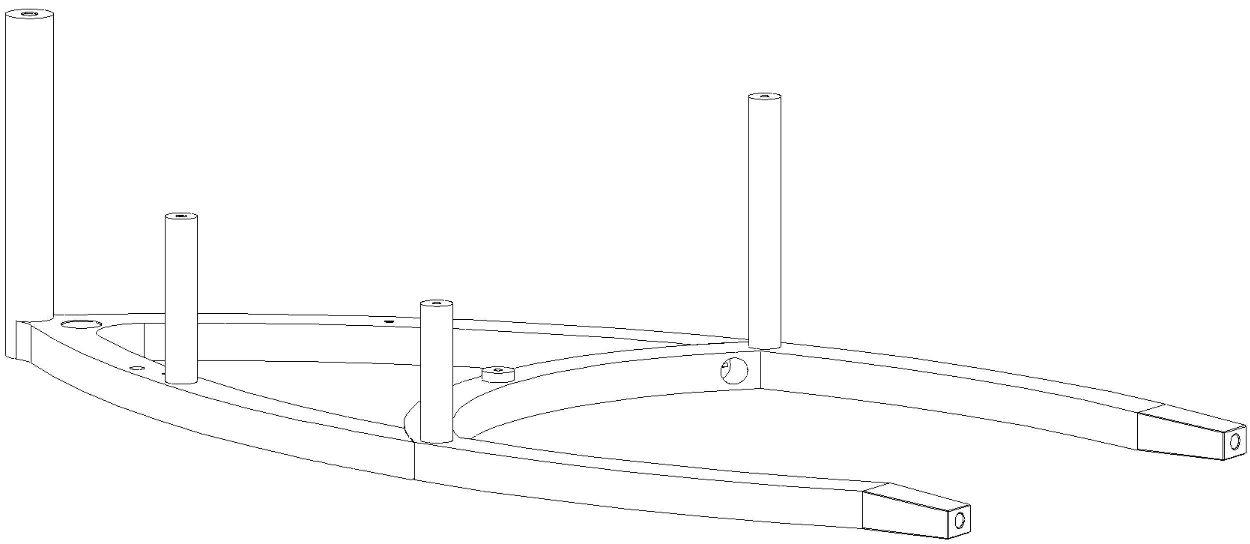


Adding the Gears

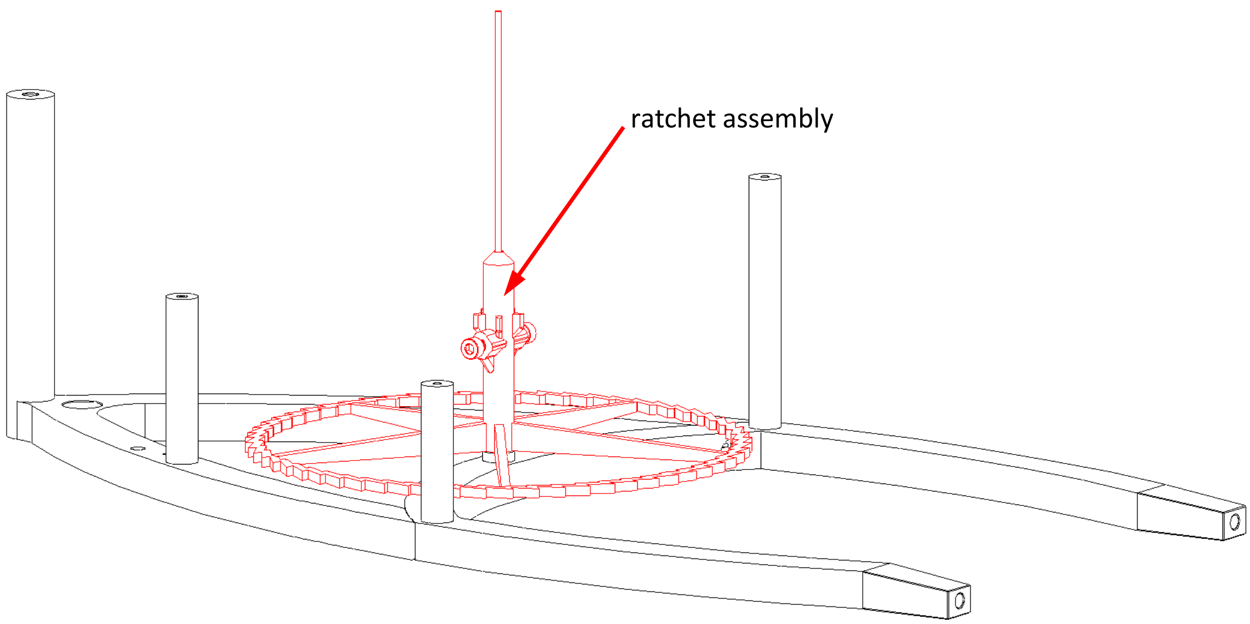
All the sub-components should be assembled at this point and the gears can be added into the clock. Lay the back frame on a table and assemble gears from the bottom to the top. For this clock, it starts with the ratchet and pendulum. The remaining gears get inserted clockwise starting with the lower left gear.

Here is a step by step progression of the gears getting added into the frame. Each new part will be highlighted in red. An arrow on the diagrams helps identify the part if you print this manual in black and white.

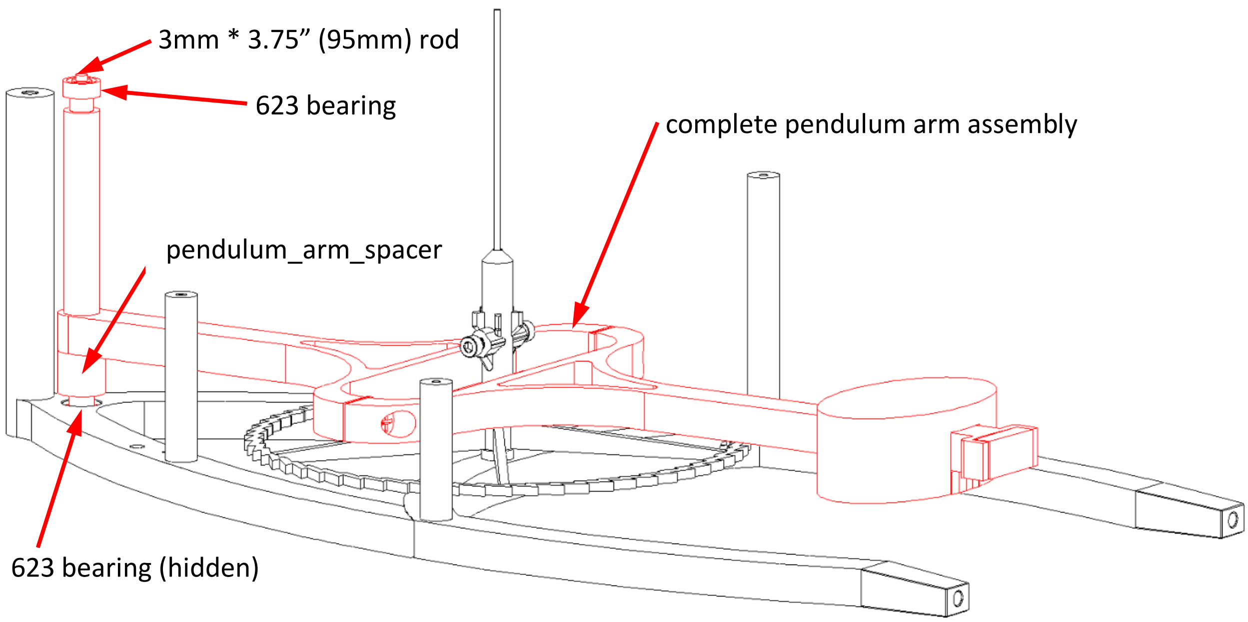
Start with the back frame laying on the table



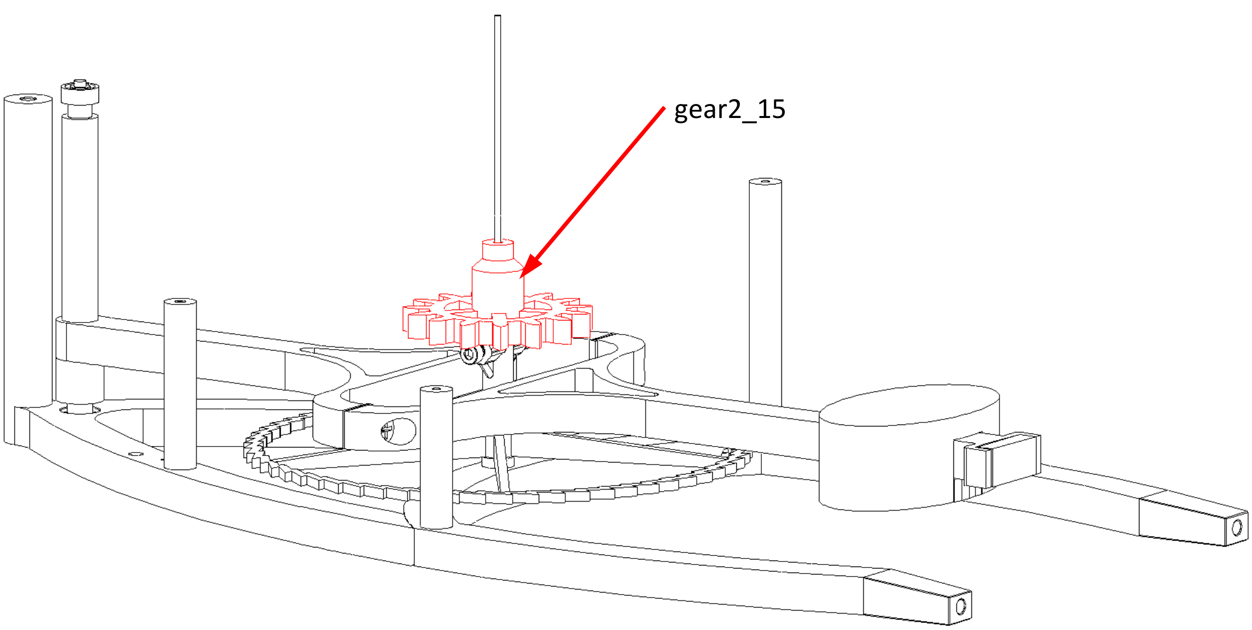
Add the ratchet assembly into the central hole



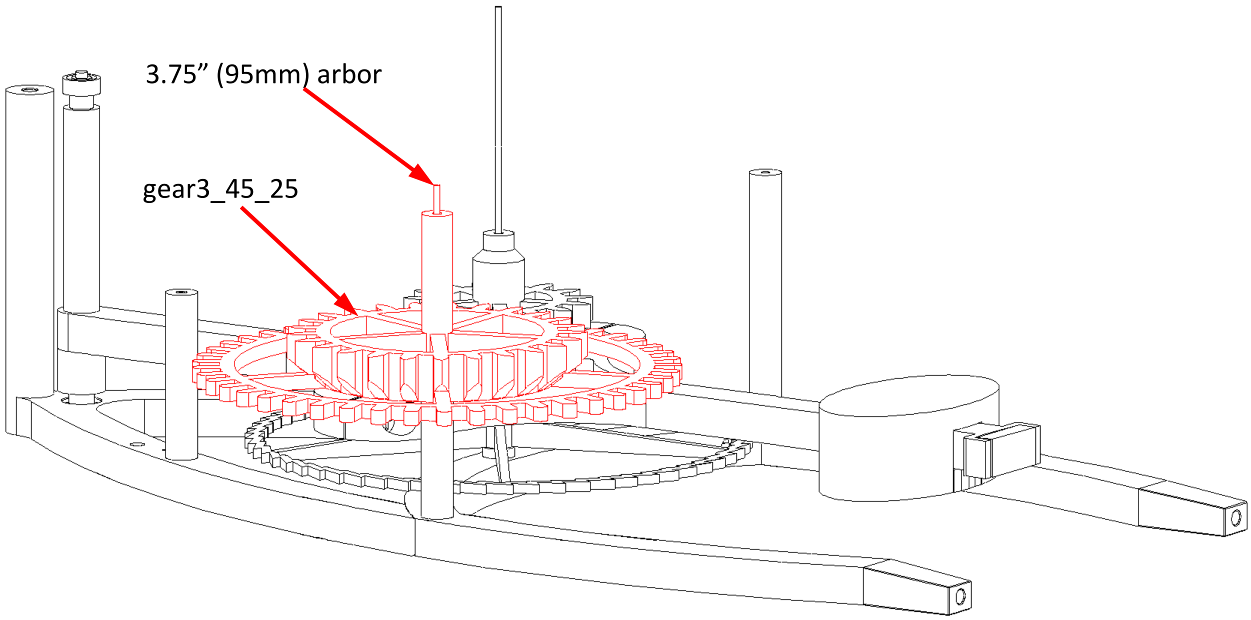
Add the pendulum arm assembly and associated components. A 623 bearing goes into the back frame mounting hole. The pendulum_arm_spacer and previously completed pendulum assembly get added to the 3mm rod. The second 623 bearing can be added to the top of the rod.



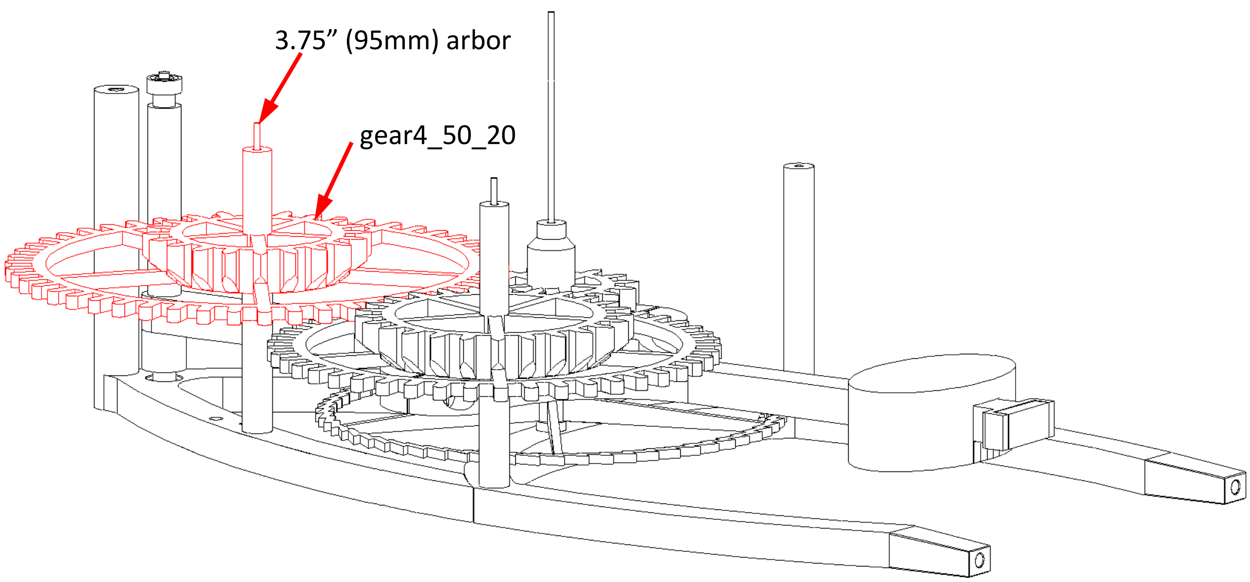
Add gear2_15 onto the ratchet. It should seat all the way down onto the spline. Creating this as a removable component with a spline allows the pendulum to be removed from the ratchet without taking it apart.



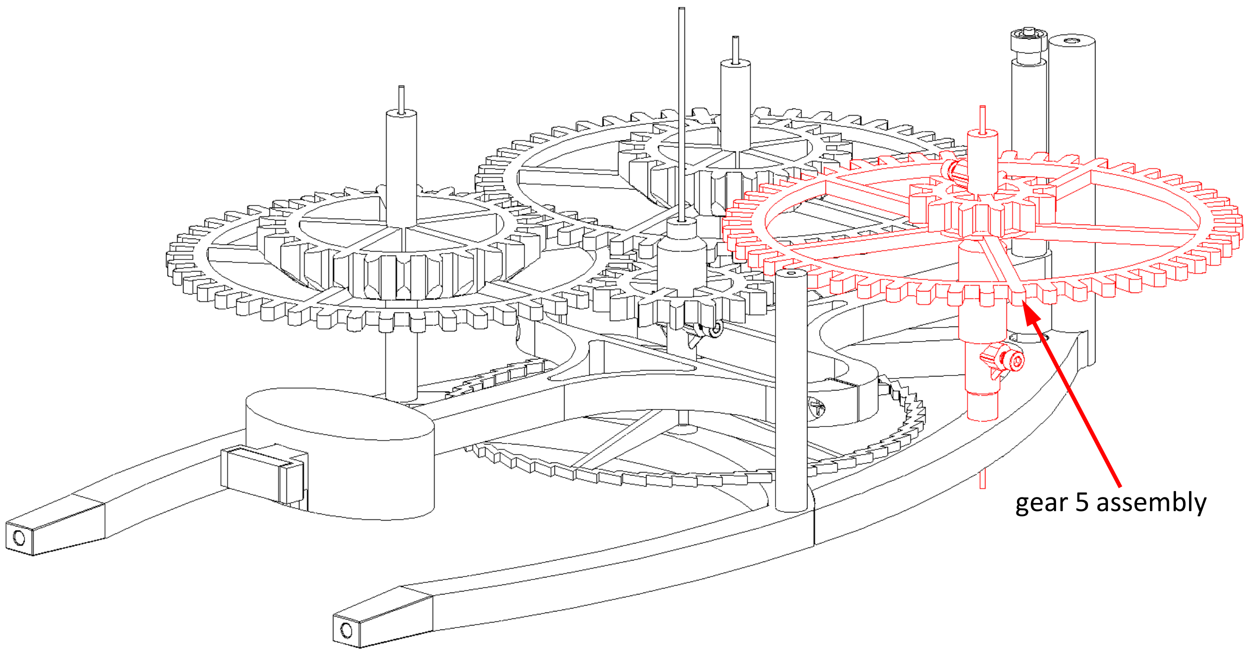
Add the 3.75” (95mm) arbor and gear3_45_25 to the lower left mounting position. It should mesh with gear2_12.



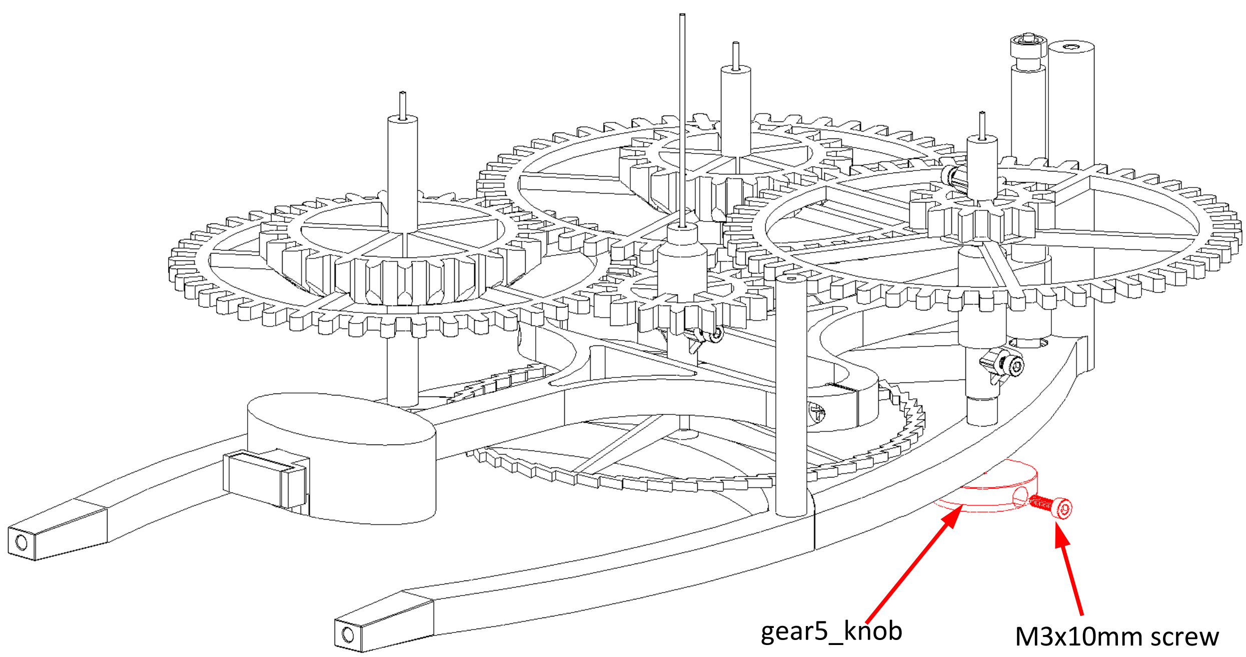
Add the 3.75” (95mm) arbor and gear4_50_20 to the upper left mounting position.



Add the gear 5 assembly into the upper right mounting hole. The shaft passes through the back frame.

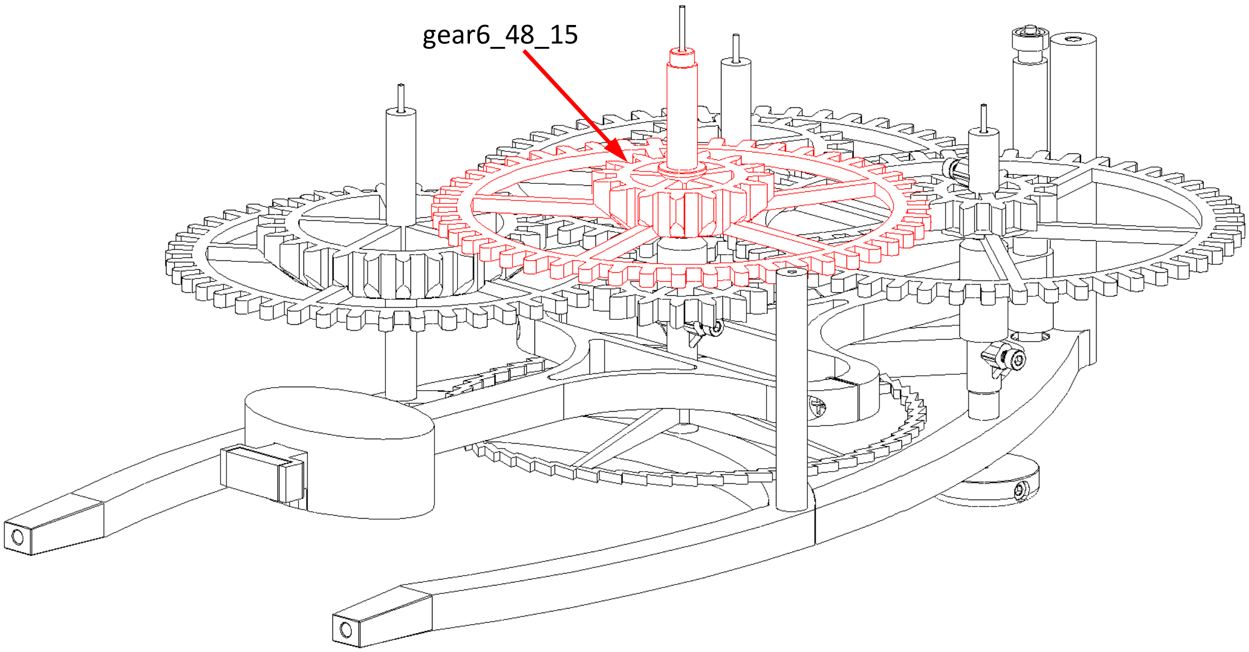


The time adjustment knob gear5_knob can be added behind the frame. It attaches using a M3x10mm screw. A #6-32*3/8” imperial screw will also work.

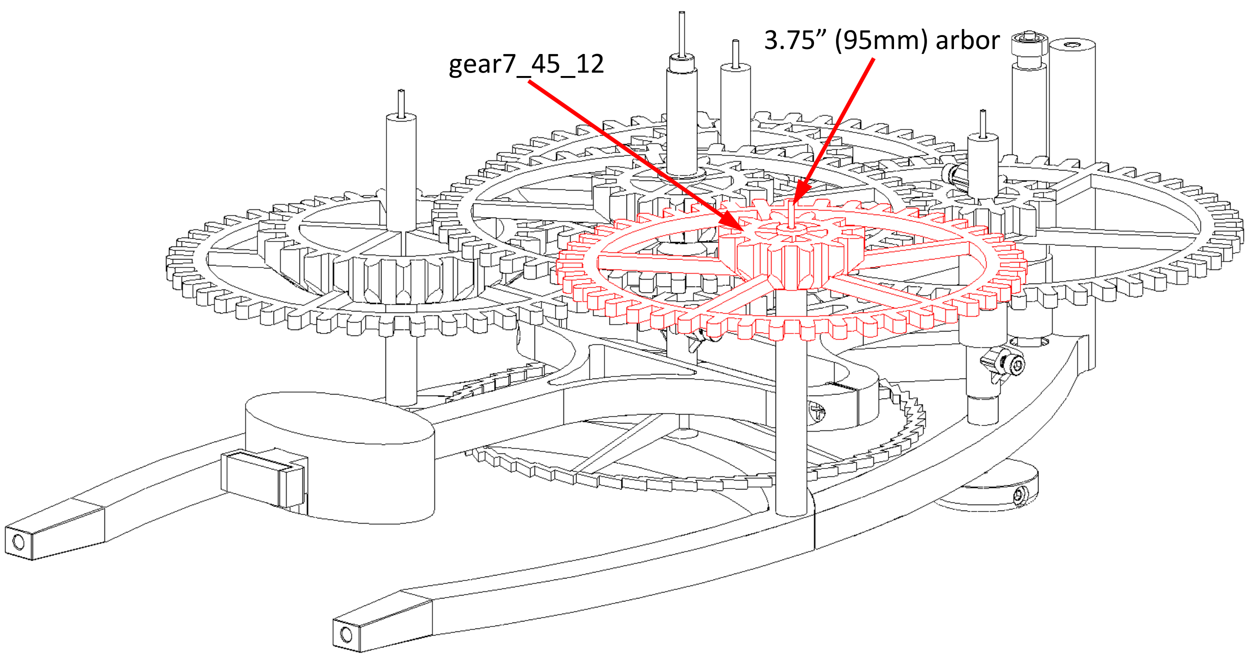


The knob sticking out the back will keep the clock from sitting flat on the table. Set the clock on an empty spool holder to support everything if desired.

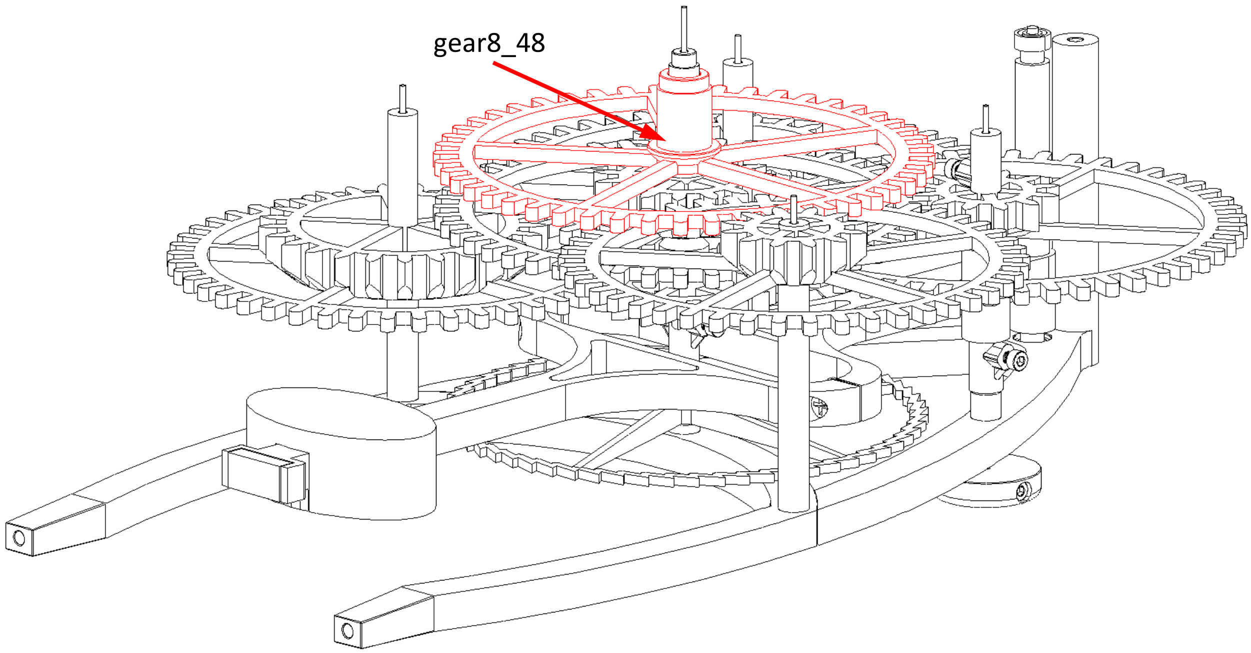
Add gear6_48_15 to the central ratchet shaft.



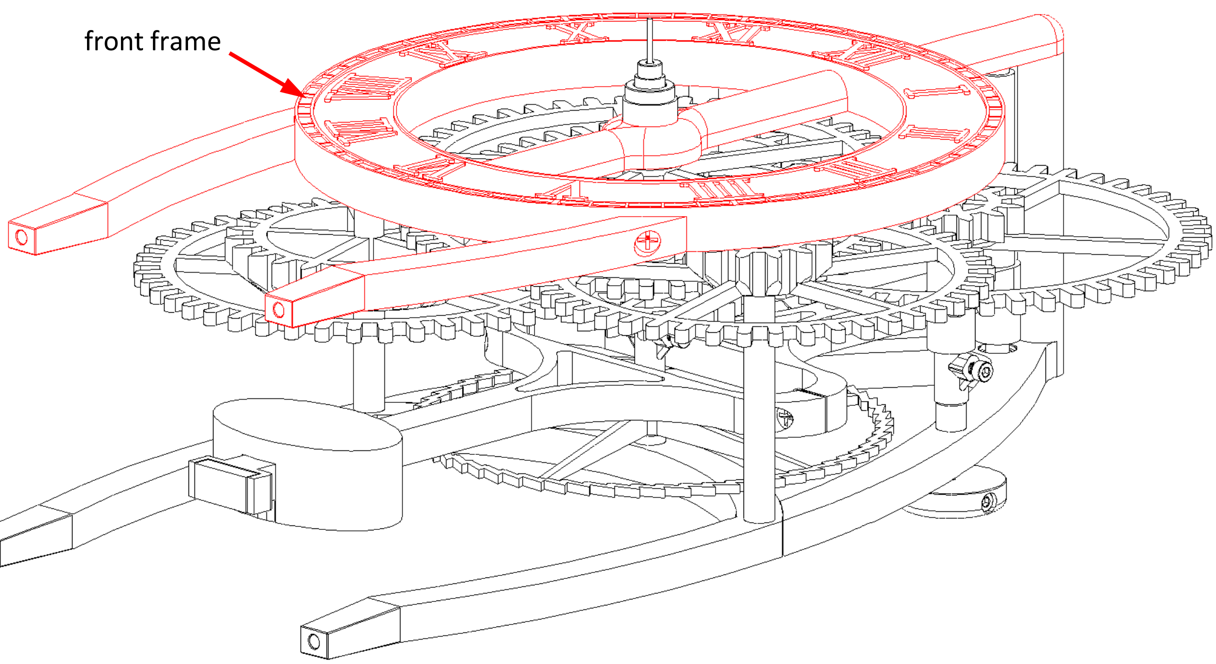
Add a 3.75” (95mm) arbor and gear7_45_12 to the lower right mounting hole.



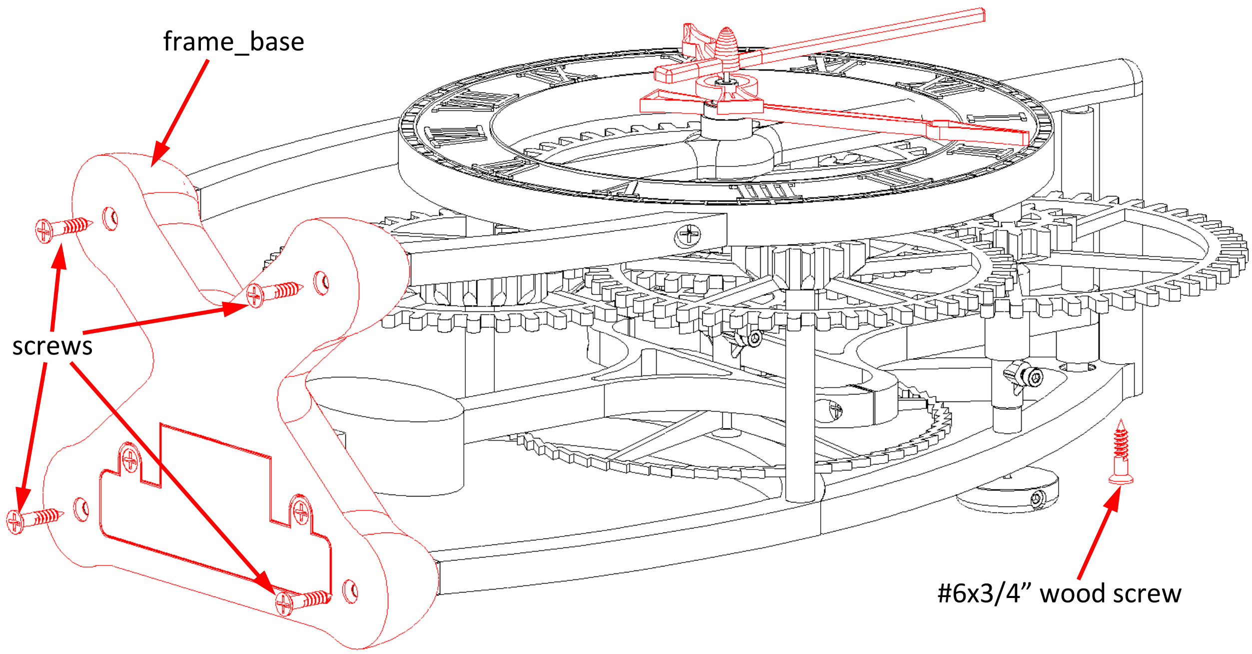
The final gear to add is gear8_48 onto the central ratchet arbor. It needs to slide over gear6_48_15 without binding up. Sand or file the gear6 shaft if needed.



Add the front frame and dial. Start by placing the dial over the ratchet arbor. Wiggle each of the 4 outer arbors and upper bearing until they are in position. The frame should drop into the final position.



Add the base to the bottom of the clock and secure it with 4 wood screws. The tapered pegs should easily slide into the holes. Add an additional wood screw to secure the top of the frame. The hands can also be added at this point. They are a press fit onto the shafts.



Ratchet

The final step is adjusting the ratchets. There are options to allow the clock to operate with pendulum amplitudes ranging from around 10-15 degrees to the maximum limit of 43 degrees. The ratchet adjustments allow proper operation across the entire pendulum range.

The ratchet uses two pawls to translate the back and forth pendulum motion into rotary motion of the second hand. The active pawl on the pendulum pushes the ratchet. A static pawl on the frame prevents the ratchet from rotating backwards when the pendulum swings back. Each of these pawls need to be adjusted.

The ratchet adjustment will take some experimentation to optimize. The pawls come in various lengths and the best option needs to be selected. This section of the manual will guide you through the adjustment process.

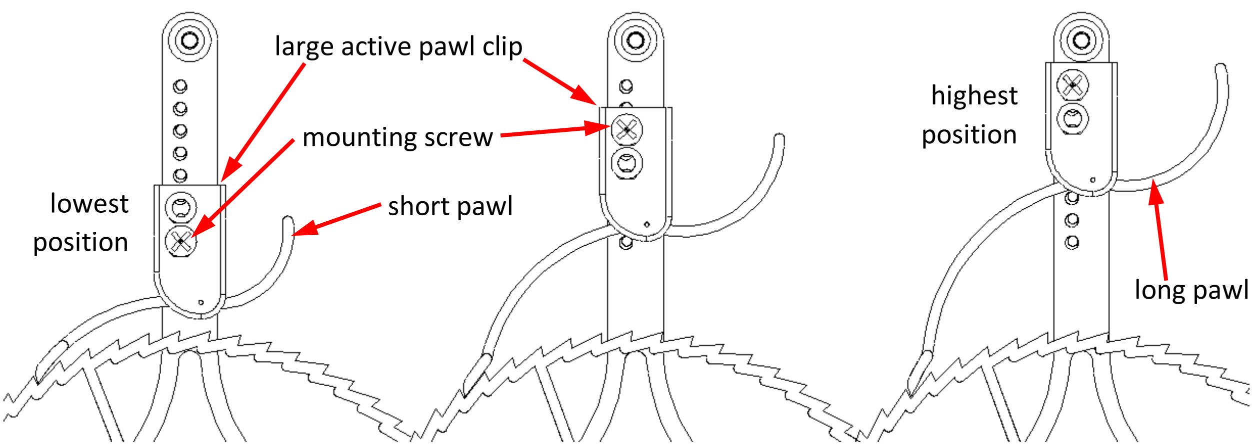
Pendulum Amplitude

The first step in the ratchet adjustment process is to determine the approximate pendulum amplitude. This will be used to determine the initial position of the active pawls. Allow the pendulum to swing with no load until it is stable for a few minutes. Estimate the amplitude compared to the maximum swing of 43 degrees. If it is close to the maximum, then the active pawls should be positioned higher so the tips move less on every pendulum swing.

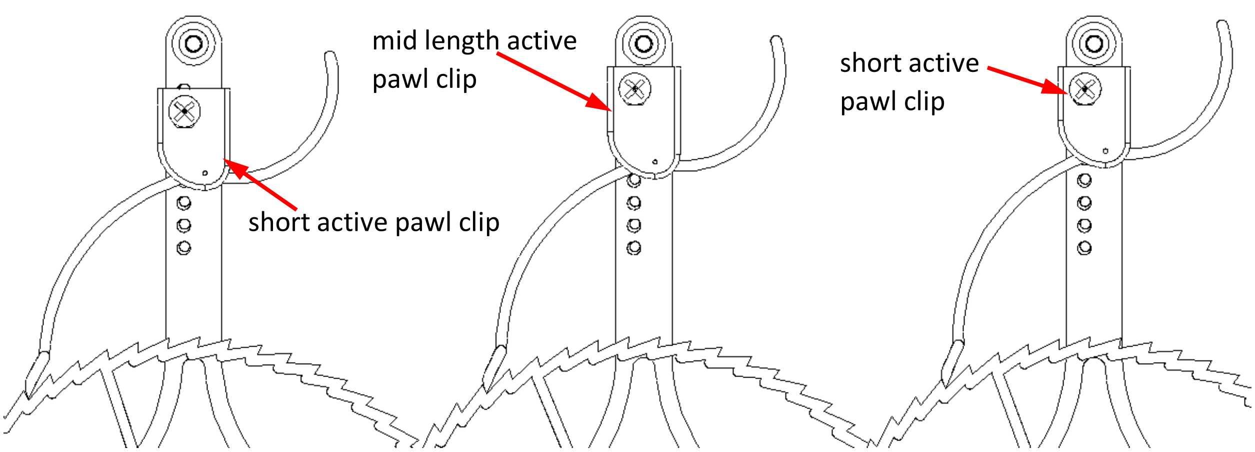
Active Pawls

The next adjustment step is to determine a good position to mount the active pawl. The position is dependent on the total pendulum amplitude. A position that works with a 15 degree pendulum swing would move the ratchet too far with a 40 degree swing. The mounting location of the active pawl can be raised or lowered across a wide range to support different pendulum amplitudes. The active pawl is mounted on the pendulum arm by the large pawl_active_clip. The clip and pendulum have multiple screw positions to attach the clip in different places. The pendulum has 7 holes spaced every 0.2" (5mm) and the clip has 2 holes spaced 0.3" (7.5mm) apart. These combinations allow the pawls to be positioned with a resolution of 0.1" (2.5mm).

The following diagram shows top portion of the pendulum with the pawl positioned in a few different positions. The lowest position uses a short pawl and the top position uses a longer pawl.

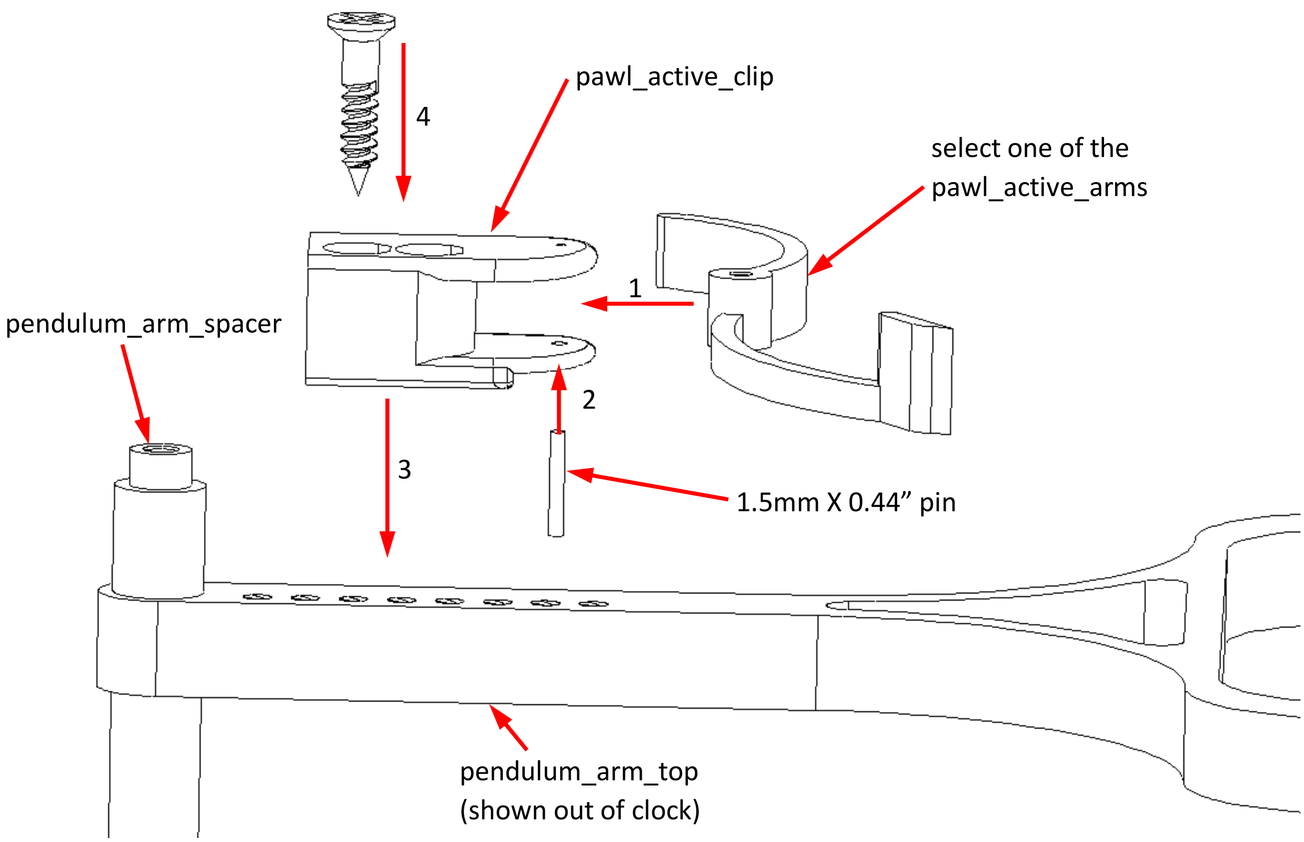


There are also some short pawl clips that can be used to position the pawl higher if you have a large pendulum amplitude. They allow the pivot point to be raised close to the pendulum pivot point. The diagram below shows the active pawl clips used for the three highest pawl locations.



Active pawls are provided in multiple lengths. They have a counter-balance to minimize the effective weight on the ratchet. Use one of the shorter pawls with the lowest clip position for small pendulum amplitudes. The longer pawls are needed with the upper clip positions for larger pendulum amplitudes. Experiment with different lengths and positions.

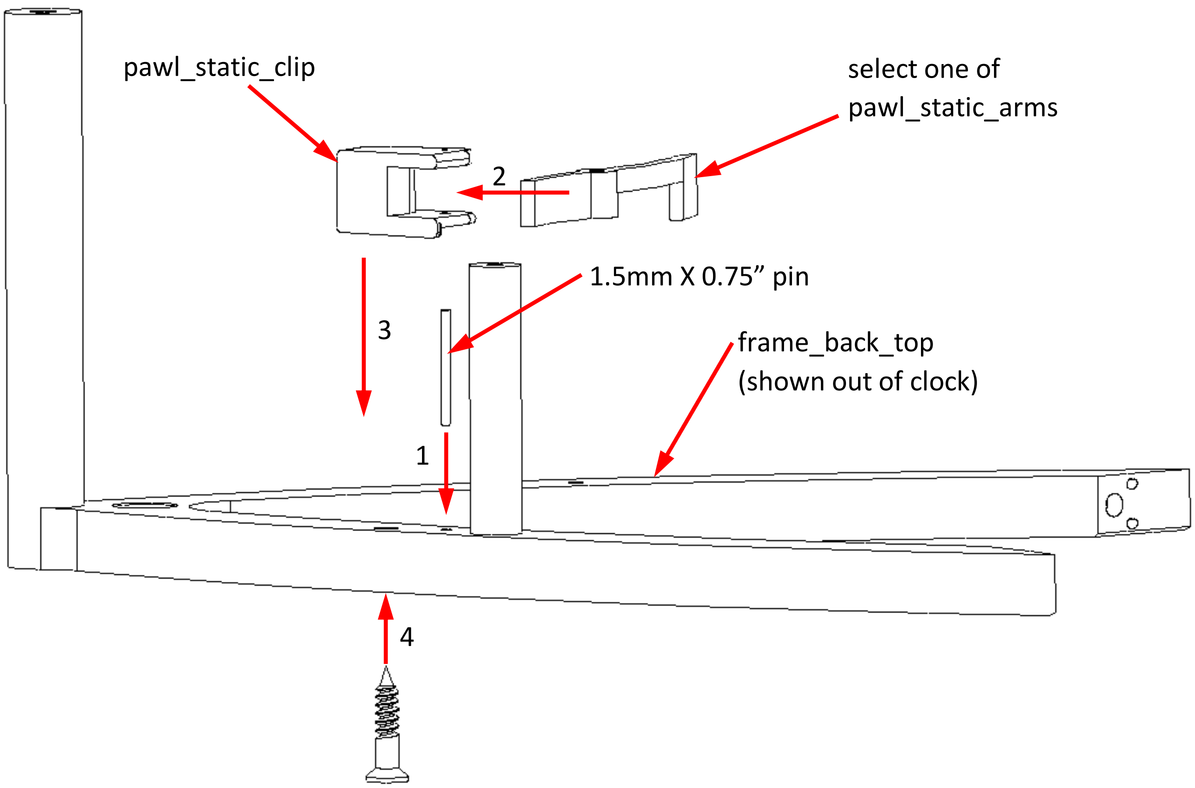
The active pawl is added to the pendulum arm using a 0.44" (11mm) length of 1.5mm music wire. Select an active pawl length that is appropriate for the expected height on the pendulum arm. Slide the pawl into the clip. Insert the 0.44" pin through the clip and pawl. The pin only goes through in one direction. There is a small hole on the top end that allows the pin to be pushed out if needed. Make sure the pawl swings easily. Attach the clip and pawl to the back of the pendulum arm using a #6x3/4" wood screw.



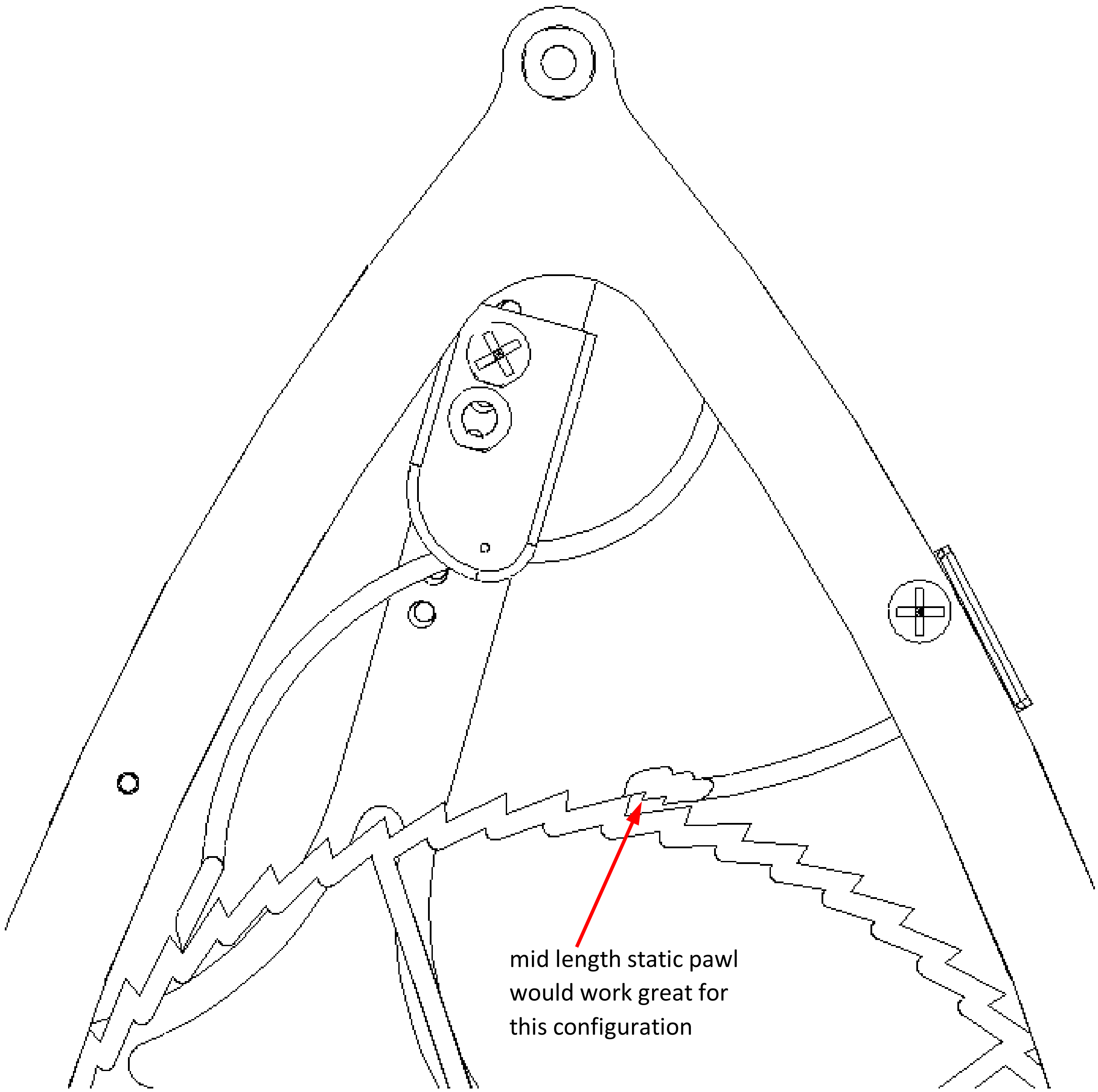
Static Pawls

Determining the static pawl length is third step in the ratchet adjustment process. The static pawl keeps the ratchet from rotating backwards. There are three different lengths of static pawls and a ratcheting pawl that helps to determine the best pawl length to use. The lengths differ by one third of the width of one ratchet tooth. Select one that allows the ratchet to clear the tip of the pawl without leaving a large gap.

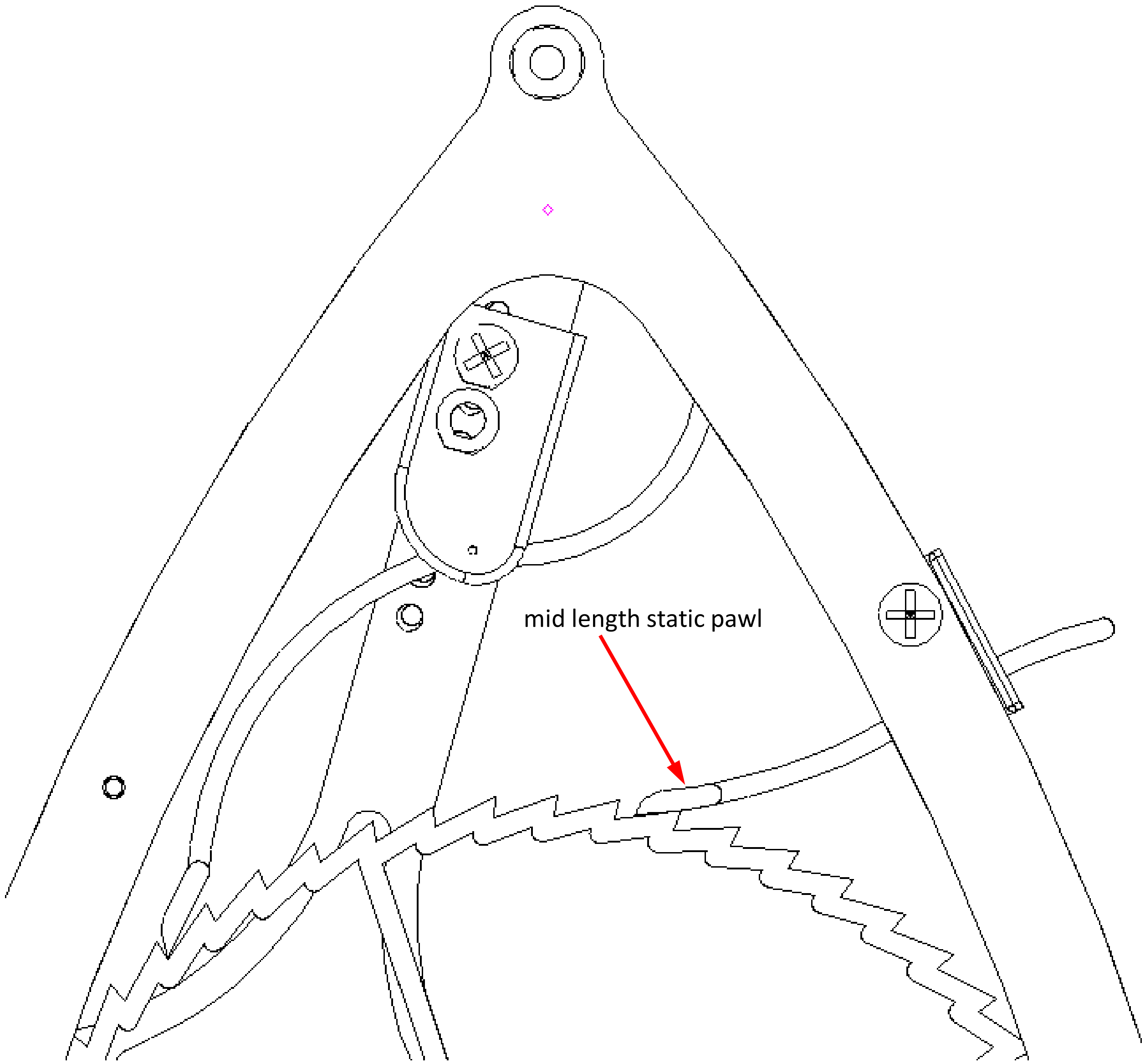
The static pawl attaches to the back of the frame using the static pawl clip and a 0.75” (19mm) length of 1.5mm music wire. This 0.75” wire should first be inserted into the back frame. Ideally, it will be snug enough to stay in position on its own. Insert a static pawl into the pawl_static_clip and slide both over the 0.75” wire. Insert a #6x3/4” wood screw from the back to hold the clip in place.



Look at the ratcheting static pawl when the pendulum reaches its maximum amplitude. There are three teeth at the positions of the three different lengths of static pawls. The diagram below would work best with the mid length static pawl.



The ratcheting static pawl has very small teeth. It should work better with one of the normal static pawls. Here is the same configuration as the previous picture with the mid length static pawl inserted.



Adjusting the Ratchet

Let the clock run for a few minutes until the pendulum amplitude is stable. If you are lucky, the clock will be keeping great time. It is more likely that the ratchets need to be adjusted. Look at the back of the clock to observe the ratchets.

Listen to the ticking sound. This clock has three ticks per full pendulum swing which is unusual compared to a traditional pendulum clock. It sounds like "tick . tick . tick . . . . . . tick . tick . tick . . . . . .". The active pawl makes a tick when it drops and it makes another tick when it first touches the ratchet. The static pawl makes the third tick.

The adjustment process is:

> Move the active pawl lower if the pendulum swing is not large enough to engage the ratchet and advance the second hand. You may need a shorter active pawl length.
>
> Move the active pawl higher if the ratchet occasionally advances two ticks per swing. You may need to use a longer active pawl length.
>
> Add the proper length static pawl after adjusting the active pawl position.

Adjusting the Rate

Set the time by turning the knob on the back of the clock. You can gently advance the ratchet to position the second hand to match a reference clock exactly.

Let the clock run for a few hours and compare the time relative to a reference clock.

The clock speed is determined by the effective length of the pendulum. A longer pendulum will run slower and a shorter pendulum will run faster.

The pendulum in this clock has a length of just under 10" (250mm). The theoretical calculations require a change in length of 0.14" (3.56mm) to add or subtract 10 minutes per day from the rate. The M3 adjustment screw has a 0.5mm pitch, so 7 turns would be 3.5mm. The weight of the pendulum arm changes the calculations so you need to move the bob further than expected to change the effective pendulum length. The actual adjustment is probably close to 1 minute per day per full turn of the adjustment screw.

Debug

The most important adjustment is to get the ratchets working properly. Missed ticks or double ticks will make the clock run inconsistently. Listen to the sound of the ratchets. Missing or additional ticks will be noticeable. If the ratchets are close to an optimal location, then missing beats may be quite rare. They can probably be ignored if they only occur once or twice per hour. The rate will be irregular if they occur several times per minute.

Missed ticks can be caused by the ratchets not being properly positioned. Lower the active ratchet and identify the proper length static pawl. A static pawl that is too far away from the ratchet tooth can allow the ratchet to be pulled back too far, requiring the active pawl to push further to get it to tick.

Missed ticks can also result from the pendulum losing energy when it pushes the ratchet. This can be observed by watching the ratchet miss a tick and the next pendulum swing is slightly larger so the ratchet can engage. The ratchet is very light weight to minimize the energy needed to make it rotate. However, the center gear stack gets pinched if the frame is warped inward. This adds friction to the ratchet and slows down the pendulum every time the pawls push the ratchet. The friction must be reduced by straightening the frame or reducing the gear stack height slightly. Apply gentle pressure near the alignment pins on the frame. Take the clock apart when bending the frame to avoid breaking the top support on the back frame. At a minimum, remove the screw that holds the top of the frame together before bending the frame. A very small amount of material can be removed by shaving a few layers from the top of gear2_15. It is easier to use a knife along layer lines than to sand away any thickness. Only remove a mm or two if needed.

Another source of ratchet friction is from the arbor rubbing somewhere. Drill out the pivot hole in the back frame where the ratchet gets inserted. Also drill the minute hand gear where the ratchet arbor passes through. Make sure the arbor is completely straight. It using the screw option, make sure both screws are equally tightened to avoid bending the shaft by the screws.

Double ticks can occur if the pendulum amplitude is too great or the ratchet is unbalanced. The active pawls need to be adjusted upwards if the pendulum amplitude is too large. The ratchet weight will be unbalanced if the second was printed with less than 100% infill. An unbalanced the second hand could advance the ratchet faster at the 3 o'clock position and slow the ratchet at the 9 o'clock position. The counter weight on the second hand prevents this from happening, but it only works when printed with extra perimeters or 100% infill so it is completely solid.

I have a discussion forum on my web site at https://www.stevesclocks.com/forum to help debug any other issues.

Final Comments

Thank you for purchasing this clock and supporting my clock design efforts. This clock has been a huge challenge to develop. The electromagnetic pendulum driver works great, but they were designed to swing a dummy pendulum. It took many iterations to get this clock to work properly when the pendulum has to do some real work. It had to be designed to work without missing a beat and without adding extra beats. The first prototype had both missing ticks and extra ticks within a single minute. The final design solves these issues.

I really like the final look of the clock. The large amplitude pendulum swing draws your attention. It has a gentle ticking sound. Once adjusted, it should run great for over a year on a set of batteries. And the electronics are reasonably cheap.

I hope you enjoy building the clock as much as I enjoyed designing it. Please feel free to support my work by purchasing my other designs at https://www.myminifactory.com/users/StevePeterson

I have a Patreon page at https://www.patreon.com/user?u=30981480 (Steve's Clocks) where I explain some of the details that go into my clocks.

Information on my clocks can also be found on my web site at https://www.stevesclocks.com There are descriptions of my latest designs, a show and tell section to post pictures, and a debug forum if you need any help getting your clock to work properly. The latest version of this assembly manual can be found there as well.

A video showing the operation and adjustment of the ratchets will be created soon. It will be posted to my YouTube channel at https://www.youtube.com/channel/UCWbKinQBavrH3iPMvgzVQzg

The size of this clock makes it a good candidate to be build using wood. The gear teeth are large enough to be made from Baltic Birch plywood. I may try to convert the design when I find some additional time. Details should show up on my web site at https://www.stevesclocks.com when they become available.

thanks
Steve

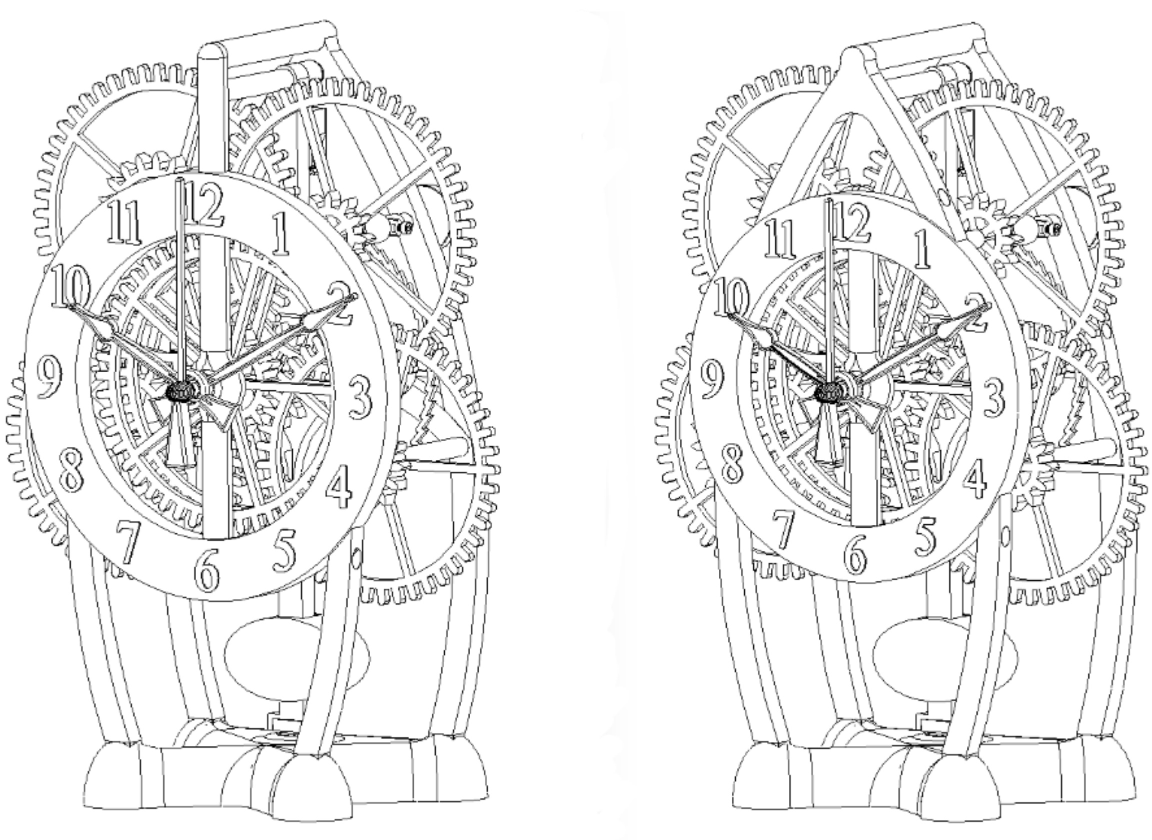
Appendix A: Small Printer Option

A question came up during the pre-release of this design about printing the clock on a Prusa Mini or similar sized printer. The clock shown on the front page will fill the print bed of a Prusa MK3S or Ender 3. The 7.7” (195mm) dial and some frame parts are larger than the 180x180mm bed on the Prusa Mini.

The overall size of the clock is dictated by the pendulum length to support a 60 tick per minute second hand. Scaling the entire clock is not feasible without changing to 70 ticks per minute or losing the second hand completely. Splitting the dial into smaller components would create a highly visible seam. I didn’t like any of these options, so other options needed to be considered.

I decided to scale the dial and re-partition the frame to fit the smaller bed size. The pendulum and gear train were left unchanged. The dial was made 7.0” (178mm) in diameter to fill the Prusa Mini bed. This pushes the arbor positions closer to the edge of the dial. The overall size of the clock remains the same.

Here is a side by side comparison of the normal clock on the left and the “mini” clock on the right. The smaller dial exposes more of the pinions.

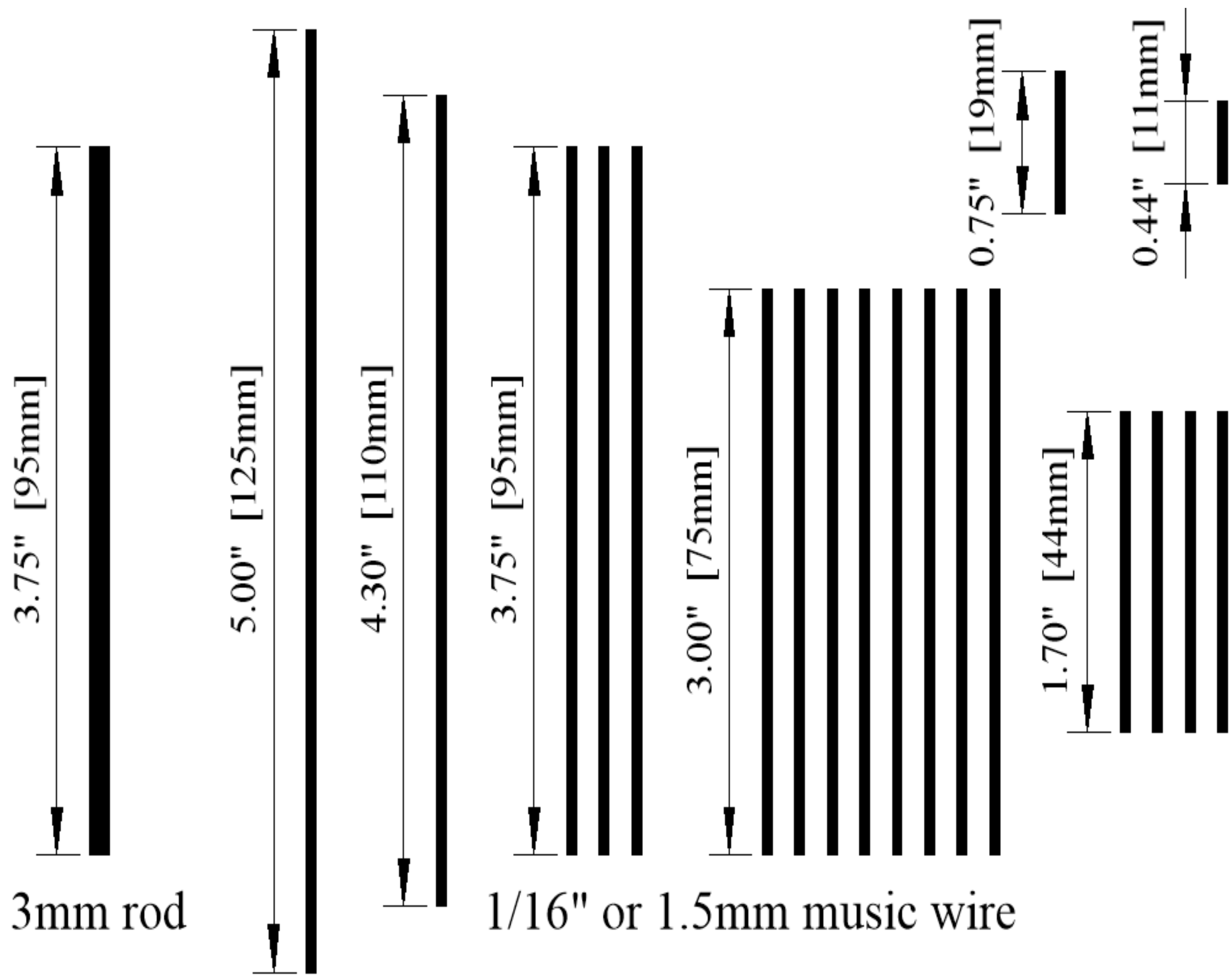


Here is a picture of the completed clock with the mini sized dial. The simple number dial is shown. Both size dials are available with traditional roman numerals and simple number dials.

Cut Metal Parts List

The frame has more seams with different length pins to align the pieces. The clock will need 54” (1.4m) of 1/16” (1.5mm) music wire and two additional wood screws.

Use the following diagram for cutting the parts.



Printing the Parts

All the parts needed for this option have the prefix “mini” before the part name. They include the back frame, front frame, and clock hands. Some of the part names are slightly different, but they should make sense. For example, the original back frame was partitioned as a top and a bottom. The mini back frame has a left, right, and top segment.

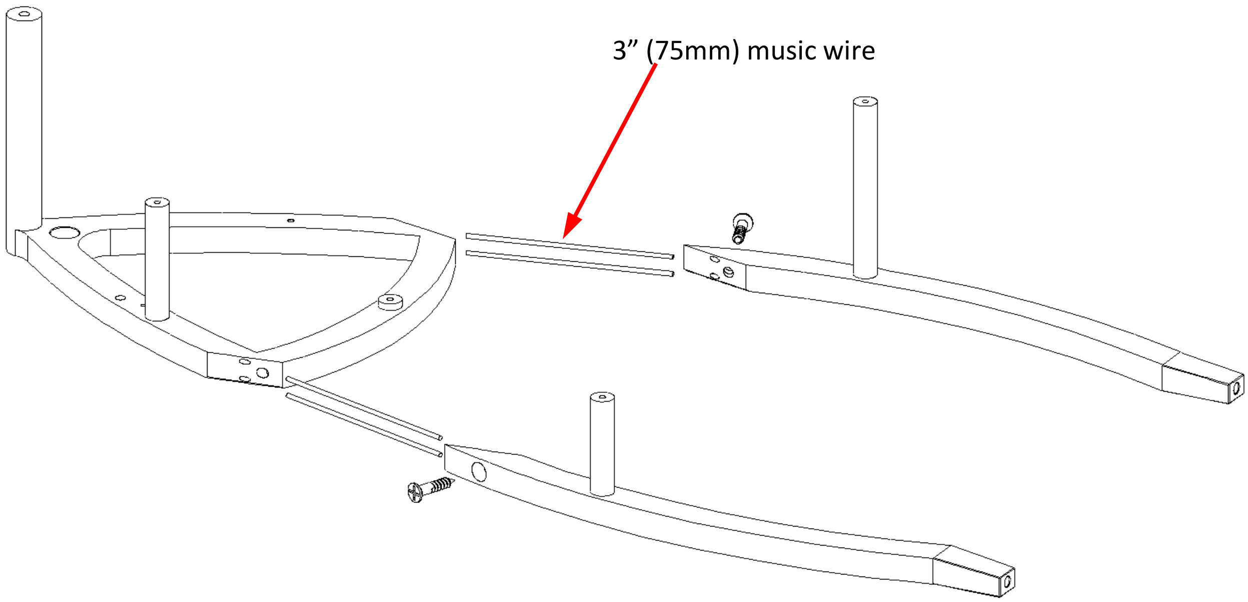
Print the following parts to build the clock (in addition to the parts from the original table):

File Name	Color	Print	Time	Filament	Notes
mini_frame_back_left	tan, purple	1	2h 20m	8.78m	Add a color change at 10.4mm
mini_frame_back_right	tan, purple	1	2h 47m	9.48m	Add a color change at 10.4mm
mini_frame_back_top	tan, purple	1	5h 35m	19.27m	Add a color change at 10.4mm
mini_frame_dial_numbers	tan, ivory, purple	1	7h 48m	39.40m	Print one of either style Add color changes at 10.40mm and 12.20mm Need to reduce skirt distance to 0.7mm to make it fit on a Mini
mini_frame_dial_roman	tan, ivory, black		7h 66m	39.72m	
mini_frame_front_left	tan	1	1h 13m	5.07m	
mini_frame_front_right	tan	1	1h 14m	5.09m	
mini_frame_front_top	tan	1	1h 34m	6.30m	
mini_hand_hour	ivory, black	1	0h 13m	0.66m	Add a color change at 2.20mm
mini_hand_minute	ivory, black	1	0h 14m	0.72m	Add a color change at 2.20mm
mini_hand_second	purple	1	0h 25m	1.27m	14 perimeters so it is solid
	Total	**10**	**23h 23m**	**135.76m**	

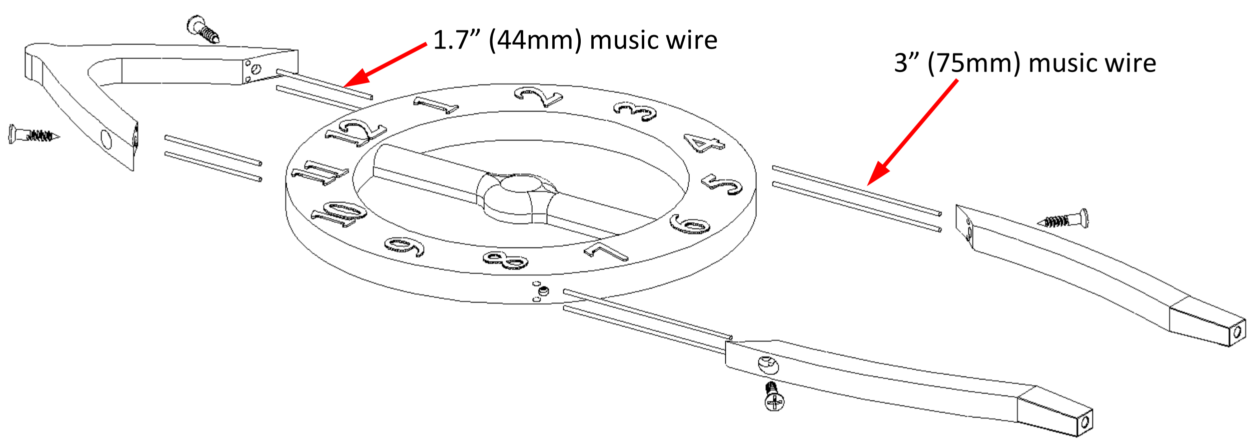
These options are not limited to Prusa Mini printers. They can also be used if you have a larger printer and provide a slightly different looking clock.

Frame Assembly

The back frame has three printed components and some 3” (75mm) music wire alignment rods. Assemble the parts and check them for flatness.



The front frame has four printed components and 1.7” (44mm) plus 3” (75mm) music wire alignment rods. Check them for flatness.



All other assembly instructions are the same as the instructions for the full size parts.

Appendix B: Similar Designs

There are a few other home-built electromagnetic pendulum clock designs. They all use a magnet and an electric coil to power to the pendulum. A ratchet translates the back and forth pendulum motion into rotation of the clock hands. Beyond the basic operation, most designs appear completely different. Mine is the only one with a second hand and the only 3D printed clock. The other designs use wood gears.

Here are a few clocks that provided inspiration for my design:

Clayton Boyer's Toucan

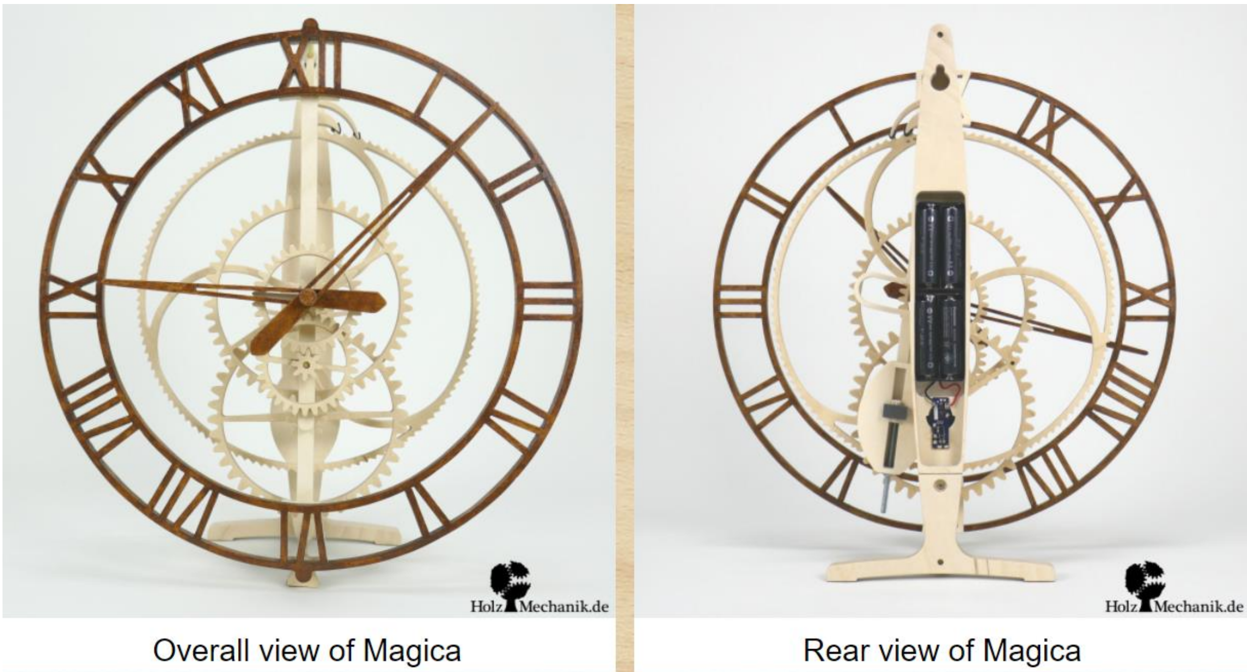
Clayton Boyer's wooden gear Toucan clock may be the most popular electromagnetic clock. A Google search will show many examples. The pawls at the top of the clock are shaped like a toucan, giving the clock its name. It uses a custom circuit and a hand wound coil. Most implementations show an external power supply or wall transformer, so I suspect the power consumption is large.

Dick Bipes Clock at Carveshop

Dick Bipes has a clock plan available at carvewright.com or carveshop.com. The electronics use a microcontroller to regulate the timing. An LED blinks green if the pendulum is too fast and red if it is too slow. Once the pendulum is within the allowable range, the algorithm adjusts the timing to keep the clock accurate. The electronics sells for around US$45.

Holzmechanik Magica Clock

Holzmechanik has a Magica clock that appears to run on a standard off the shelf drive unit. Runtime is listed as 3-4 months using 4 AA batteries.



Holzmechanik Magica clock

Every electromagnetic pendulum clock that I can find appears to be a completely different style. All are fascinating. Send me a message if you know of any other electromagnetic pendulum clocks.