3D PRINTED PENDULUM CLOCK

SP13 Build Notes

Assembly notes for a 3D printed pendulum clock with an 8-day run time

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09-Nov-2023 Original version

Description

I started designing 3D printed clocks shortly after receiving a Prusa MK3 in 2018. My first functional clock has been downloaded from Thingiverse, MyMiniFactory, and Printables over 45,000 times. This is a new and greatly enhanced version of the original design. It incorporates all the best features from my other designs with a similar look as the original. This version is significantly easier to build with no complex machining steps. It is my most reliable classic style weight driven design. It has an 8 day runtime using around 6 pounds (3kg) of drive weight.

The design requirements for this clock are:

1) The clock must be accurate. This clock typically maintains an accuracy of 1-2 minutes per week.
2) The clock must be reliable. The deadbeat escapement used in this design has proven itself to be very robust. The clock often starts ticking as soon as the weight is applied.
3) The clock must have a long runtime. Eight days is a reasonable length allowing for winding once per week. It could have been made longer, but this would come at the expense of less reliability.
4) The clock must look good. I like the classic look of this clock. Hopefully, you do as well.
5) The clock should be easy to assemble. This criteria has lower priority, but is still important. Assembly is a one-time task that should finish with a minimum of hand tools. Many difficult assembly steps have been eliminated. The stainless steel bushings used in the first design have been eliminated. The frame screws together without glue. And the pendulum arm simply drops into place similar to my "Easy-Build" clocks.

The clock can be printed on a Prusa MK3S (250x210mm) or Ender3 (250x250mm) style printer. A split option for smaller 170x170mm printers is also included.

Quick Start

This clock is designed to be easy to print and assemble. Feel free to start printing the parts using 4 perimeters and 30% cubic infill with a 0.4mm nozzle. Here are the most important sections of this manual that may be good to print as a quick reference:

1) Component print list on pages 13-14.
2) Gear and spacer cross reference charts on pages 15-16.
3) Additional components and cut metal part list on pages 17-18.

Component pre-assembly steps start on page 19.

The step-by-step process of adding the gears starts on page 30.

Details

A pendulum clock is conceptually very simple. A spring or falling weight provides energy to a pendulum swinging at a constant rate, dependent only on length. A series of gears convert the periodic motion into a display for the hours and minutes. The challenge is to make everything work elegantly and accurately. Designing clocks has been a hobby of mine for many years. I start with a basic sketch of the clock, then fit gears to be as symmetrical as possible.

The total print time is around 65 hours plus a few hours for assembly. A little over 0.7kg of filament in multiple colors will be used. A few non-printed parts are hidden as much as possible. Some basic tools may be required, such as screwdrivers, drill bits, files, etc. The skill level required is intermediate to advanced.

Involute gear profiles were designed using Gearotic and imported into TurboCAD for final adjustments. One early experiment determined a good gear size. They needed to be large enough to print accurately, but not so large to exceed the capabilities of my printer. I printed various gear sizes ranging from 10 diametrical pitch down to 40 DP. A 60 tooth gear would be 6" in diameter at 10 DP, 3" at 20 DP, and 1.5" at 40 DP. The 40DP gears were printable with some distortion. 10 DP gears would be great for building a wooden gear clock, but too large for this small clock. I selected 20 DP for this clock as the perfect size for a small printed clock.

The next step is to design the overall gear train. Most pendulum clocks share the same basic structure with slight differences in the gear ratios. The primary requirement is that the minute hand should rotate once per hour and the hour hand should rotate once per 12 hours. The rest of the design uses simple math to calculate the sizes of the different gears. There is a bit of trial and error to find good gear ratios. Eventually, everything starts looking like a clock. Figure 1 shows the model of the final gear train.

Most clock designs have just one gear between the escapement and the minute hand. This often uses gear ratios of 8:1 and 7.5:1. I chose an alternate design using an additional gear with 4.5:1 ratios between stages. This has several advantages, primarily the ability to allow 12 tooth pinions with reasonably small tooth counts on the larger gears. This helps reduce friction to enable long runtimes.

The gear ratios selected have the escapement rotating once every 39.5 seconds. This could have been built using a 20-tooth escapement and a pendulum length of around 39 inches. Instead, I chose a 30-tooth escapement with a period of 0.658 seconds per swing in each direction. A pendulum with a length of just under 17 inches will satisfy the requirement. This length pendulum seems proportional to the size of the clock body. The pendulum beats at a rate of 5467.5 beats per hour.

The next step in the gear train design is a 12:1 ratio between the minute hand and the hour hand. There are many different tooth counts that would satisfy this ratio. Many clocks use 32:8 and 30:10 tooth gears to provide a 12:1 ratio. This clock uses 48:18 and 54:12 tooth gears with 2.67:1 and 4.5:1 ratios between stages. This places the arbor just outside the footprint of the minute hand so the gears can be placed without using an intermediate frame. The hour hand still rotates at $1/12^{th}$ the rate of the minute hand.

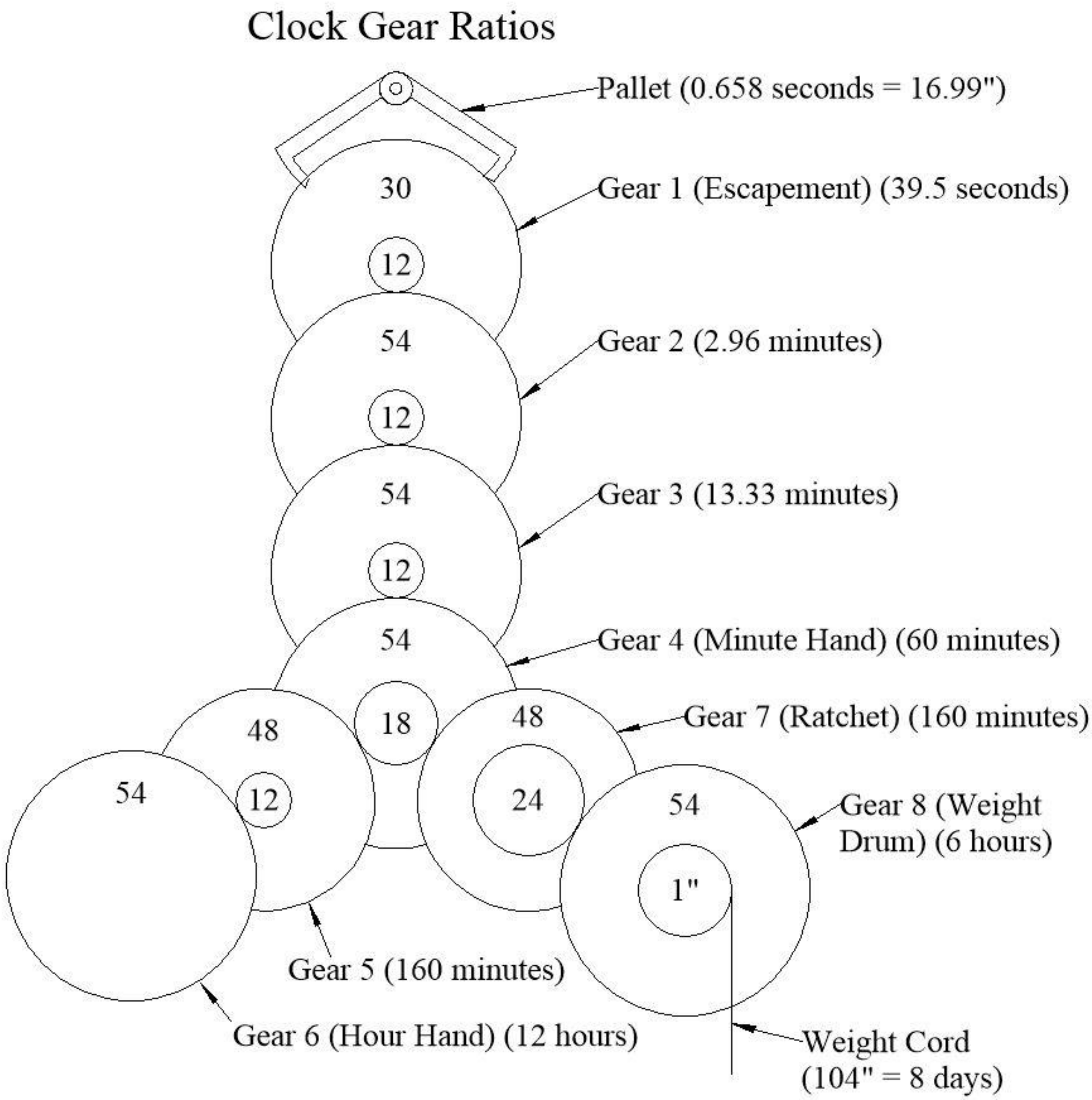

Figure 1: Clock gear train

The final component is the weight train to provide power. The target for this design is to have an 8-day runtime. The weight is placed along the center line of the clock for good balance. The cord is on one side and a pulley shifts the center of gravity back to the center line. Gear ratios and weight drum diameter were chosen to support the 8-day run time.

An 8-day run time with 52" of drop means that the weight can drop 6.5" per day. A pulley doubles the length to unwind 13" of cord per day. The 1" weight drum rotates once every 6 hours. Two gear sets divide this down to one rotation per hour of the minute hand. A 4.3 pound weight shell has just enough power to keep my clock running for 8 days, but it runs much more reliably using 6.3 pounds. Your clock may need slightly more or less weight.

The clock frame is a two piece shell with front and back segments. One great thing about 3D printers is the ability to integrate many details into each piece. All of the arbor locations and support columns are fully integrated with the large flat portions of the frame. A printed keyhole hanger hangs the clock on the wall. The top of the frame has a robust support bar to prevent frame sag from the heavy weight shell. This design could easily handle double the weight with minimal sagging. The support bar also includes a convenient location to store the winding key.

The front frame integrates the dial and numbers into a single 3D print. The first few layers are printed tan colored with pauses for the ivory colored dial and black numbers. The front and back frame sections fit diagonally on the MK3S print bed. The pendulum bob is a two-piece clamshell with a few pennies added for weights. It pivots on two small ball bearings with the grease removed to lower the friction. The pendulum rod was simplified to use full printed parts that drop into position. Adjustable nuts below the pendulum are used to set the period. One full turn adds or subtracts about 3.25 minutes per day. It is easy to fine tune the accuracy to within 1-2 minutes per week.

The gear thicknesses and clearances were defined using the mockup in figure 2. Most gears are 0.15" thick. Gears 7 and 8 have the most weight on them, so they were made thicker with bearings supporting the weight on gear 8. The escapement and pallet were made slightly thicker to provide a larger wear surface, although the initial design of this clock has been running for over 4 years with no visible wear. The pallet has tiny ball bearings to support the weight of the pendulum. I experimented with several different sized bearings and picked a size that allowed a pendulum to "free swing" the longest. The load is significantly below their design limit so I am expecting them to last a long time.

The diagram below shows a mock-up of the gear locations relative to the frame. It was used as the starting point for determining gear thicknesses and clearances. Finally, the gears were built into a 3D CAD model to check again.

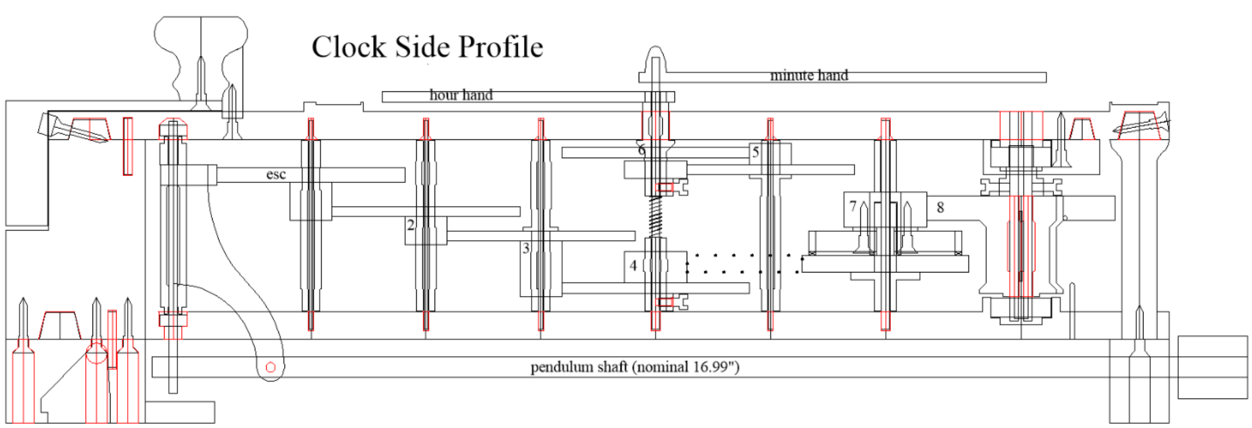

Figure 2: Clock side profile

Design Updates

The first iteration of this design was posted on Thingiverse, MyMiniFactory, and Printables. I believe it has been quite successful. Many builders have provided feedback and I continue to help makers debug their clock to make it functional. This design has many significant improvements to make the clock easier to build and also more reliable. The pictures below show a big improvement in the gear tooth profile. The first image shows how a traditional gear tooth would look in the slicer. Notice how every gear tooth has a small dot of infill that results in many retractions with an increased likelihood of stringing or small blobs.

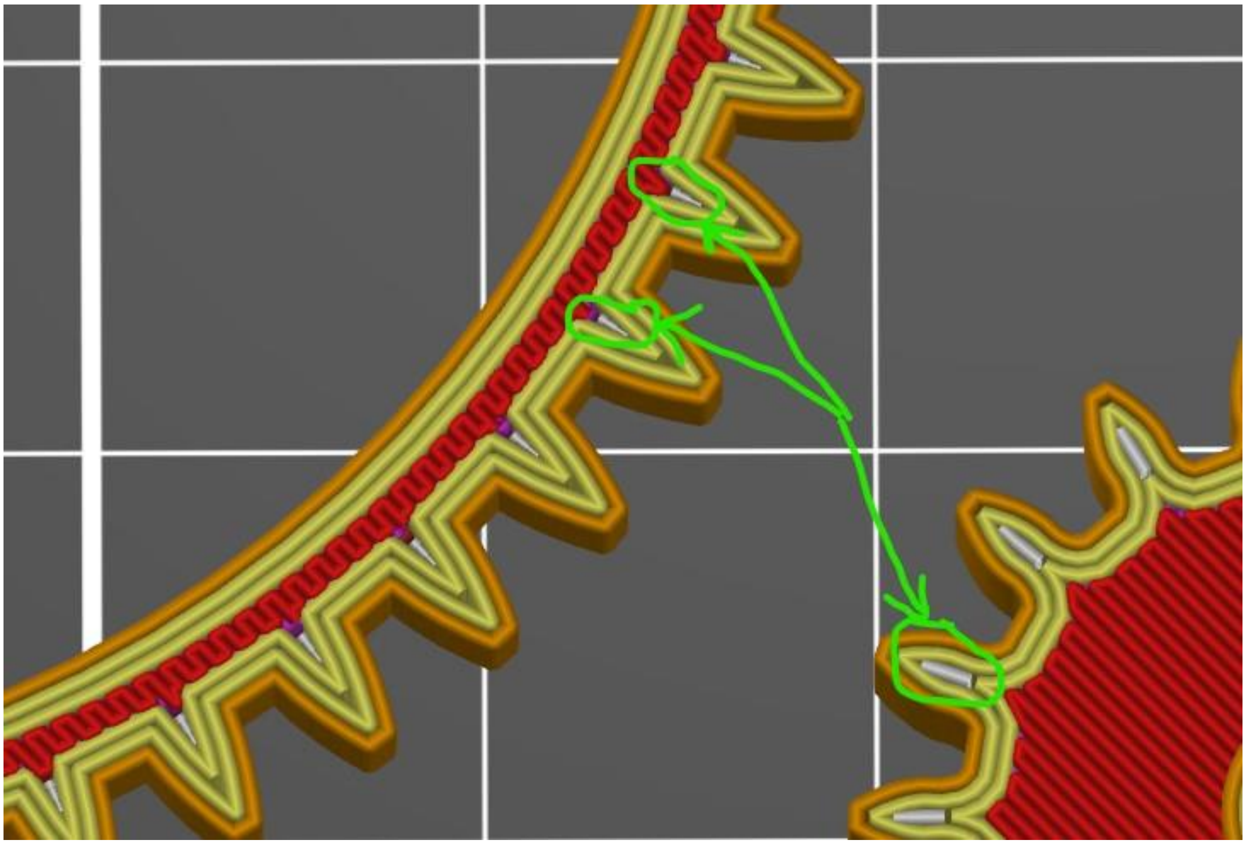

Figure 3: Original gear slices

The first design used this standard involute tooth profile. Some builders mentioned that their gears were binding and they reduced the sizes to get a working clock. I realized that a traditional gear profile is not optimal for 3D printing. A concept called “fancy gears” described at “Gary’s Wooden Clocks” website was the starting point for the gears used in this clock. Unfortunately, the link appears to be dead, but the basic premise is that clock gears operate with different criteria than most other gearing applications. Clock gears only turn in one direction so only one edge is used. The other edge can have any shape as long as it does not interfere with the neighboring gear teeth. Also, clock gears are always under load so there is never an issue with extra backlash. In fact, extra backlash is beneficial in reducing the possibility of binding.

Below is the slicer output after optimizations for fancy gears. Notice how each gear tooth gets created using continuous flows of filament. There are no unnecessary retractions. These gears are designed so that the teeth, rim, and spokes end up printing completely solid. A few additional optimizations were made so the gears print better using the new Arachne slicing algorithm. Backlash has been reduced considerably.

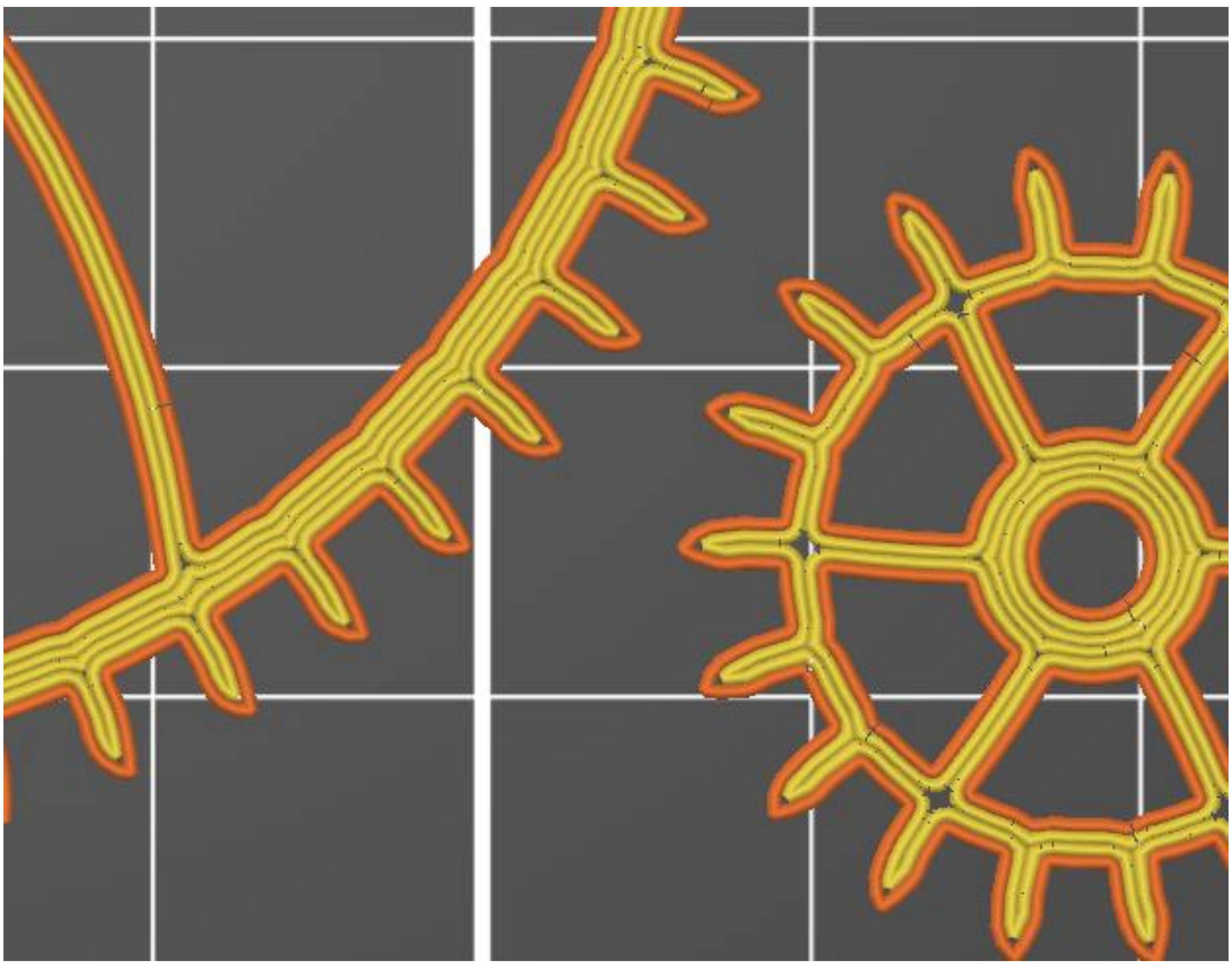

Figure 4: Sliced gears after optimization

The escapement and pallet received similar improvements. This had a big effect on functionality since the they are among the most important components in a clock. The original escapement has sharp teeth that round off when 3D printed, resulting in the escapement releasing way too early. I compensated by changing the size to make it work with my printer, but this may not be the optimal for other printers.

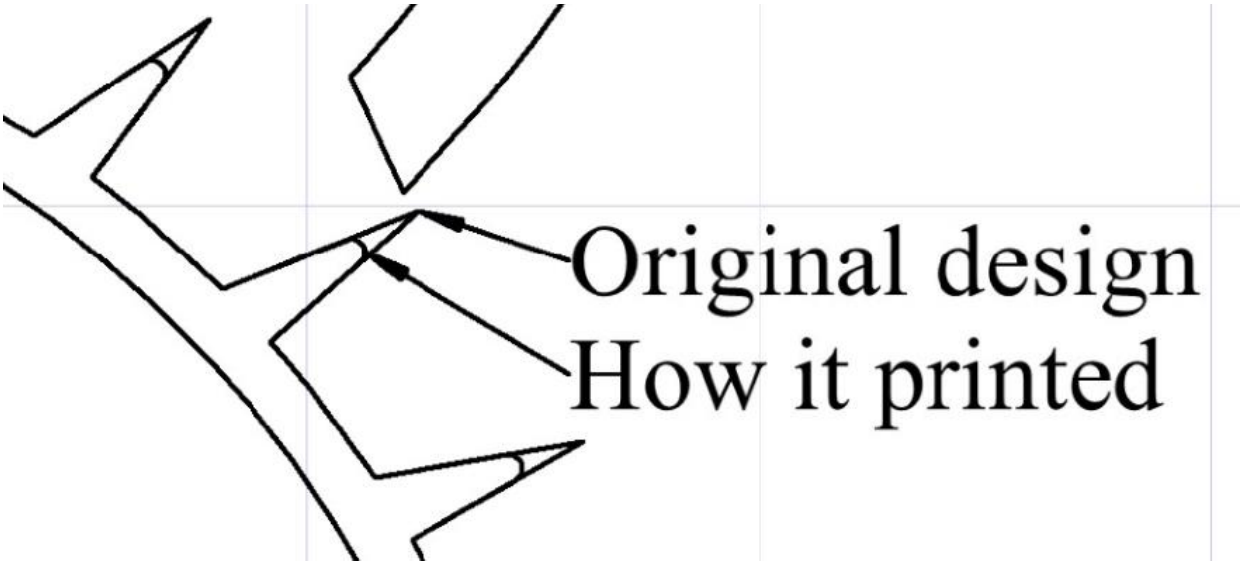

Figure 5: Traditional deadbeat escapement

The solution used in this design is to widen the tips of the escapement teeth and maintain the width back to the rim and spokes. The pallet width was reduced to provide the proper clearance. It may look different than a traditional escapement, but the active surfaces are the same. The predictable length of the escapement teeth makes it very reliable in a 3D printed design.

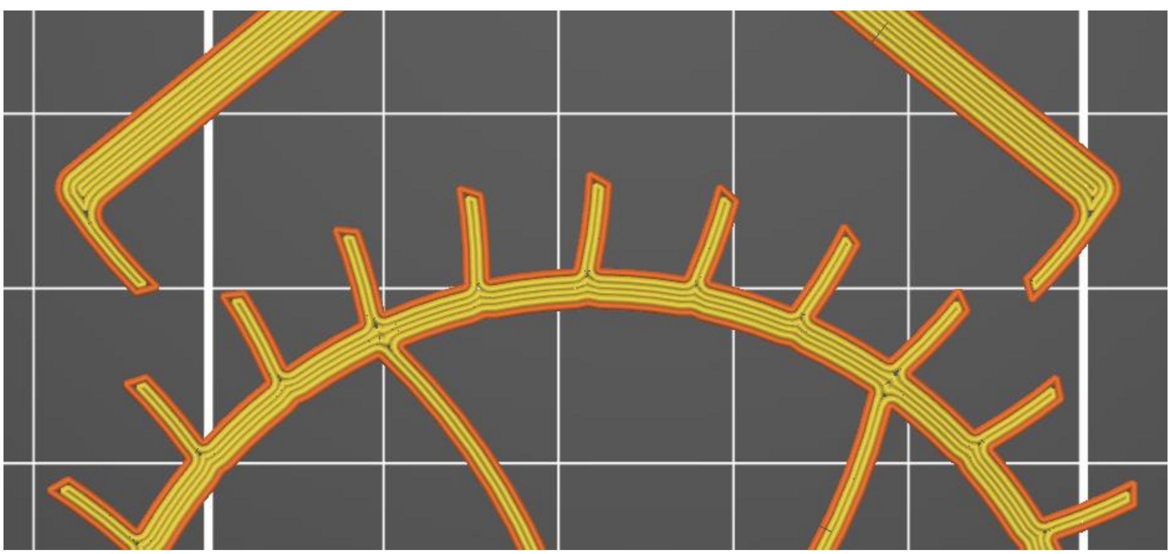

Figure 6: Escapement and pallet slicer output

Printing the Parts

Most parts can be printed flat with the largest surface already positioned to sit flat on the build tray. No supports are needed for any parts. The two largest components are the front and back frames. They just fit on a 250mm x 210mm Prusa MK3 at the default 35-degree angle.

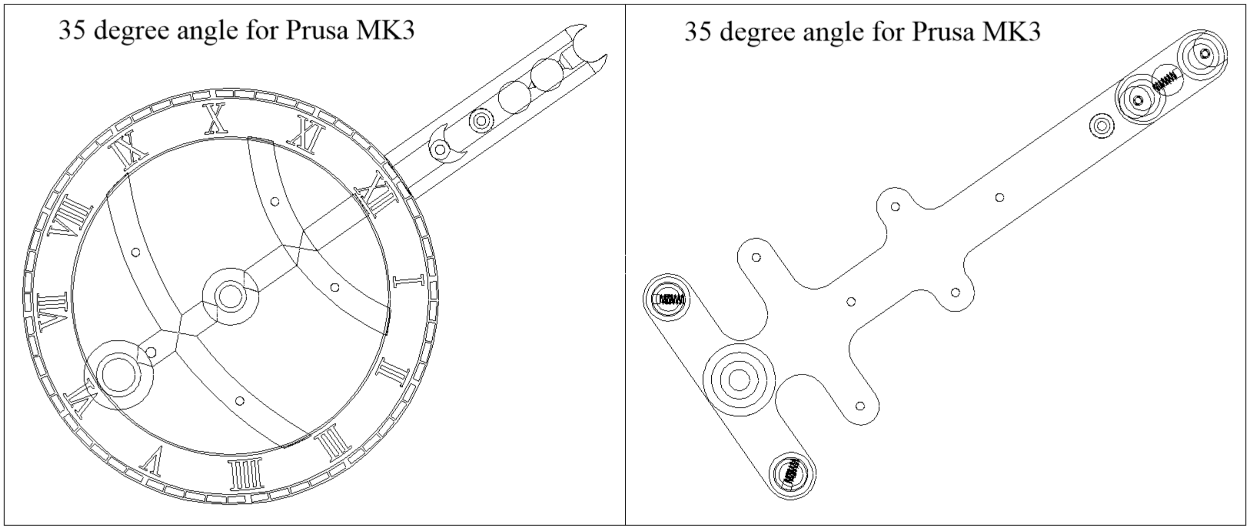

Figure 7: Prusa MK3 orientation

Another popular printer appears to be a Creality Ender 3 with a 220mm by 220mm tray. The frame should fit on this printer with a 45-degree rotation. The STL files are released with a 35 degree rotation, so they would need an additional 10 degrees of rotation to fit on an Ender 3.

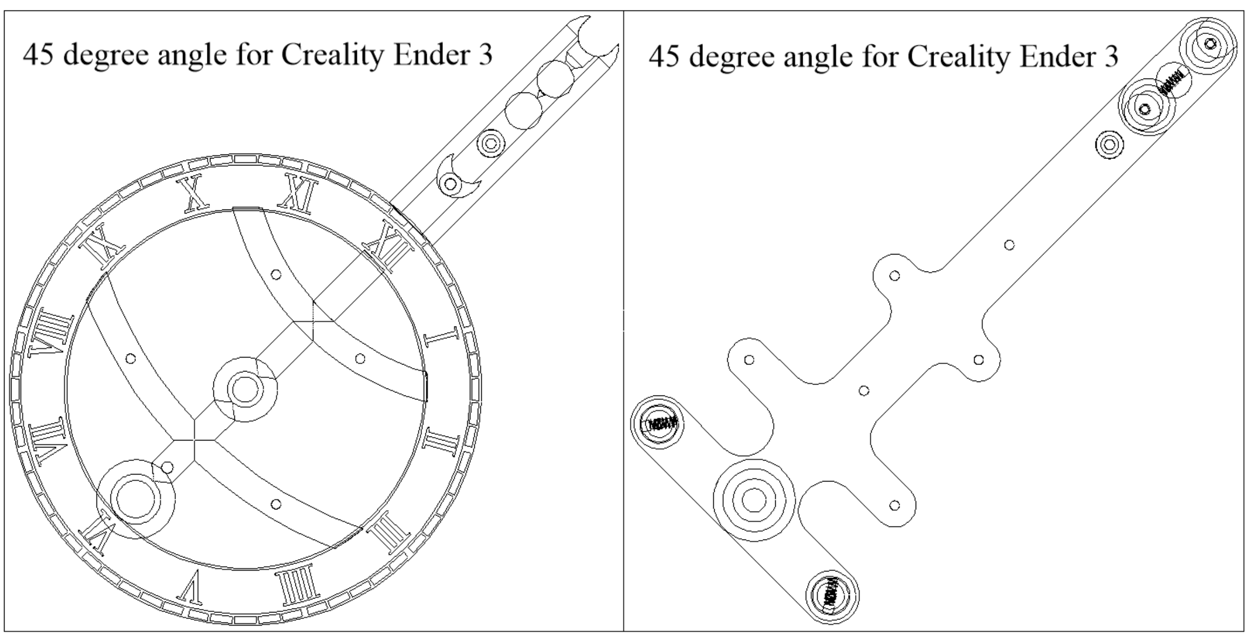

Figure 8: Creality Ender 3 orientation

The large frame components might print better with a brim. They are relatively thick so the corners have a tendency to lift from the bed. And you may not see problems until you are 10 hours into a 12 hour print. I had one failure printing the front frame where the left side started curling up just as the numbers were being added. This caused half of the numbers to be squished and really horrible looking. I added a 5mm brim and the next print was OK. It just barely fit on the print bed.

I have printed many working clock models using PLA as the only filament. Other filament types might work just as well or maybe even better. PLA works for me, so I continue to use it.

All of the parts are designed to fit directly on the bed without any additional supports. I typically leave everything at 30% density with 4 perimeters. The frame might work just fine at 20% density, but I don't want to risk having it sag after hanging the weight. Most other parts are small or they have thin walls so there is almost no difference between 20% density and 50% density. The primary settings 0.2mm layer heights, 4 perimeters, random seam positions, and 30% cubic infill. Random seam positions are important on the weight shell to prevent a long diagonal stripe where each layer starts. The gears in this clock have been optimized to print using the Arachne slicing algorithm.

The color choices listed in the table below are one example using colors to match the one shown on the front cover. The gears are printed using purple silk PLA. The frame is a neutral tan color with ivory and black highlights for the dial. The print times were reported in Prusa Slicer 2.6.1 for a Prusa MK3S. Many of the new faster printers would reduce this time considerably. It is OK to combine parts into one long print job.

The following default print settings are used on all parts unless specified differently in the tables:

Filament type:	PLA
Nozzle size:	0.4mm
Layer height:	0.2mm
Perimeters:	4
Top layers:	7
Bottom layers:	6
Seam position:	Random
Algorithm:	Arachne
Fill density:	30%
Fill pattern:	Cubic
Top/bottom:	Monotonic
Supports:	Never needed!!!
Elephant foot:	0.08mm

This is the list of frame and miscellaneous components to print. Print times are for a Prusa MK3S and may be different on your machine.

Part Name	Color	Print	Time	Filament	Notes
frame_back	tan	1	10h 8m	122.77g	
frame_back_split_lower	tan	0	5h 59m	72.72g	Optional split frame for smaller printers. See notes
frame_back_split_upper	tan	0	4h 15m	52.24g	
frame_bearing_holder	tan	1	1h 3m	9.85g	
frame_dial_roman	tan, white, black	1	9h 33m	129.35g	Color change at 10.4 & 12.8
frame_dial_roman_split_upper	tan, white, black	0	8h 30m	116.95g	Optional split frame for smaller printers. See notes
frame_dial_split_lower	tan	0	1h 36m	17.45g	
frame_standoff_base	tan	2	0h 28m	4.01g	
frame_standoff_cap	tan	2	0h 25m	4.97g	
frame_standoff_nut	tan	2	0h 11m	1.48g	
frame_standoff_upper	tan	1	2h 29m	25.77g	
hand_gothic_hour	gold	1	0h 21m	2.34g	
hand_gothic_hour_tight	gold		0h 21m	2.34g	Optional hour hand. See notes
hand_gothic_minute	gold	1	0h 24m	2.74g	
pendulum_bob_back	gold	1	0h 59m	15.38g	
pendulum_bob_front	gold	1	3h 48m	47.48g	
pendulum_nut	tan	2	0h 11m	1.48g	
pendulum_shaft_lower	tan	1	1h 24m	16.32g	
pendulum_shaft_mid	tan	1	1h 20m	17.30g	Nominal length pendulum arm
pendulum_shaft_mid_long	tan	0	1h 28m	19.12g	Optional long pendulum arm
pendulum_shaft_mid_short	tan	0	1h 13m	15.47g	Optional short pendulum arm
pendulum_shaft_upper	tan	1	1h 47m	23.66g	
winding_key_arm	tan	1	1h 9m	11.29g	
winding_key_knob	gold or purple	1	0h 51m	10.78g	
winding_key_support	tan	1	0h 26m	3.06g	Not needed with split frame
	Total	**22**	**38h 10m**	**461.83g**	

Table 1: Frame and miscellaneous parts

Notes:

Print the frame as full size components if your printer is large enough. Smaller printers such as a Prusa Mini can print the “split” frame components and glue them together using epoxy and short lengths of threaded rod. Further details are on page 20.

The default orientation of the full size frame is optimized to fit the rectangular bed of a Prusa MK3S. Rotate it 10 degrees for a square print bed such as an Ender 3.

The default hour hand should fit on the shafts. However, depending on printer tolerances, it may be slightly loose. A “tight” version is included if needed.

The middle portion of the pendulum shaft (pendulum_shaft_mid) should work with the default pendulum length. Different infill densities may change the effective pendulum length, so a shorter and longer middle section are included if needed.

The gears used are included in a separate table from the frame components. These gears have been optimized to print using the Arachne slicing engine and 4 perimeters unless otherwise specified.

Part Name	Color	Print	Time	Filament	Notes
gear_spacers	purple	1	1h 49m	12.25g	All spacers in one file
gear0_pallet	purple	1	1h 35m	12.43g	
gear1_30_12_esc	purple	1	1h 13m	9.30g	
gear2_54_12	purple	1	0h 57m	7.35g	
gear3_54_12	purple	1	0h 55m	7.23g	
gear4a_54_18	purple	1	1h 9m	8.67g	
gear4b_18	purple	1	0h 23m	2.39g	
gear5_48_18	purple	1	0h 39m	5.62g	
gear6_54	purple	1	0h 48m	6.30g	
gear7a_48_ratchet	purple	1	1h 26m	12.74g	
gear7b_24	purple	1	1h 12m	9.85g	
gear7c_clicks	purple	1	0h 39m	5.77g	
gear8_54_8days	purple	1	3h 25m	26.53g	Print with 5 perimeters
	Total	**13**	**12h 45m**	**99.9g**	

Table 2: Gears

The weight shell can wait until the clock is completed and you have tested how much weight is needed. The components needed are weight_shell_bottom_xxx, weight_shell_top_xxx, and weight_shell_pulley. Weight_shell_short_xxx is included for printers that are not tall enough for weight_shell_top_xxx. Weight_shell_quarter_xxx is an extension to add extra weight. More details are on page 28.

File Name	Color	Print	Time	Filament	Notes
weight_shell_bottom_2p4	Gold	0	0h 49m	10.77g	2.4” diameter weight shell
weight_shell_top_2p4	Gold	0	9h 19m	98.09g	
weight_shell_short_2p4	Gold	0	7h 55m	83.21g	
weight_shell_quarter_2p4	Gold	0	4h 52m	46.95g	
weight_shell_bottom_2p6	Gold	0	1h 2m	13.94g	2.6” diameter weight shell
weight_shell_top_2p6	Gold	0	10h 21m	109.71g	
weight_shell_short_2p6	Gold	0	8h 44m	92.44g	
weight_shell_quarter_2p6	Gold	0	5h 16m	51.55g	
weight_shell_bottom_2p8	Gold	1	1h 14m	17.35g	2.8” diameter weight shell
weight_shell_top_2p8	Gold	1	11h 24m	122.06g	
weight_shell_short_2p8	Gold	0	9h 34m	102.32g	
weight_shell_quarter_2p8	Gold	1	5h 39m	56.33g	
weight_shell_bottom_3p0	Gold	0	1h 28m	21.17g	3.0” diameter weight shell
weight_shell_top_3p0	Gold	0	12h 31m	134.91g	
weight_shell_short_3p0	Gold	0	10h 27m	112.69g	
weight_shell_quarter_3p0	Gold	0	6h 2m	61.07g	
weight_shell_bottom_3p2	Gold	0	1h 44m	25.43g	3.2” diameter weight shell
weight_shell_top_3p2	Gold	0	13h 37m	147.65g	
weight_shell_short_3p2	Gold	0	10h 27m	112.69g	
weight_shell_quarter_3p2	Gold	0	6h 30m	65.89g	
weight_shell_pulley	Gold	1	1h 0m	11.84g	Pulley used for all sizes
	Total	**4**	**13h 38m**	**151.25g**	

Table 3: Weight shell

Here is a summary of the gears used in the clock. The names include the arbor number and gear tooth counts to help identify them.

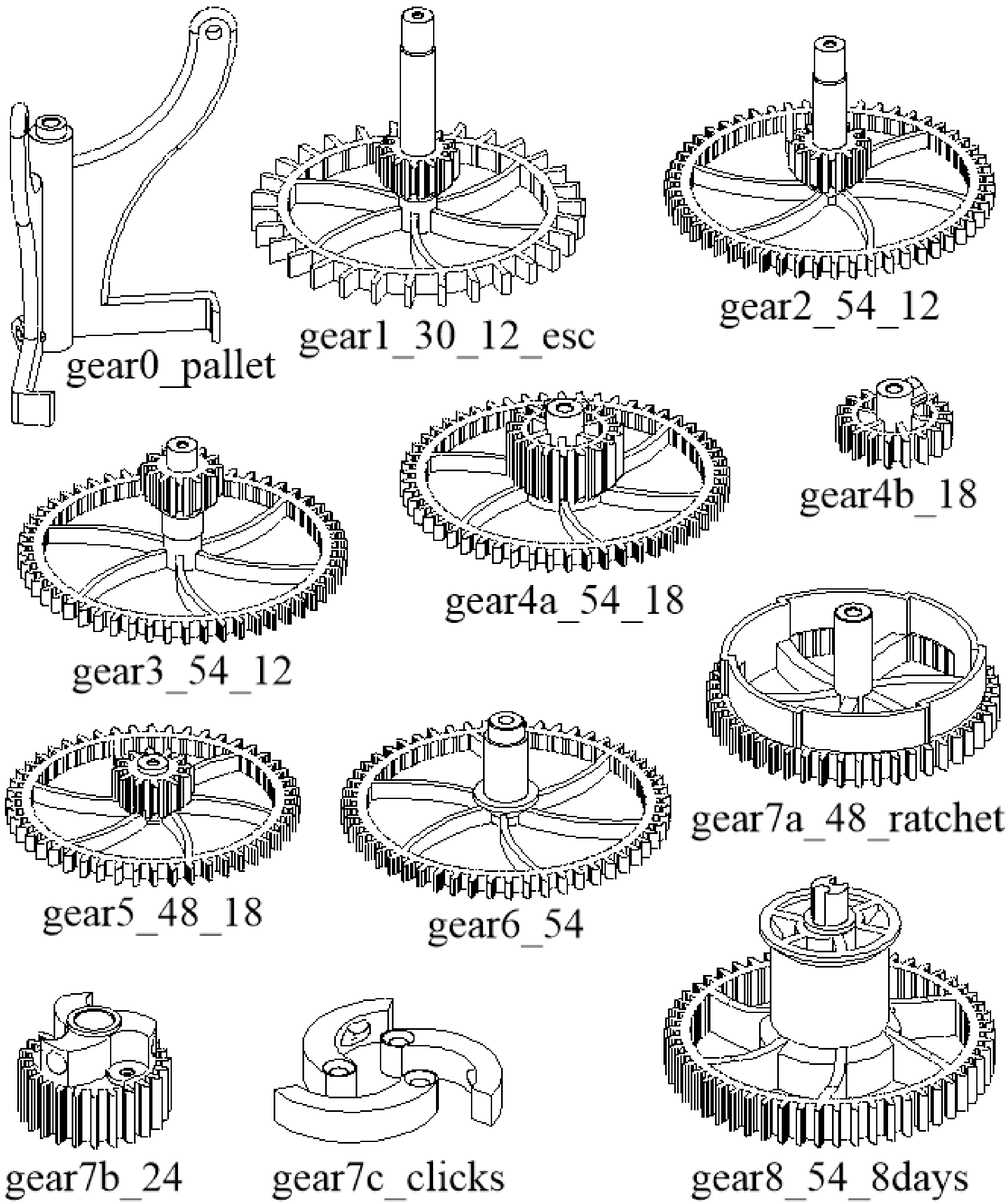

Figure 9: Gear reference chart

The spacers used are all combined into a single file, gear_spacers.stl. They will be referenced later in this document as spacer_{arbor_number}. The numbers in the diagram below indicate the gear each spacer is associated with. For example, spacer_0 goes on the same arbor as gear0_pallet.

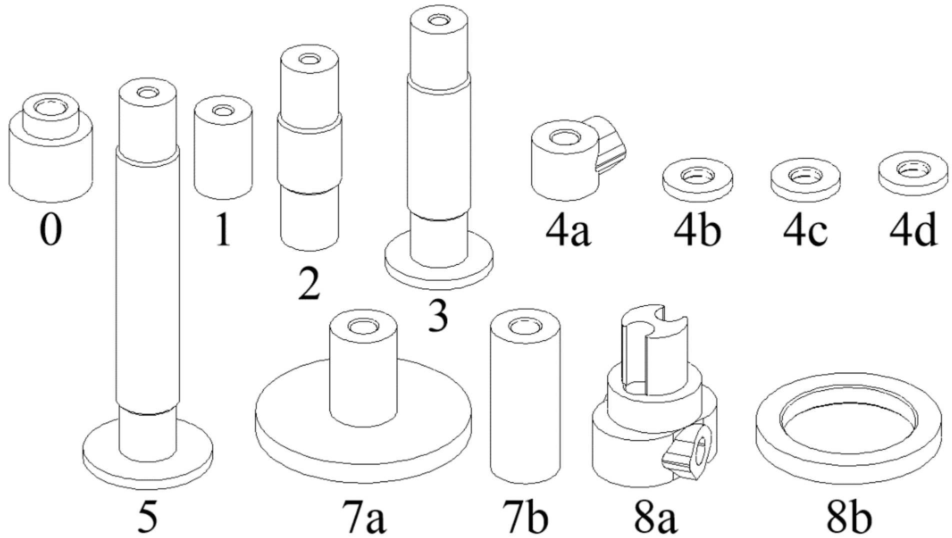

Figure 10: Spacer reference chart

Color Changes

The front frame has an integrated dial that needs a color change at 12.80mm to highlight the numbers. Another color change can be added at 10.40mm to add light color dial. My clock starts with a tan base layer, with a change to ivory at 10.40mm, and black at 12.80mm for the numbers.

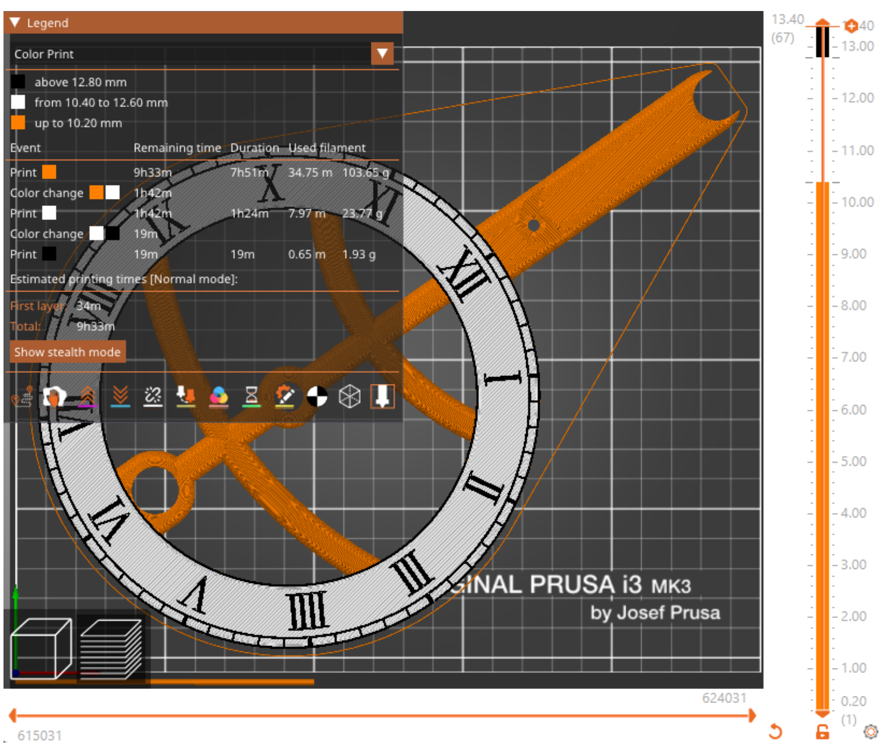

Figure 11: Layer changes for front frame

Additional Components

This clock consists mainly of 3D printed parts, but a few metal components are required. The bill of materials has been significantly reduced compared to the original design. Several hard to find parts have been eliminated and the screws have been consolidated to a small number of sizes.

Small ball bearings and metal arbors have been used to reduce friction in a few critical locations. A clock built completely from 3D printed parts would have higher friction and shorter run times. 1/16” music wire is much stronger and significantly lower friction than a printed PLA arbor. Steel screws are much stronger than printed screws. I tried to keep most non-printed parts hidden as much as possible.

The following non-3D printed components are required. Part numbers from McMasterCarr are provided for some parts although many can be found cheaper at your local hardware store. Many parts can be substituted with the closest metric or imperial size. For example, the arbors can use either 1.5mm (0.059”) or 1/16” (0.0625”) music wire. I prefer 1.5mm because a 1/16” (1.6mm) drill bit can be used to clean up the holes leaving the perfect amount of clearance.

Qty	Component	McMC Part No.	Notes
21	6x3/4” flat head wood screw	90031A151	Metric equivalent is M3.5x20mm
1	6x1-1/4” pan head wood screw	90190A201	for mounting clock on wall
8	M3x8mm socket head screws	91292A112	6mm or 10mm lengths may also work
22" (56cm)	3mm stainless rod	1272T33	Brass or plain steel rod should be OK. See cut list
12" (30cm)	1/16” or 1.5mm music wire	8908K62	Either 1/16” or 1.5mm diameters can be used. See cut list
6” (15cm)	3mm threaded rod	98861A040	Optional splines only needed for the “split” frame option
12' (3.6m)	microfilament fishing line		I use PowerPro Spectra Fiber braided fishing line 65 lb. test, Eq Dia 16. Other brands of braided line are OK
~6 lb.	lead shot or BBs		BBs are safer than lead shot and only need a slightly larger weight shell
2	608 bearing (8x22x7mm)	5972K91	Generic skateboard bearings
3	623RS bearing (3x10x4mm)	4668K214	Used to support the pendulum.
4	click pen springs		

Table 4: Non-printed parts

Low friction bearings used to support the pendulum are critical to reduce friction on the fastest moving part. I find that cheap 623RS bearings available for around US$8 for 10 work great. The rubber seal is easy to remove for cleaning out the thick factory grease. The larger 608 bearings used in the winding barrel are commonly called skateboard bearings. Any quality is acceptable since they rotate very slowly. The McMaster-Carr part numbers shown above for the bearings should only be used as a reference to identify the proper sizes. Bearings can easily be found from alternate sources for significantly cheaper prices.

Metal Cut List

The following diagram can be used to cut the metal parts. The gears near the escapement use small diameter 1.5mm or 1/16” music wire to reduce friction. Either size is acceptable. Music wire needs to be cut with a hardened cutter. An abrasive Dremel cut-off disk also works.

All other metal rods are 3mm in diameter. Stainless steel works best, but brass or plain steel should also work. The minute hand arbor uses a 3.9” long section of 3mm rod with a flat notch filed at one end to fit into the minute hand.

Smaller printers using the “split” frame will need four pieces of 3mm threaded rod to glue the frame together. Straight rod roughed up to improve glue adhesion could also be used. #6-32 threaded rod could also be made to fit.

Four short 3mm x 0.8” (20mm) pins are used to help align frame components that support the heavy weight shell. They are included in the metal cut list, but might be optional. See the descriptions later.

Cut all metal pieces and clean up the ends by rotating them while gently touching them to a bench grinder or sanding disk.

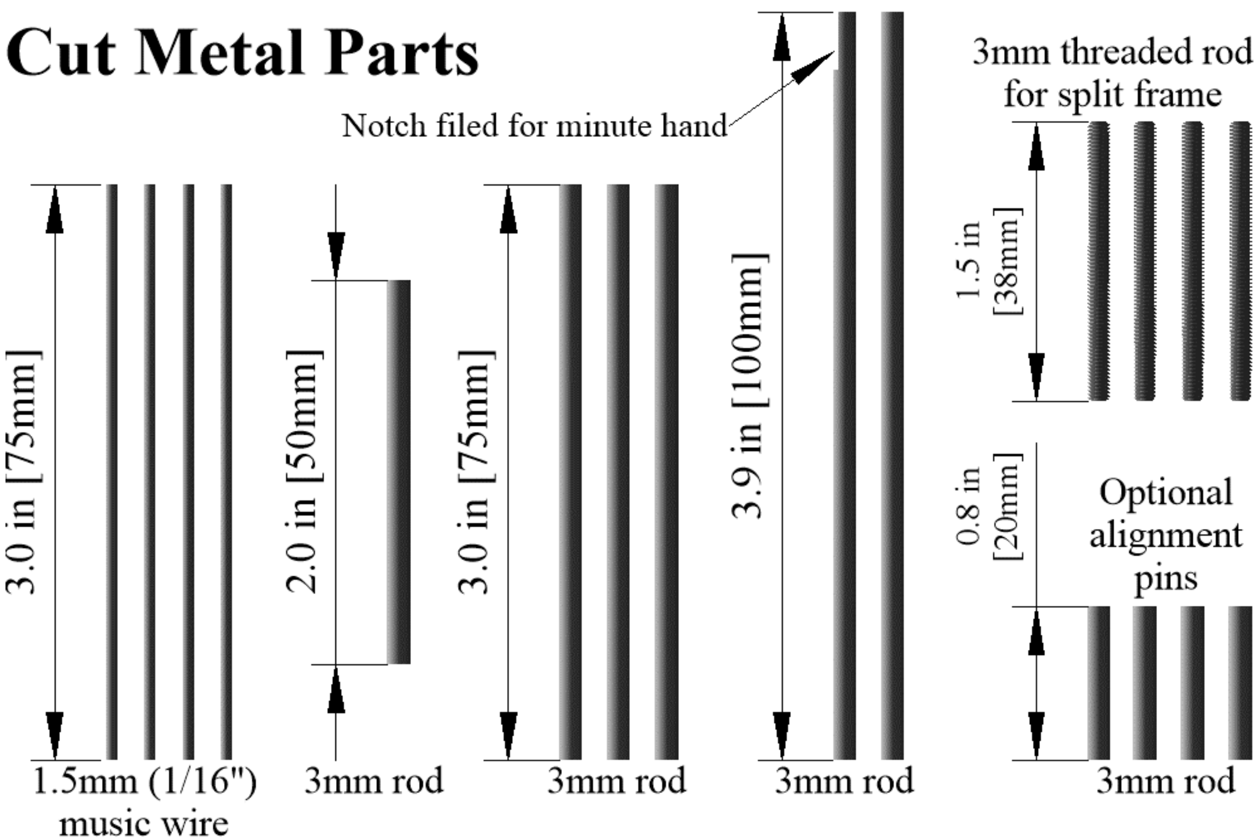

Figure 12: Metal part cut list

Component Pre-Assembly

The parts in this clock are designed to be easy to print with the intention of assembling everything straight off the printer. However, different printers have different tolerances so some minor cleanup is usually expected. The most important consideration is the hole sizes that need to be loose, but not sloppy. I have heard reports that fast coreXY printers can end up with different hole sizes compared to slower printers. The simple solution is to drill all arbor holes to the proper size.

A 1/16" (1.6mm) drill bit is the perfect size to clean up holes for 1.5mm music wire. A 1/8" (3.2mm) bit works great for the 3mm arbors. It leaves a slightly oversized hole with the perfect amount of clearance. Put the drill bit in a hand chuck and twist slowly. One pass with a slightly oversized bit is sufficient. Check that all gears spin easily on their arbors and also check that the arbors spin in the frame.

Gears with tall shafts will only need to be drilled a short distance when cleaning up the holes. The central portion of the shafts usually open up to make it easier to drill out to fit the arbors. Here is side profile of a gear showing the center portion of each shaft opening up. You only need to drill through the tight portion to a depth of around 0.4" (1cm).

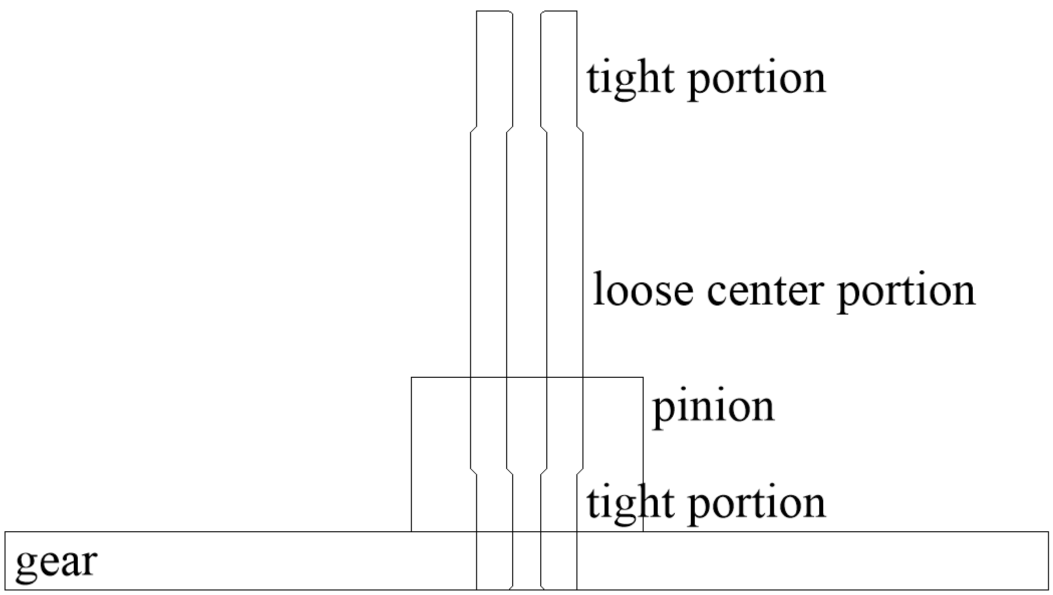

Figure 13: Gear side profile

Additional things to check are where printed parts fit inside each other and need to move smoothly. Gear6_54 needs to pass through the front dial for the hour hand and gear7b_24 needs to fit over the center post of gear7a_48_ratchet. Place the parts together and test that they can be rotated without binding. If they are tight, wrap sandpaper round the shafts and twist to remove a small amount of material. These parts can also be greased to reduce friction if desired.

Split Frame Option

The frame is easiest to build in a single piece if you have a Prusa MK3S, Ender3, or larger printer. A segmented frame that needs to be glued together is also provided for smaller printers. The "split" back and front frame pieces are glued together using four sections of 3mm threaded rod. Alternatively, #6-32 threaded rod can be filed down to fit. Straight 3mm rod could also be used if it is roughed up to provide good grip for the glue. Threaded rod works best since it provides plenty of glue surface.

Epoxy the threaded rod into the holes in the split frame segments and set them flat while the epoxy hardens. Make sure the parts are straight.

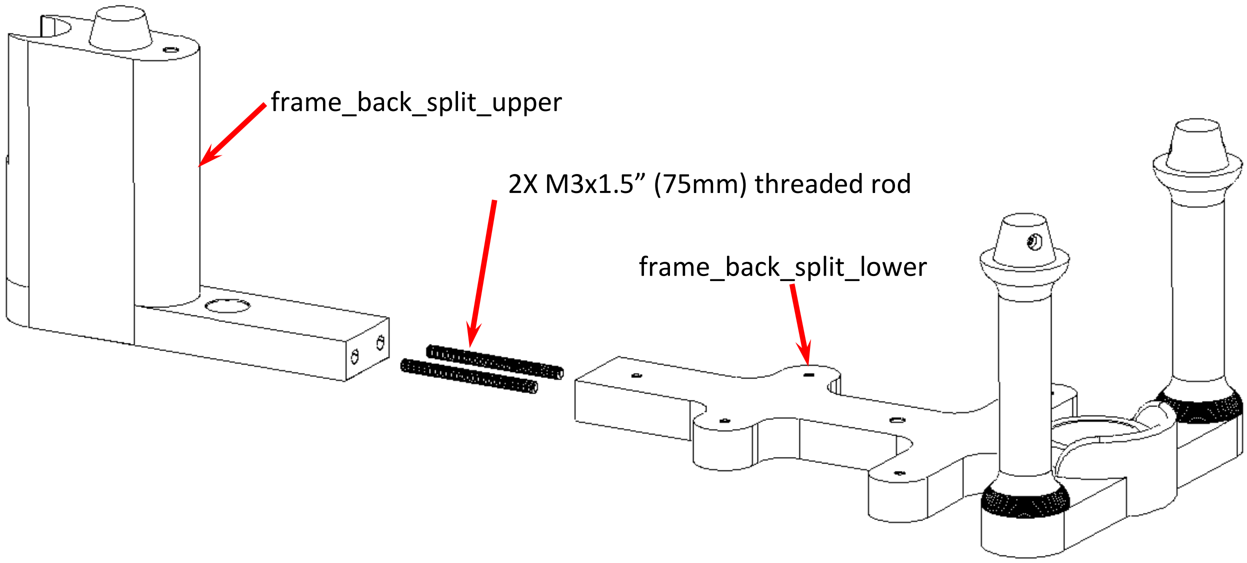

Figure 14: Split back frame pre-assembly

The front dial uses similar assembly. One slight simplification is that the winding_key_support is built-in, so it will save an assembly step later.

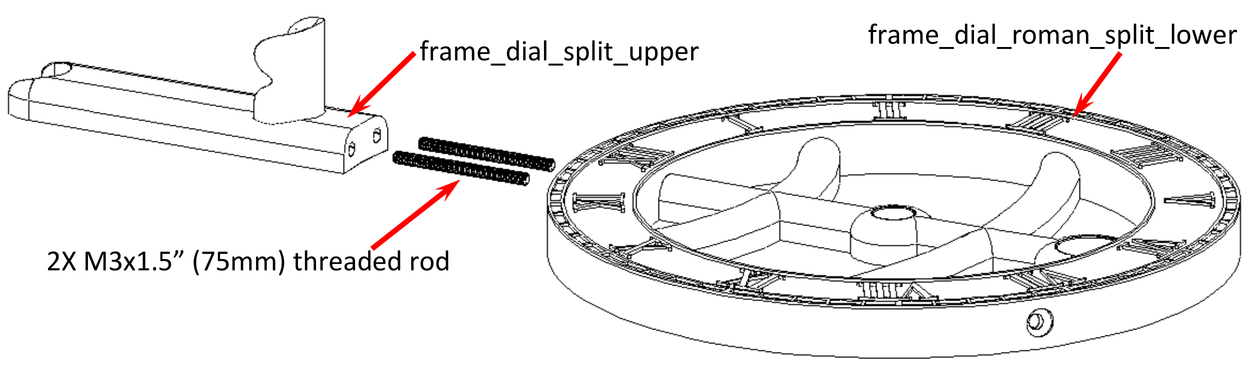

Figure 15: Split front frame pre-assembly

Frame Assembly

The back frame uses standoffs to provide room for the pendulum behind the frame with a built-in keyhole hanger to hang the clock. The entire weight of the clock including the weight shell is supported by one screw in a wall stud and three screws in the back frame. The upper standoff has a tapered alignment tab that should provide sufficient support. Two additional M3x0.8” (M3x20mm) steel alignment pins can be added for more security. The wood screws used are #6x3/4” or M3.5x20mm with a flat head. M3x20mm wood screws may also work.

The lower standoffs are a new adjustable design that allows the lower portion of the frame to be adjusted perfectly flat against an uneven wall. Attach frame_standoff_base to the back frame using wood screws and add the nut and cap.

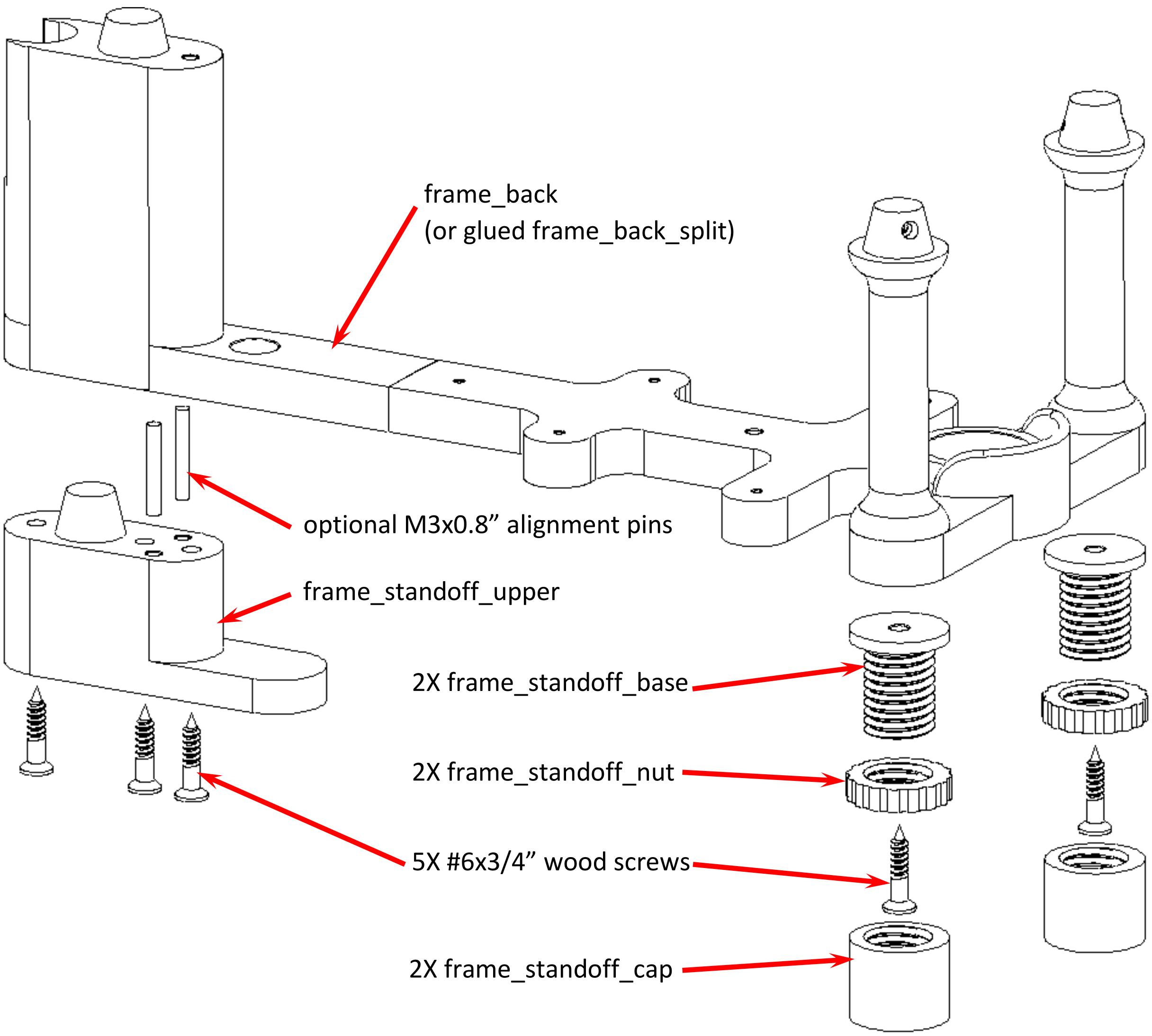

Figure 16: Back frame assembly

Place one of the 608 skateboard bearings and the bearing spacer into the bearing holder and attach it to the back of the dial using two #6x3/4” (M3.5x20mm) wood screws. An optional M3x0.8” (M3x20mm) alignment pin can be added if desired. I usually recommend removing the rubber seals and cleaning out the factory grease from clock bearings, but this bearing rotates so slowly that it may be OK as it comes from the factory. Any quality of bearing will work here. Hybrid bearings with ceramic balls are a great option to prevent rust if you can find them cheap. There is no need for an expensive bearing here.

The small projection on the left side of the frame_bearing_holder is used to hold one end of the winding cord when the weight shell is added. It is hidden from view behind the dial.

The winding_key_support gets added to the upper portion of the front frame using a #6x3/4” wood screw.

An optional M3x0.8” alignment pin can be added to the upper portion of the frame if desired.

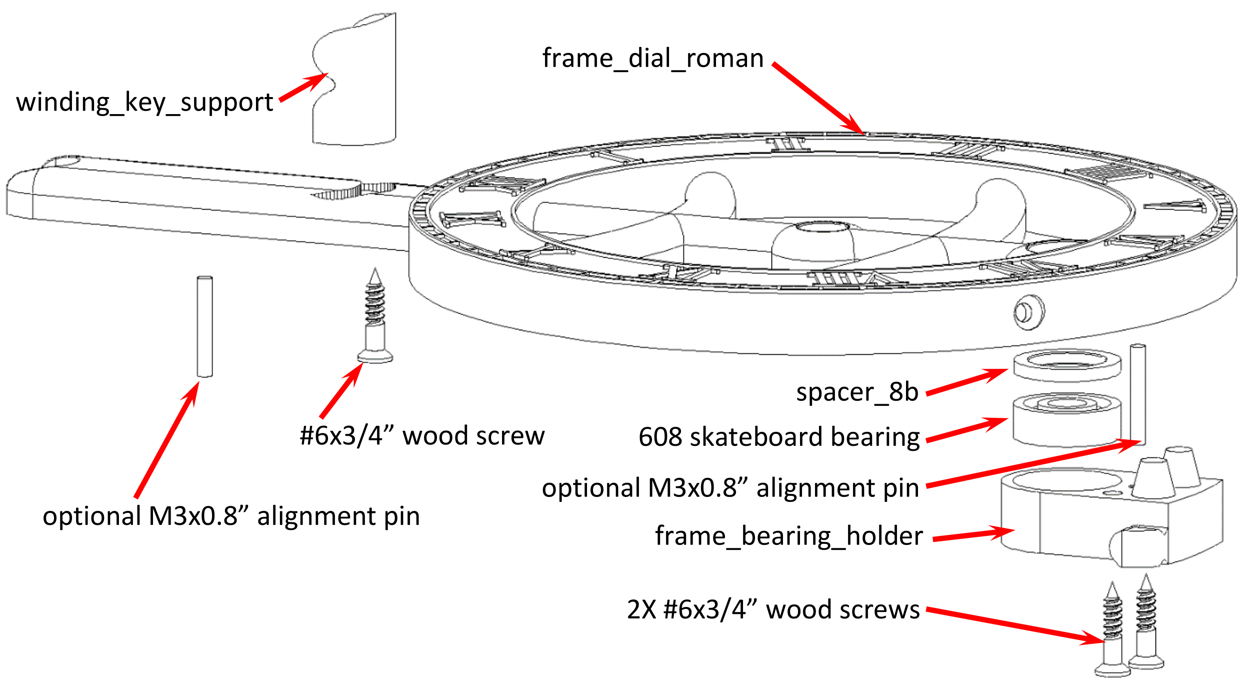

Figure 17: Front frame assembly

Winding Drum and Ratchet

The gear 8 winding drum assembly has been greatly simplified in this clock, while also making it much more secure when winding the clock. The only machining needed is cutting two steel rods to length.

Assemble gear 8 according to the diagram below. You may need to drill the holes in spacer_8a and gear8_54_8days to get the rods to fit. A 1/8" or 3.2mm drill bit provides just enough clearance for the 3mm rods.

The M3x8mm screws thread directly into spacer_8a. They only need to be tightened enough to keep the steel rods from sliding forward over time. Position the rods to project through spacer_8a by about 0.5". They will slightly extend through the bottom of gear 8.

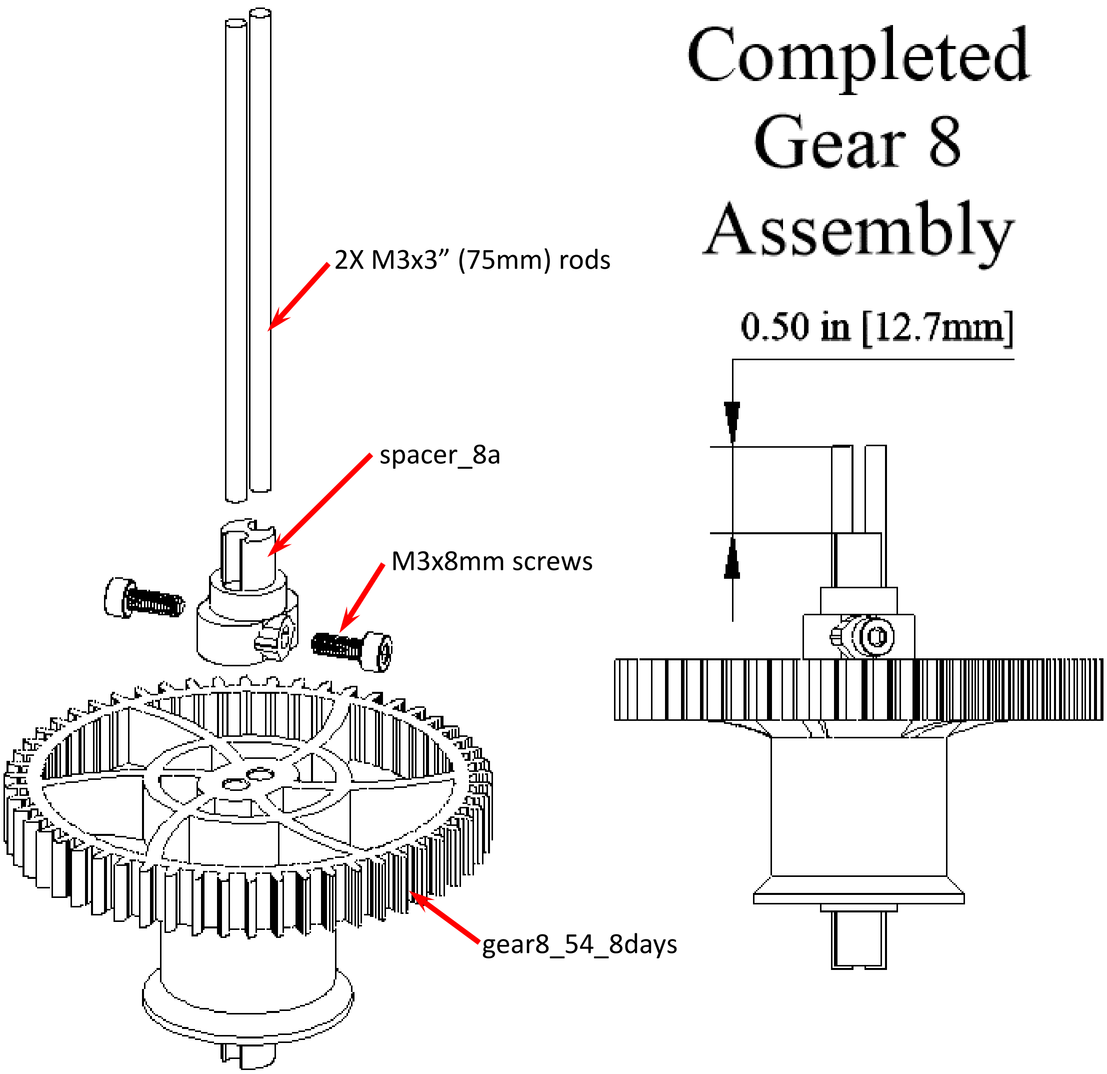

Figure 18: Winding drum assembly

One of the spokes on gear 8 has a small hole to tie the braided fishing line. They make cord specifically for hanging clock weights, but braided fishing line is easier to find and probably cheaper. I typically use 65-80lb line to provide plenty of safety margin for holding a 6-8lb weight shell. The brand I use is Power Pro Spectra Fiber Braided Fishing Line, but any brand of non-stretch fishing line should work.

Tie one end of the cord to the small hole and cut it to about 12’ (3.5m) in length. Wrap the cord around the drum in the direction shown. The other end of the cord should have a small loop for hanging over the projection on frame_bearing_holder.

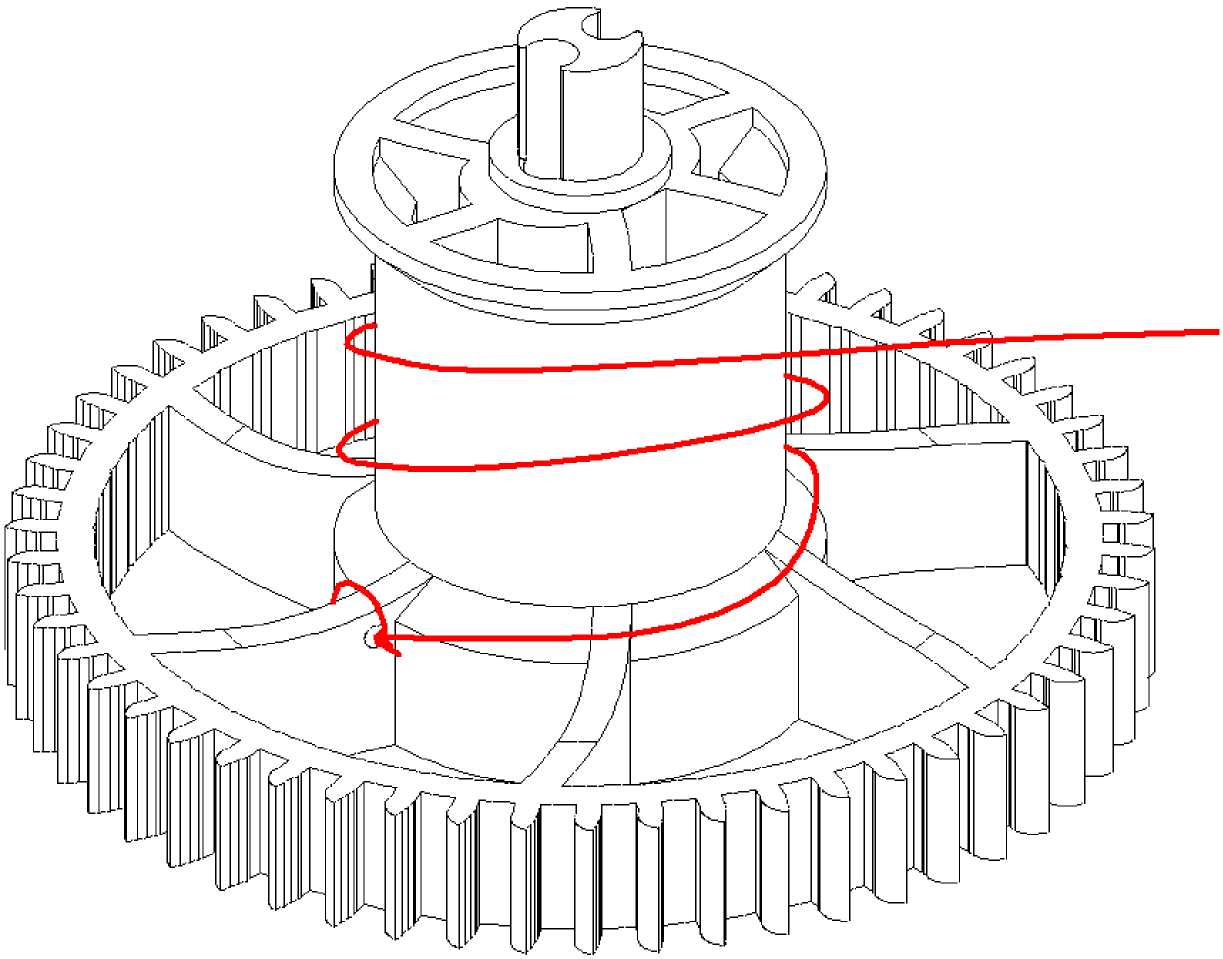

Figure 19: Winding drum cord assembly

The ratchet is the part you hear when winding the clock. It allows the winding drum to turn in one direction when winding the clock and prevents the cord from unwinding. This clock uses three ratchet arms for stability. Springs from a ball point click pen are used to push the clicks into the ratchet. The natural length of most pen springs is a bit too long to fit the tiny space available, so the springs should be compressed or cut to a length of about 0.7" (18mm). It is often easiest to slide the springs over a piece of music wire and squeeze the springs to reduce their length.

Before starting assembly, test that gear7b_24 fits over the center post of gear7a_48_ratchet. Twist sandpaper around the center post to reduce the diameter if needed. Also check that the 3mm rod fits through the gears and spacers. Drill them using a 1/8" or 3.2mm drill bit if needed.

Attach the three clicks (gear7c_clicks) to the ratchet center hub (gear7b_24) with #6x3/4" wood screws. Tighten the screws until they are snug, then back them off so the clicks swing freely. Add the three pen springs into the holes in the clicks and gear 7b. Turn the module over and add it onto the center post on gear 7a. The ratchet should spin easily in one direction. Add the center rod and spacers to match the diagram.

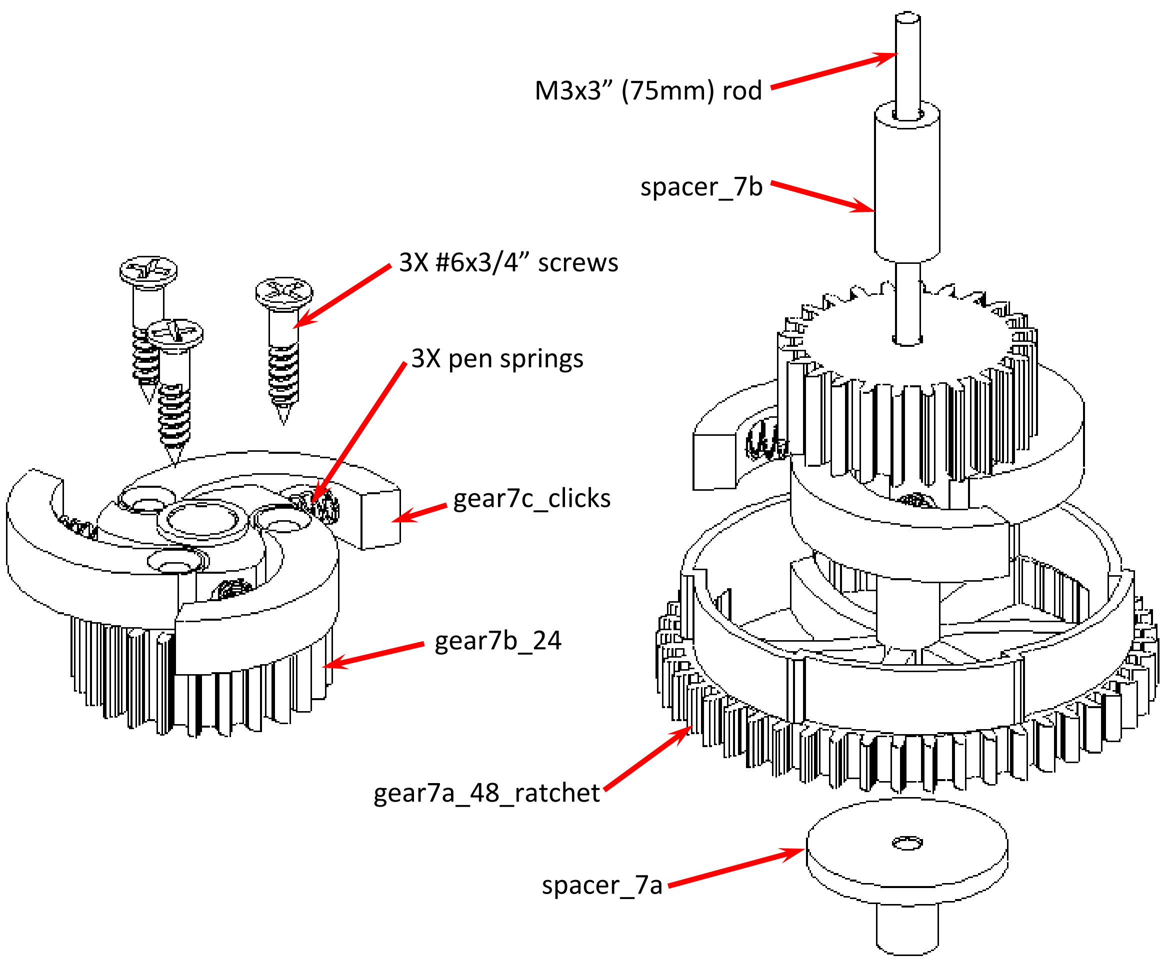

Figure 20: Ratchet assembly

Minute Hand Arbor

The lower portion of the minute hand arbor contains a mechanism for the time to be changed while the clock is running. A spring holds the position during normal operation and allows it to slip when changing the time.

Start by filing or grinding a flat segment on the end of the M3x3.9” (M3x100mm) rod to match the “D” shaped hole in the minute hand. The minute hand should slide easily over the flat portion.

Assemble the components to match the diagram below. Position the spacer_4a at the bottom end of the 3mm x 3.9” minute hand arbor with 0.25” sticking out. It uses an M3x8mm screw.

Place gear4a_54_18 over the bottom spacer. Drill the center hole of gear4a_54_18 using a 1/8” or 3.2mm drill bit so the gear spins easily on the 3mm arbor. Add the remaining components and secure gear4b_18 with another M3x8mm screw. The gap between pinions should be about 1.05” (27mm).

You should be able to rotate gear4a_54_18 relative to gear4b_18 with a slight amount of force. The spring allows both gears to rotate together when the clock is running, and it allows them to move independently when changing the time.

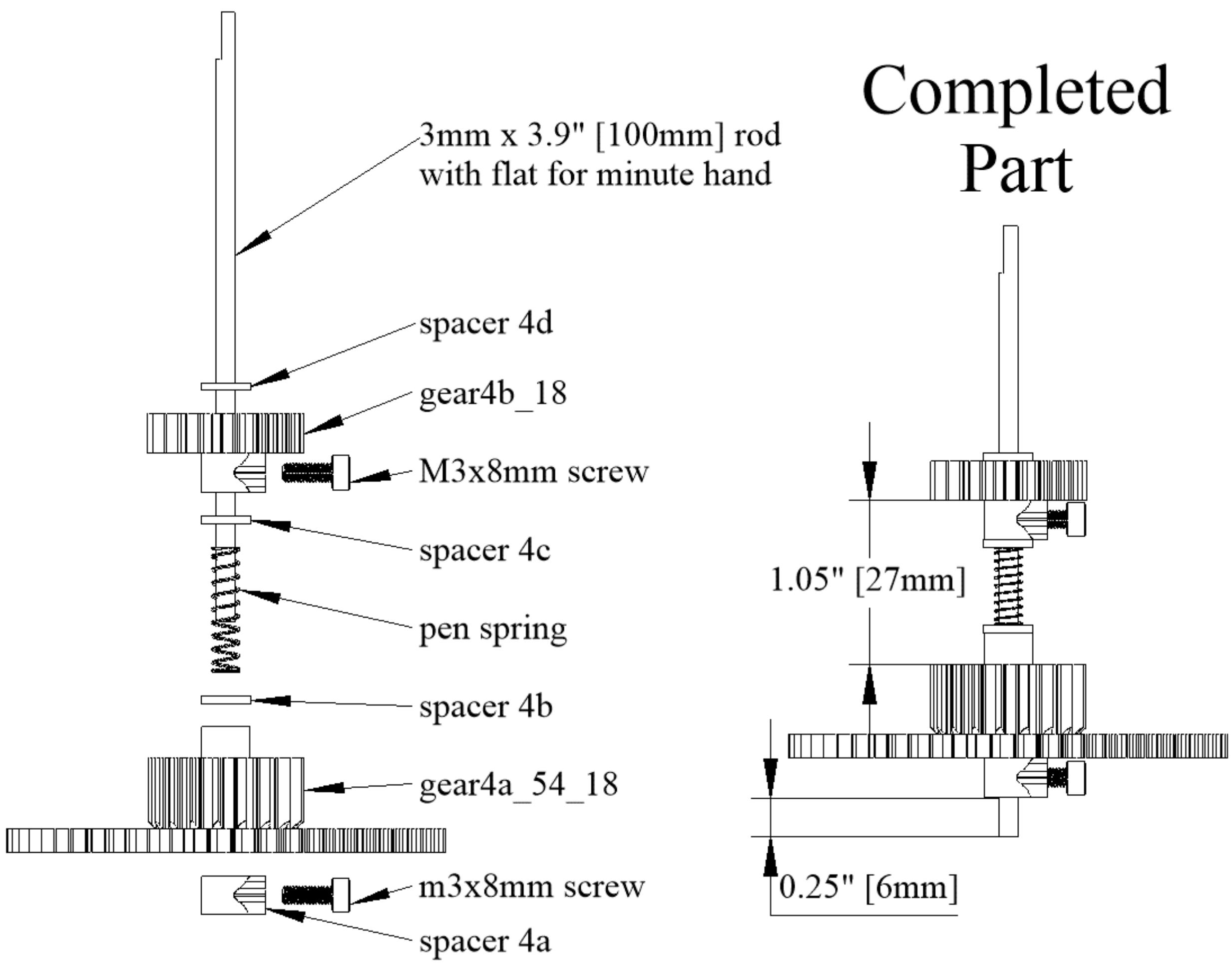

Figure 21: Minute hand gear assembly

Pendulum

The pendulum bob is a two-piece shell filled with pennies or washers for weights. The actual weight is not a significant factor in regulating the time. A heavy bob and a light weight bob will both swing at approximately the same rate. It only needs enough momentum to continue swinging during minor disturbances and not be so heavy that it creates excess friction at the pivot point. The bob could be filled with washers, small rocks, or anything that fits. Pennies are cheaper than washers and they fit nicely. Secure the back of the pendulum bob with two #6x3/4" wood screws. The assembled pendulum bob on my clock weighs just over 6 ounces (175g). The bob slides over the lower portion of the pendulum shaft when assembled. Two printed nuts are used to adjust the length of the pendulum to set the rate. Start with the nuts positioned near the center of the available threads.

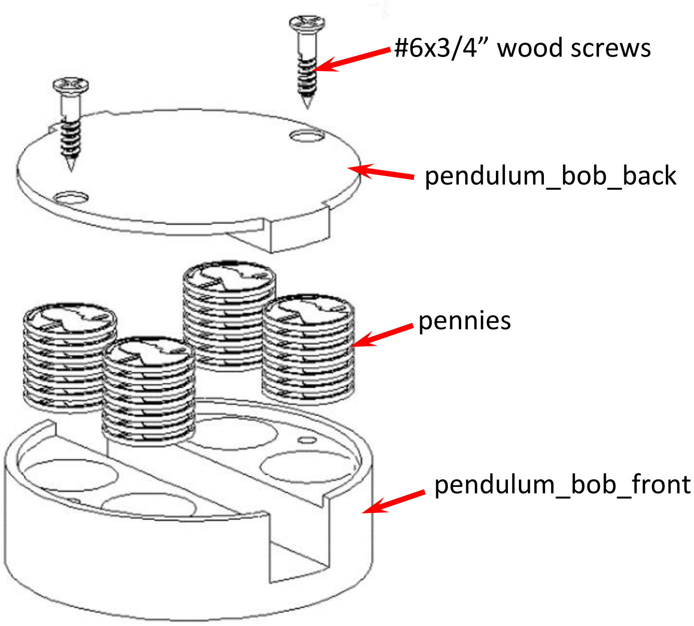

Figure 22: Pendulum bob

The winding key is a simple part that should have obvious assembly. Attach the winding_knob to the winding_arm using a #6x3/4" wood screw. Tighten the screw until it is secure, but still loose enough to spin easily. A small drop of oil could be added.

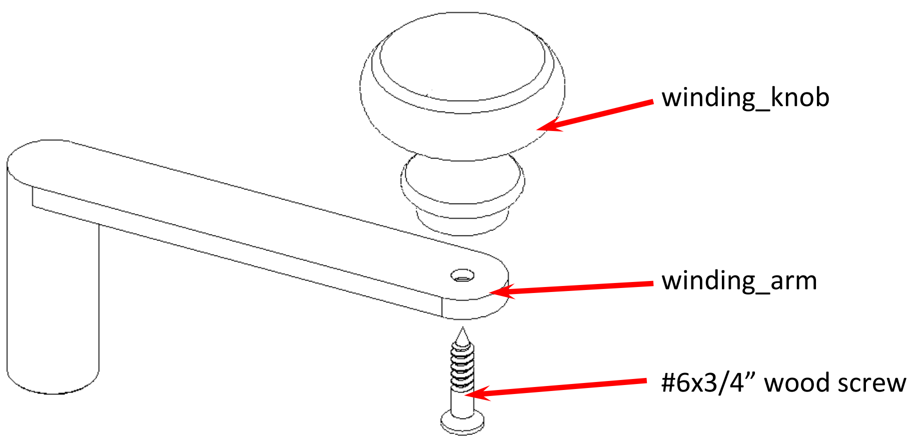

Figure 23: Winding key

Weight Shell

The weight shell assembly is described here, although you may want to delay printing the weight shell until after your clock is assembled and you test how much weight your clock actually needs.

The weight shell is filled with BBs or lead shot to provide energy to run the clock. There are multiple options to create different size weight shells using different densities of fill material.

Copper plated steel BBs have around 80% of the density of lead shot, so a weight shell filled with BBs would only need to be 25% larger than one filled with lead shot to achieve with the same weight. BBs are less toxic and easier to find than lead shot, so it makes sense to use BBs to fill the weight shells.

Below is a table showing the approximate weights of various size weight shells. I have built a few of the sizes and extrapolated the rest. The normal height column uses weight_shell_top_xxx by itself. The weight added by a single extension is listed. You can add multiple extensions if needed.

Weight Shell Diameter	Lead Shot Normal Height	Lead Shot with One Extension	Normal Height Filled with BBs	One Extension Filled with BBs
2.4”	5.3lb (2.4kg)	6.4lb (2.9kg)	4.3lb (2.0kg)	5.2lb (2.4kg)
2.6”	6.5lb (3.0kg)	8.0lb (3.6kg)	5.3lb (2.4kg)	6.4lb (2.9kg)
2.8”	7.9lb (3.6kg)	9.7lb (4.4kg)	6.3lb (2.9kg)	7.8lb (3.6kg)
3.0”	9.4lb (4.3kg)	11.7lb (5.3kg)	7.6lb (3.5kg)	9.4lb (4.3kg)
3.2”	10.9lb (5.0kg)	13.5lb (6.1kg)	8.8lb (4.0kg)	10.9lb (5.0kg)

Table 5: Approximate weight shell capacities

One of the final steps after putting the clock together is determining the amount of weight needed to keep the clock running. Too small of a weight will result in a shallow pendulum amplitude that can stop from minor disturbances. Too much weight can cause the frame to sag and adds extra stress to the gears. The trick is to find a good balance for smooth operation.

Start by adding small weights directly on the cord. Increase the weight until the clock starts running. Some people use water jugs where it is easy to add or subtract small increments. Double the weight to account for the weight shell pulley and add about 50% extra as a safety margin.

My clock just barely runs using 2 pounds of weight directly placed on the cord. The pendulum amplitude is shallow with this small weight. Doubling the weight to account for the pulley and adding a 50% margin brings the target weight to around 6 pounds. The clock runs very reliably with a 6.3 pound weight using the 2.8” shell filled with BBs.

A large container of 6000 BBs weighs around 4.5 pounds (2.0kg), so two containers should be plenty. Also, it doesn’t hurt to print a larger weight shell than needed and only fill it part way.

The weight shell is constructed using a pulley with a small bearing at the top end. The two halves of the pulley enclose the bearing and a pin is pushed in from the side. A tapered tip on the pin helps when lining up with the bearing center hole. The pin is a snug fit. It is OK to drill the hole 90% of the way through so only a small portion is tight. It is also OK to have a loose fit and add a small drop of glue to hold the pin. The pulley should spin freely when assembled.

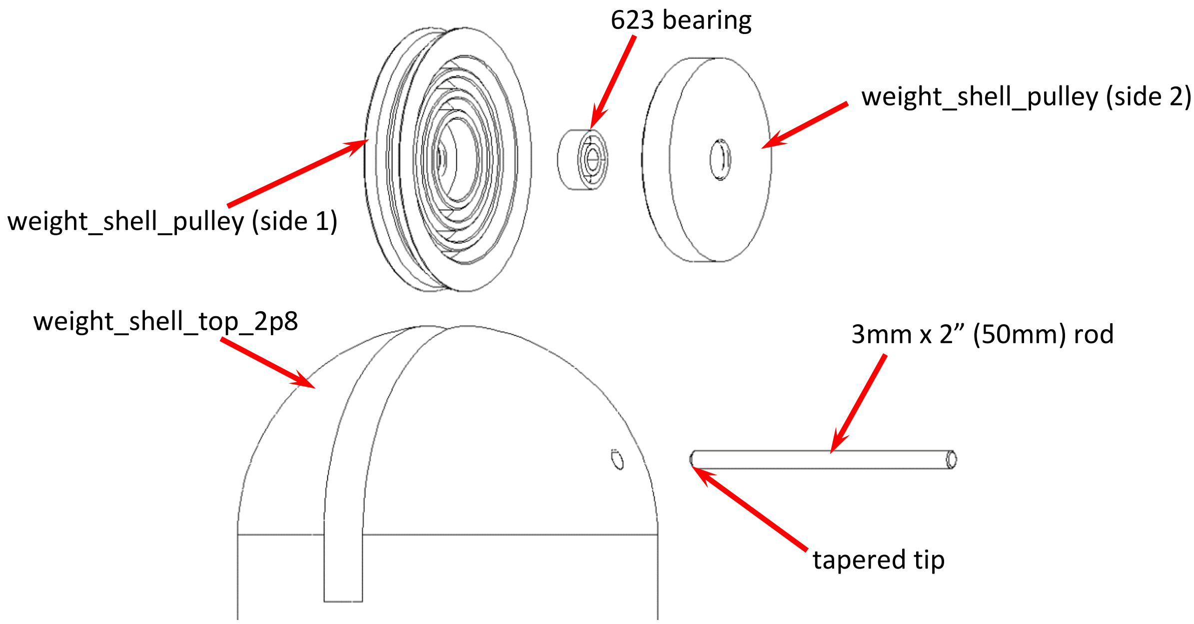

Figure 24: Top portion of weight shell

Turn over the weight shell and fill it with BBs (or lead shot). Take appropriate safety precautions if using lead shot. Assembly should be obvious when you see the parts. The bottom weight shell cover attaches using four #6x3/4” wood screws. Each weight shell extension uses an additional four #6x3/4” wood screws. Multiple extensions can be used if needed.

Building the Clock

Notes on Friction

It is worth stating how important it is to reduce friction in a mechanical clock. This clock uses 6.3 pounds of weight falling 52” every 8 days. The pendulum will tick 1,049,760 times in 8 days, so the energy of the weight shell dropping 0.00005” needs to provide enough energy to keep the pendulum swinging. After 78 ticks, the weight shell will drop the thickness of a sheet of printer paper. This gives us an idea about how little energy is available to keep the clock ticking. There is not much room for wasted friction.

Another way of looking at the energy in the clock is to calculate the forces at various places. The 6.3 pound weight uses a pulley, so there is only 3.1 pounds of force at the winding drum with a distance of 0.5” from the pivot point. The outer rim of gear 8 is 1.3” away from the pivot point, so it only has 1.19 pounds of force. Gear 7 has a 2:1 ratio, so it only has 0.60 pounds of force. Each gear in the drive train has less force than the previous gear, although the energy is the same because they rotate at higher speeds. The escapement only has 0.035 ounces of force remaining, which coincidentally is about the same as the weight of a common house fly. Theoretically, the clock would be stopped by a house fly landing on the escapement wheel. This gives us an indication of the tiny amount of energy available for each tick of a weight driven clock. Btw: a fly landing on the escapement could stop the clock, but it should start up again if he flies away before the pendulum loses its swing.

My clock has been running great using around 6.3lbs of drive weight. Your clock may require slightly more or less weight depending on overall friction in your clock. Hold off on printing the weight shell until you clock is closer to completion.

I sometimes add dry Teflon lubrication to all of the moving parts of the clock, but the clock also seems to run just fine without any lubrication. I have also used lithium grease on the pinions and pallet arms. Just a tiny bit is needed. Apply it with a toothpick and wipe away most of it. It is generally considered a bad idea to oil the escapement or clock gears because oil holds dust that can scrape the surfaces. I have not noticed any bad effects from oiling PLA clock gears, even after running for several years. PLA even seems to be safe with the solvent in dry Teflon lubrication, but try a small component before adding lubricants.

The small 623 bearings used to support the pendulum work best with the thick factory grease removed to minimize friction. Remove the rubber seals using a needle and wash the grease using solvent (paint thinner, mineral spirits, acetone, 90%+ alcohol, etc.). Add a drop of dry Teflon lubrication or lightweight oil to minimize rust.

Adding the Gears

The gears are easiest to add from the bottom layer and working towards the top. Start with the back frame sitting on a workbench. Place the pre-assembled minute hand arbor into the 3mm hole in the center of the clock.

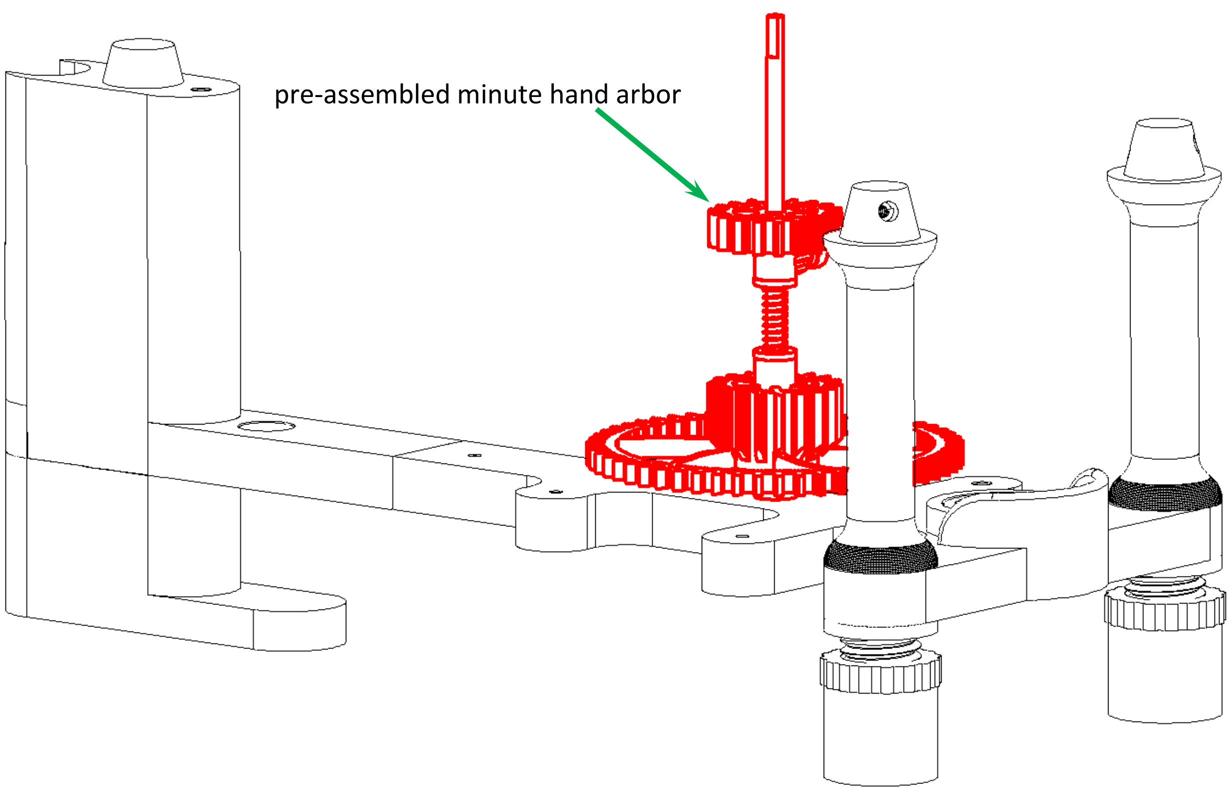

Figure 25: Minute hand gear

Add a 1.5mm x 3” (75mm) arbor, gear3_54_12, and spacer_3 into the upper left position. Both gears should spin easily.

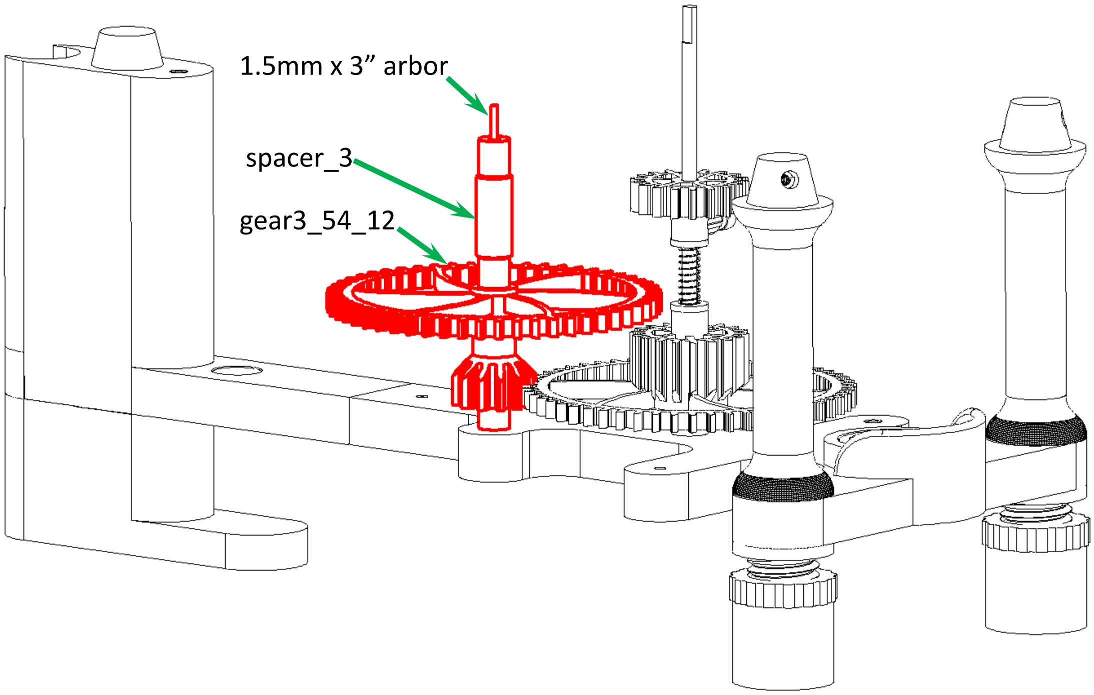

Figure 26: Add gear 3

Add a 1.5mm x 3” (75mm) arbor, gear2_54_12, and spacer_2 into the upper right position.

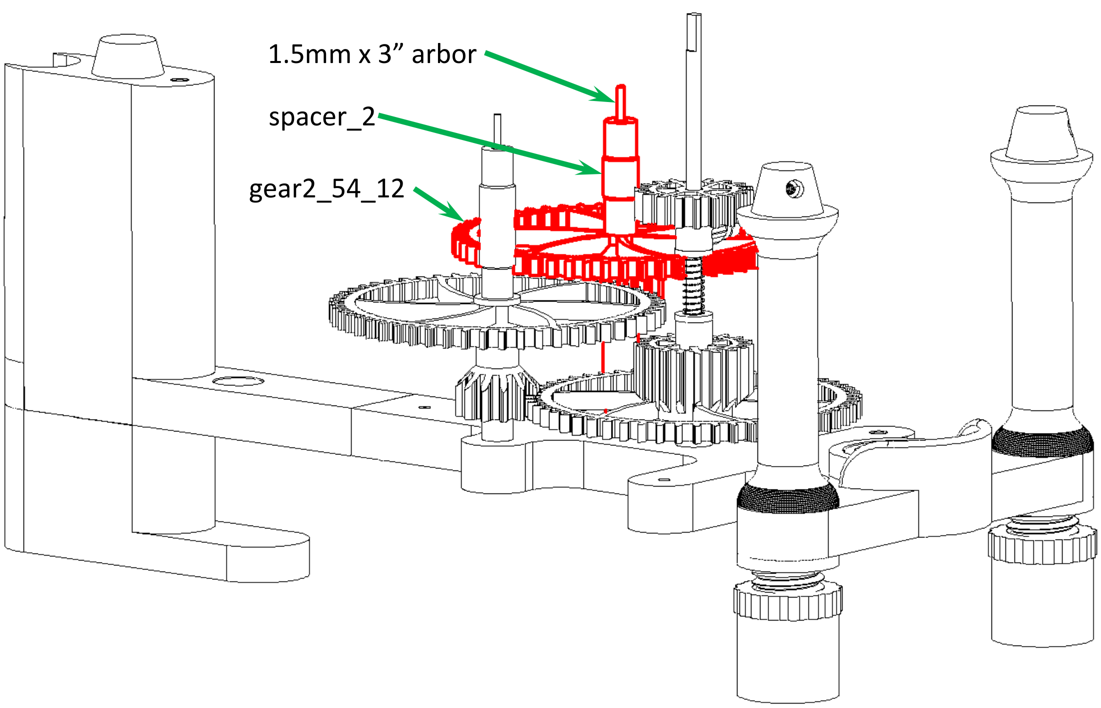

Figure 27: Add gear 2

Add a 1.5mm x 3” (75mm) arbor, gear1_30_12_esc, and spacer_1 above gears 2 and 3.

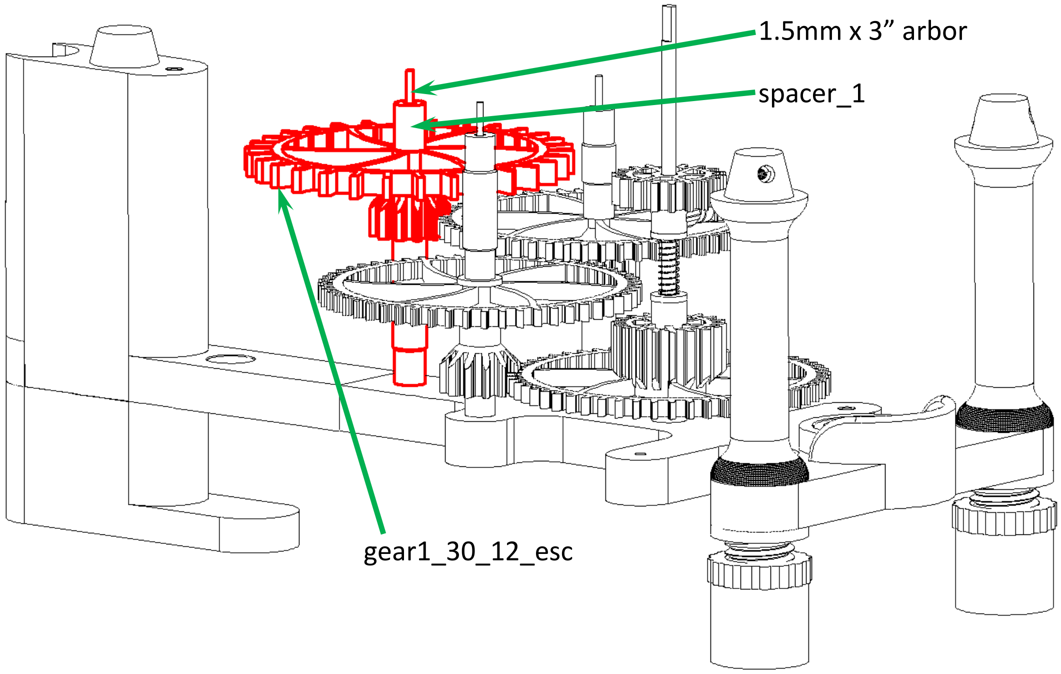

Figure 28: Add the escapement

The pallet assembly has several components. Add a 623 bearing into the back frame. Pass the 3mm x 3.9” arbor through the bearing, frame, and upper pendulum shaft. Add gear0_pallet, spacer_0, and a 623 bearing. The bearings should be cleaned as previously described to reduce friction. Four M3x8mm screws hold everything together.

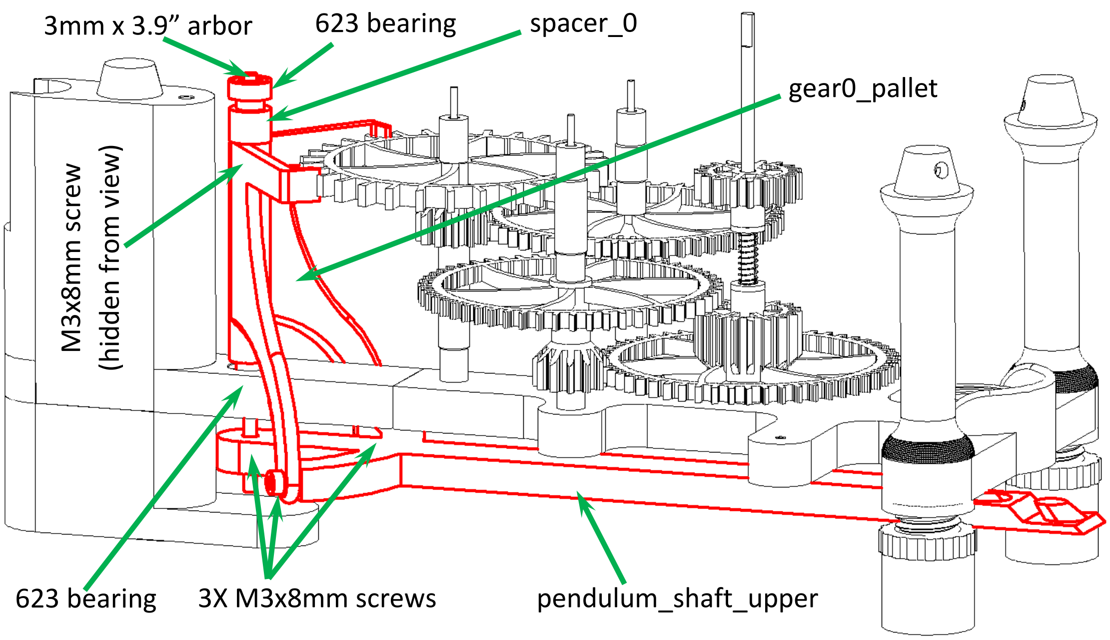

Figure 29: Pallet and top of pendulum

Here are all of the added components from the previous diagram shown at a different angle and without the frame cluttering the image. Of course, the arbor needs to pass through the frame before the pendulum arm can be added.

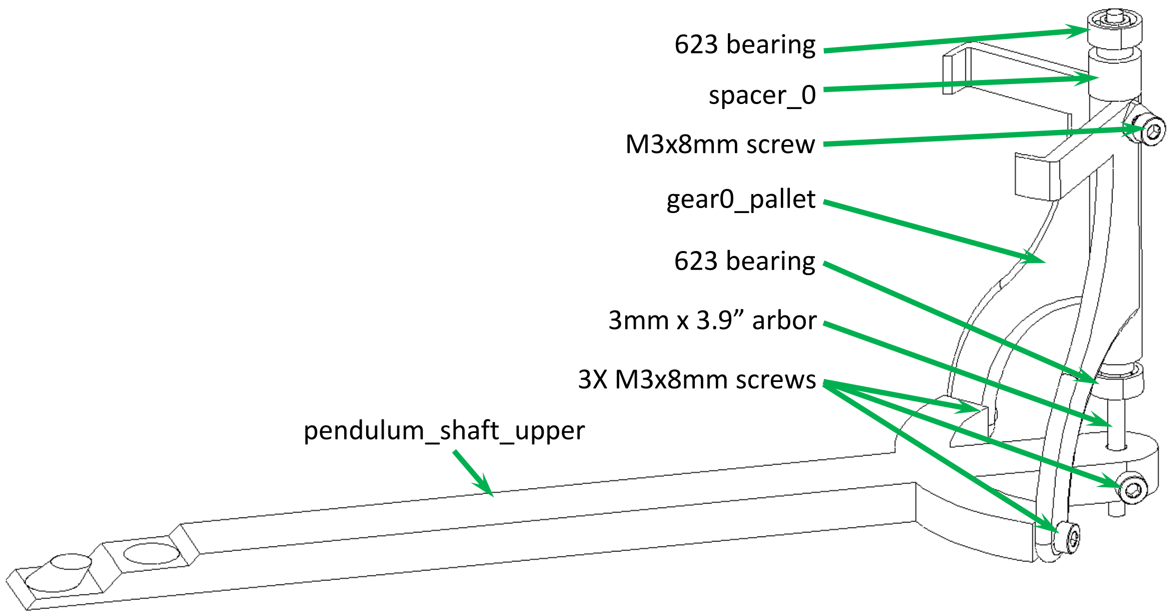

Figure 30: Another view of the pallet

The previously assembled ratchet assembly is added to the lower right position.

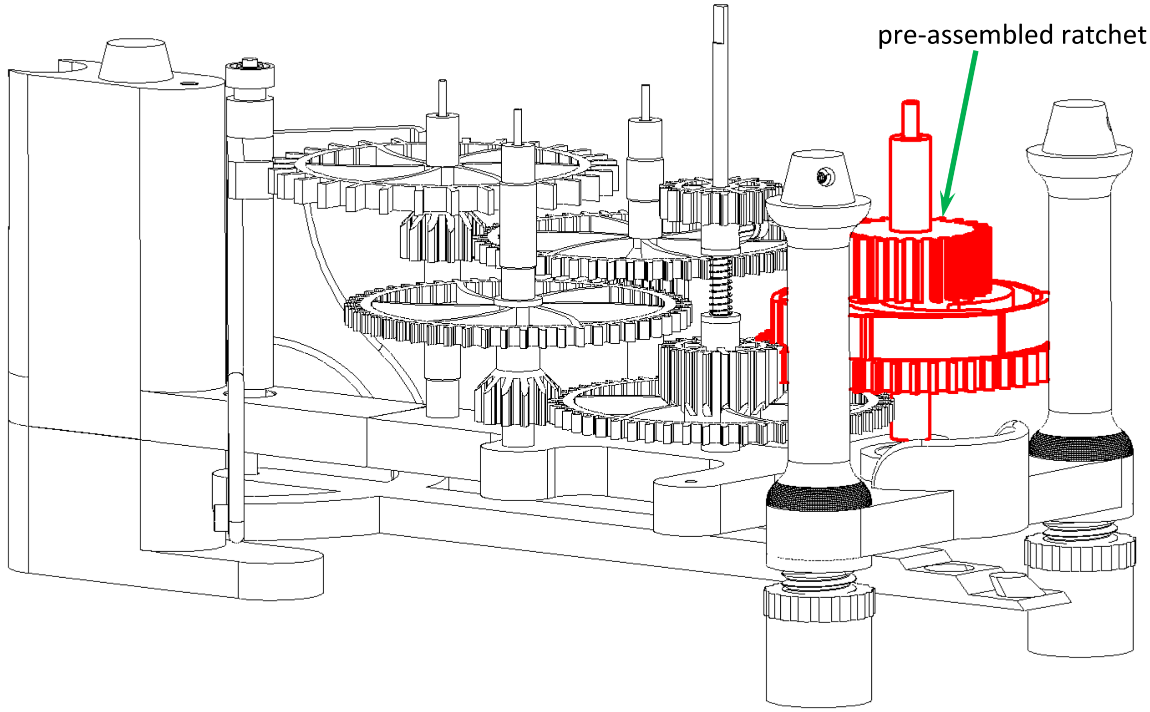

Figure 31: Add ratchet

Add a 608 skateboard bearing into the lower bearing pocket and insert the pre-assembled winding barrel into the bearing.

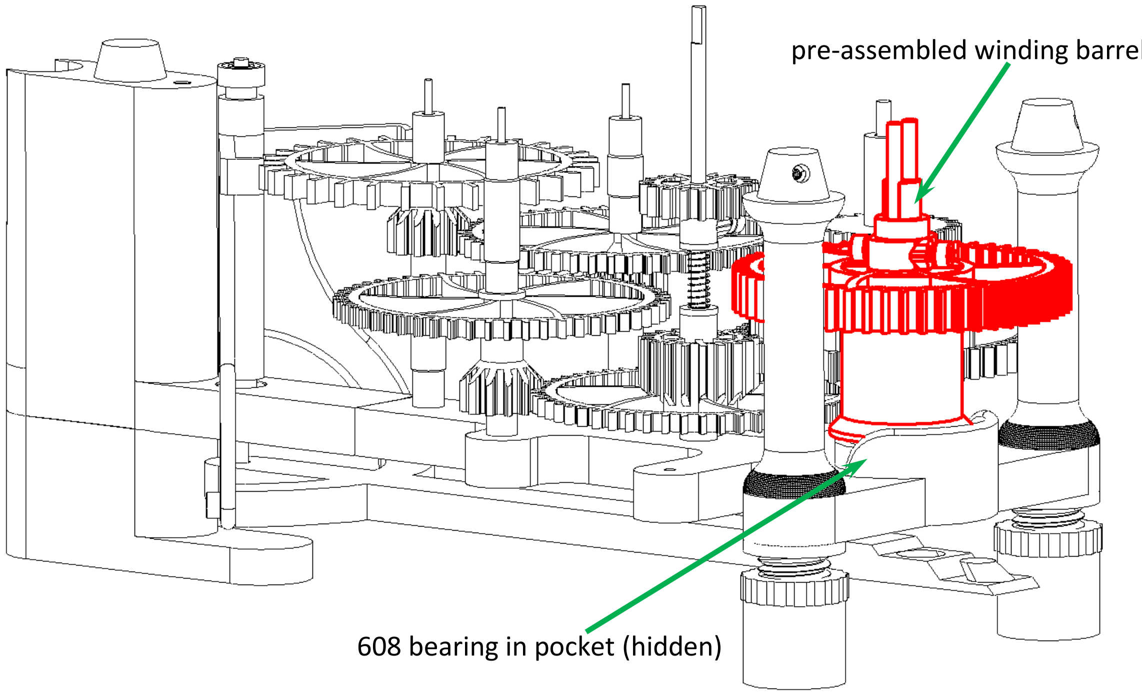

Figure 32: Add winding barrel

Add a 1.5mm x 3" arbor, spacer_5_ and gear5_48_18 into the lower left position.

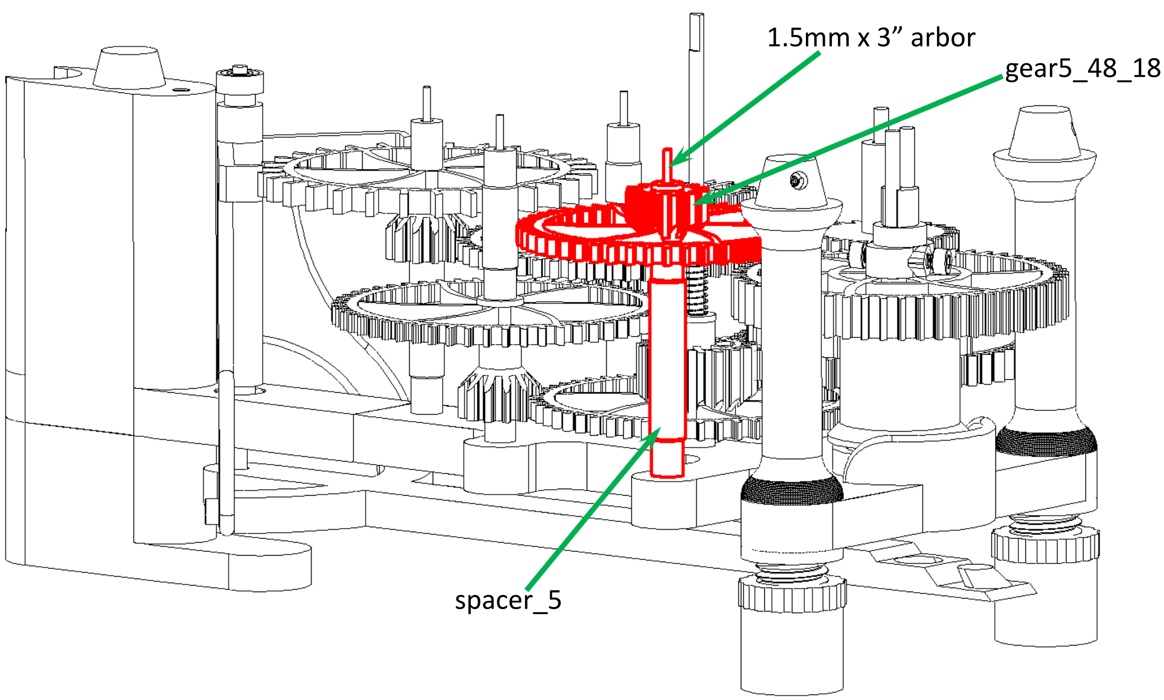

Figure 33: Add gear 5

The last gear to add is gear6_54 onto the central minute hand assembly. Make sure spacer_4d is positioned between gear4b_18 and gear6_54.

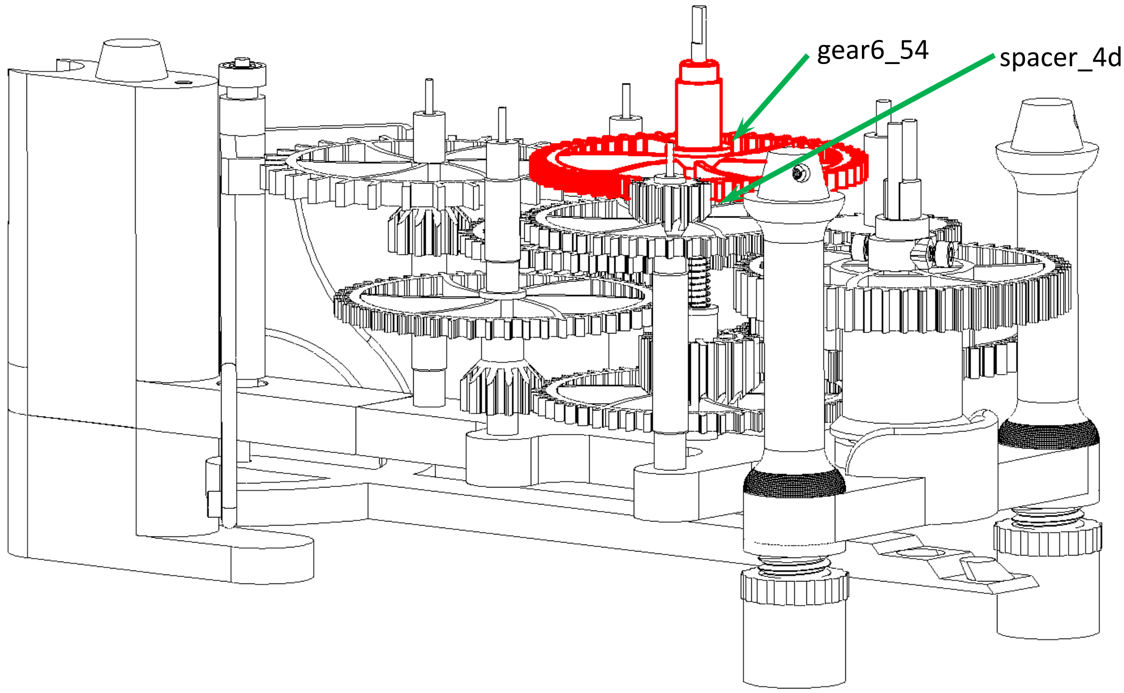

Figure 34: The final gear

The front frame can finally be added. Start by placing the dial over the minute hand arbor and wiggle each arbor into position one by one. Eventually, the frame should drop into position when all the arbors are lined up. Secure the frame using three #6x3/4" wood screws.

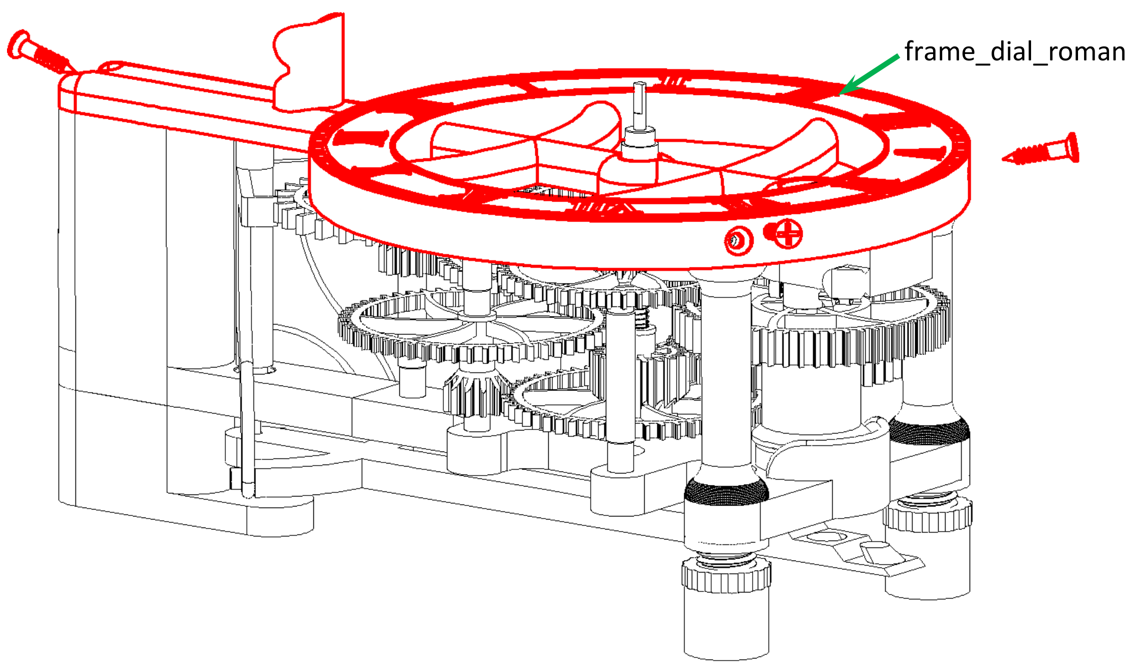

Figure 35: Add front frame

Everything is starting to look like a clock now. Add the hands and test the friction clutch to ensure the time can be changed by rotating the minute hand. There are options for the hands with different amounts of grip on the clock if needed. The hour hand can be placed in any orientation and can be rotated to match the minute hand position.

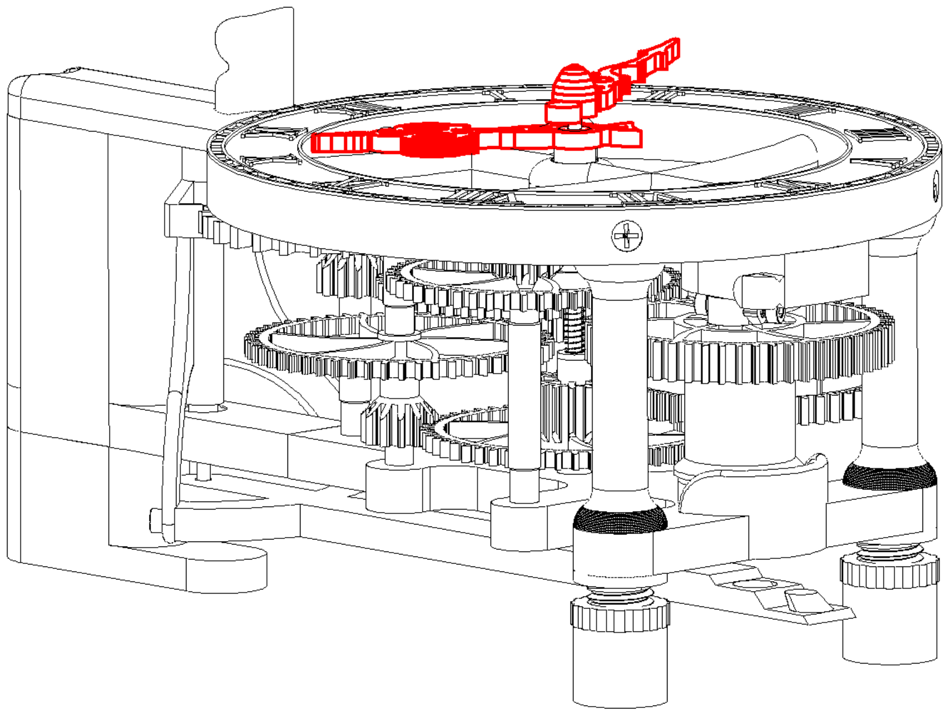

Figure 36: Add hands and test friction clutch

Testing the Clock

The clock mounts on the wall using a single screw driven into a wall stud. I use an 8x1-1/4" pan head wood screw, but anything that fits securely in the keyhole hanger should work. Placing the screw 69" (1.75m) from the floor will give around 52" (1.32m) of drop for the weights to fall during 8 days of run time. Leave the screw sticking out from the wall just enough for the clock to be snug. Adjust the lower standoffs so the clock sits flush against the wall.

The pendulum on this clock uses simple drop-in components. Add two pendulum_nuts near the center of the threaded portion of pendulum_shaft_lower. Place the completed pendulum bob onto the shaft and hang everything from pendulum_shaft_upper which should already be on the back of the clock.

It might be a good idea to test the pendulum free-swing time to make sure the pendulum support bearings have low friction. You may need to remove the escapement so it doesn't interfere. Hang the clock on the wall and add the pendulum including the bob. Move the pendulum all the way to one side and release it. Measure the amount of time that it takes for the pendulum to stop swinging. It should be at least 5 minutes, and possibly as long as 10 or 20 minutes of free swing time. Anything less than 5 minutes indicates too much bearing friction. Clean out the factory grease or try different bearings.

Hanging the Weight

Tie a loop at the end of the line on the winding drum. The loop should be a few inches long. It needs to be able to slip over the small hook on the side of the bearing holder. The hook is hidden behind the dial on this clock.

Insert the end of the line through the weight shell pulley. Make sure that the line stays in the pulley groove and not along the side of the pulley. Hold the pulley in your right hand and loop the end of the line over the hook on the bearing holder. The hook is hidden so you may have to feel where to hook the line. I usually stick my left index finger into the loop, place my finger onto the hook, and slide the loop over the hook.

You can lower the weight shell when the line is attached properly. The line should still be running down the center of the pulley. The clock should start ticking when you push the pendulum to one side.

Setting the Beat

Move the pendulum slowly to the left and right until it ticks. The clock needs to be adjusted until the left and right sides are balanced. This is called setting the beat. You want the clock to make the sound of "tick…..tock…..tick…..tock….." instead of "tick.tock………tick.tock………". Tilt the frame to either side to set the beat.

The clock should tick with a minimum pendulum amplitude of about 1 degrees to either side, however it will be much more reliable with larger amplitudes. The deadbeat escapement allows the pendulum to swing several degrees above the required minimum.

Push the pendulum all the way to one side and release. The clock should continue ticking and the amplitude will reduce to its natural state depending on the drive weight. Additional weight would increase the swing and the clock would be more reliable, although it does get louder.

Set the time by rotating the minute hand.

Congratulations, you have completed your clock!!!

Adjusting the Rate

The clock should be reasonably accurate with the pendulum nuts near the middle of the adjustment range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. Every 0.025" in change in pendulum length should change the rate of the clock by about a minute per day.

The threads below the bob have around 12.3 threads per inch. One full rotation changes the length by 0.081". This would change the time by about 3.25 minutes per day. It is relatively easy to make small adjustments to get the time accurate to about a minute or two per week.

The clock may change its rate during the first week or two as the components settle in to position and everything stabilizes to a consistent rate. Get past this break-in period before attempting the final timing adjustment. My clock is accurate to about a minute per week. I consider this to be pretty amazing.

Winding

Wind the clock by placing the key in the winding hole and rotate counter-clockwise. The ratchet should click as the cord is wound. Watch the cord to keep it spread across the winding drum instead of piling up in one spot. Sometimes, I push the line to one side while winding to help distribute the cord evenly.

The clock mounts to the wall on a single screw, so the clock may shift when winding and change the beat. I usually hold the frame steady with one hand while winding to keep it from moving. You may need to reset the beat after winding if the position shifted.

Debugging

Once the clock is working properly, it should continue to work for a long time. I have tested mine for a few months so far and expect it to last for many years. This clock has many features that make it easy to print so your clock should easily be as reliable as mine.

If the clock has less than 2 degrees of swing, then there is probably friction or binding somewhere. You could take out all the gears and put back two at a time to see that they mesh properly. Test each pair of gears individually to see that they move smoothly with no noticeable friction. Then put in all of the gears and leave out the pallet. You should be able to apply pressure to the winding drum and have the entire gear train rotating.

If my clock does stop, it is usually only from disturbing the beat while winding. Observe the beat after winding and adjust the frame position if the beat has changed.

It is acceptable to use lithium grease to help reduce friction. Only a tiny amount needs to be added to the pinion teeth. Wipe most of it off and it will work its way onto the larger gears. The pallet arms can also be greased.

I have a forum on my web site at https://www.stevesclocks.com/forum if you have questions during your build. Feel free to post pictures. Anything clock related is welcome, even clock designs from other designers.

Final Comments

Designing this clock has been a lot of fun. This design is a huge improvement over my first clock released on Thingiverse. I originally attempted to make wooden gear clocks, but never had a really functional clock until I started optimizing them for the 3D printer. This design is the result of nearly five years of development and appears to be my most reliable weight driven clock. Once it starts working, it should continue running for many years. I have a few more printed designs in progress, but I hope to get back into the workshop to start making a wooden gear clock soon. Stay tuned for more information.

Good luck with your clock build.

Check out my other 3D printed clock designs at https://www.myminifactory.com/users/StevePeterson

Steve

Here are a few of the other clocks I have built. Some may eventually be released for others to build. The first is a grasshopper escapement to replace the deadbeat escapement in my largest clock. It needs a bit of fine tuning before it can be released. The deadbeat escapement version of this clock has already been released. The second image is a rendering of the clock as it may look after porting to use wooden gears.

Figure 37: Grasshopper clock modification and a wood clock rendering

These are some sample wooden gears cut from solid wood using my own method to prevent expansion from humidity changes. They will eventually be used to create the rendered clock on the previous page.

Figure 38: Wooden gear experiments

These are my “crazy gear” desk clocks with lots of additional dynamic motion. A stepper motor with an Arduino Nano and a few other components keep them accurate to about a minute per year. The filament is dual color Quantum PLA from MatterHackers.

Figure 39: Crazy gear desk clocks