3D PRINTED SKELETON CLOCK

SP3 Assembly Notes

Instructions for building a medium sized 3D printed pendulum clock with large exposed gears

Steve Peterson
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18-Nov-20 Original version

Description

This document describes the assembly of a medium sized 3D printed pendulum wall clock with large exposed gears. It is a slightly smaller version of my largest clock posted to MyMiniFactory at https://www.myminifactory.com/object/3d-print-137009

The primary purpose of a clock is to tell the time. It needs to be accurate and it needs to be reliable. This clock is accurate to within a minute or two per week and should run for many years. My oldest printed clock has been running continuously for nearly two years with no signs of wear. The runtime must also be long enough that winding will not be a burden. This clock runs for nearly 5 days of runtime using 3kg of weight. I know that I can go away for a weekend and the clock will still be accurately keeping time when I return.

Another design goal for my clocks is that they must look good. I like the symmetry of this design and the visibility of the gears, especially the large escapement near the front. The complete clock is around 165mm wide by 420mm tall not including the pendulum and drive weight. The large components are split into segments that can be printed on a Prusa Mini or any FDM printer with a 175x175x100m print volume.

Details

A pendulum clock is conceptually very simple. A spring or falling weight provides energy to the pendulum and gears convert the periodic motion to a display of time. An escapement provides a periodic release of energy to the pendulum. The challenge is to make everything work elegantly and accurately.

I use a Prusa MK3S to develop my 3D printed clocks, but this design is scaled to easily fit the print volume of a Prusa Mini or similarly sized machine. A few non-printed components are used to reduce friction so the clock can have a long run time. This design uses metric sized components that should be available anywhere in the world. I am in the US and have no trouble finding the metric sized parts.

Optimizations for 3D printing

This design has been the most reliable of my three pendulum wall clock designs. I attribute this to the optimizations that were made specifically for 3D printing. Porting a traditional clock design to a 3D printer might result in a working clock, but it may be far from optimal. A much better design is possible by taking advantage of the specific characteristics of a 3D printer.

The biggest optimization in this clock is the gear tooth profile. Clock gears have a unique characteristic that they only run in one direction, so only one surface of each gear tooth is engaged at a given time. The opposite surface is unused and can be any shape as long as it doesn't interfere with the other teeth. This "fancy gear" concept was originally seen at a website designed for wooden gear clocks at http://garysclocks.sawdustcorner.com/fancy-gears.html and expanded further for 3D printing. The gear profiles used in this clock are the result of many iterations between CAD and the slicer to print as smoothly as possible.

Below is the slicer output after optimization for fancy gears. Notice how each gear tooth gets created using continuous filament lines. There are no unnecessary retractions. These gears are designed so that the teeth, rim, and spokes are solid when printed using 3 perimeters. Eliminating retractions gets rid of stringing and other surface irregularities. The resulting teeth are very smooth and strong.

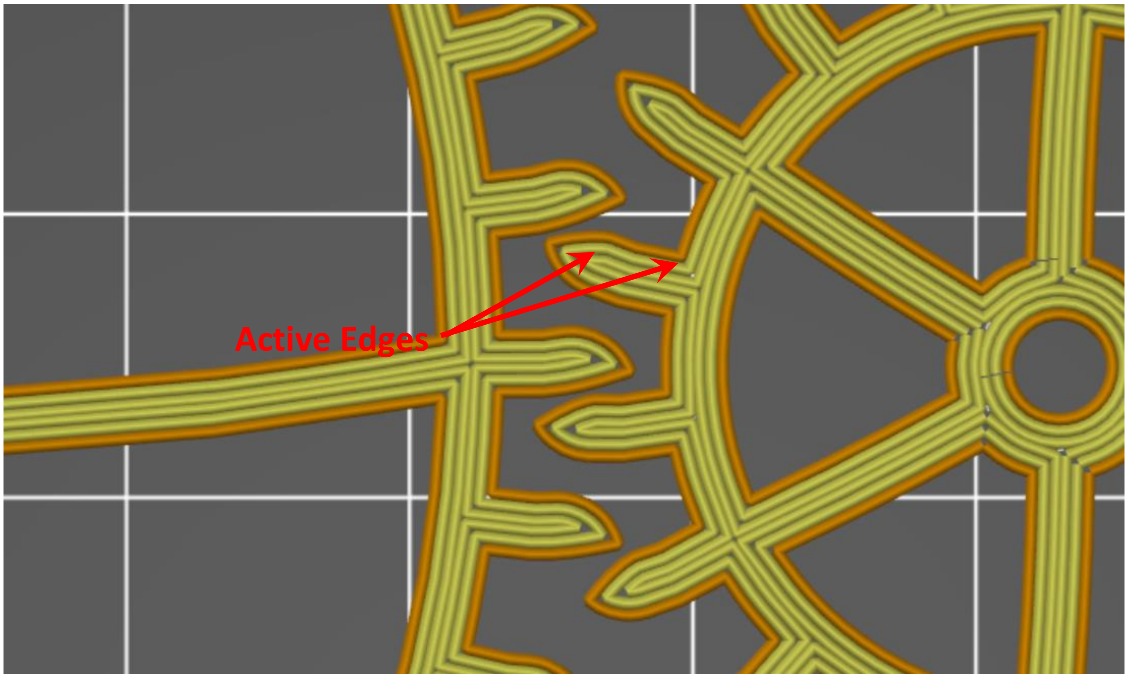

Figure 1 Sliced gears after optimization

Similar optimizations were made to the escapement and pallet, which are among the most important components in a clock. A traditional design has sharp escapement teeth that become rounded off when 3D printed, resulting in the escapement releasing way too early.

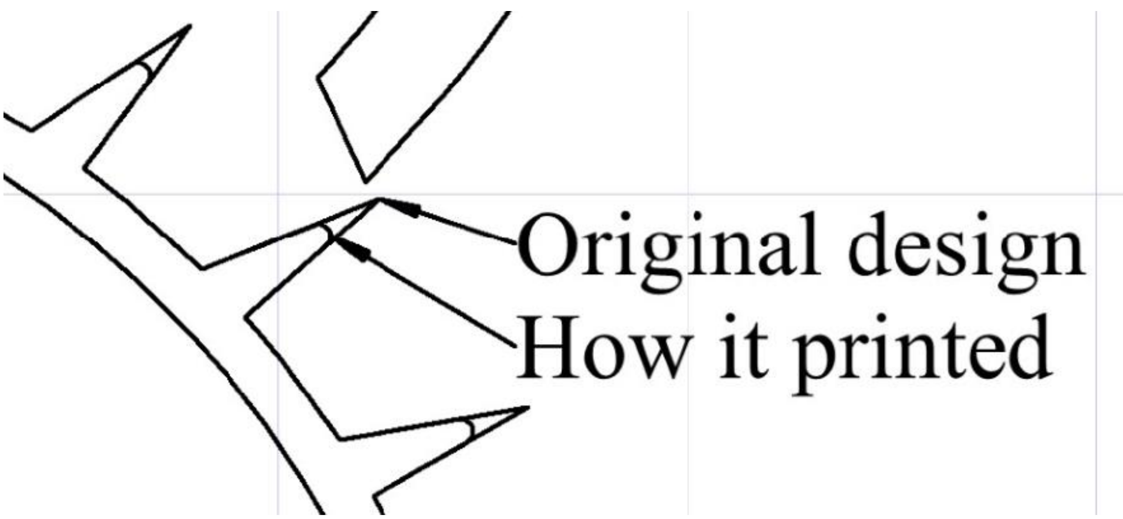

Figure 2 Traditional Deadbeat Escapement

The teeth can be lengthened to compensate, but different printers might need different compensation. The solution used in this clock is to widen the tips of the escapement teeth to provide a very predictable active edge. The pallet width was reduced to provide the proper clearance. It looks different than other designs, but the operation is similar and the combined width of the pallet plus escapement are the same as the original design. The predictable length of the escapement teeth makes it very reliable in a 3D printed design.

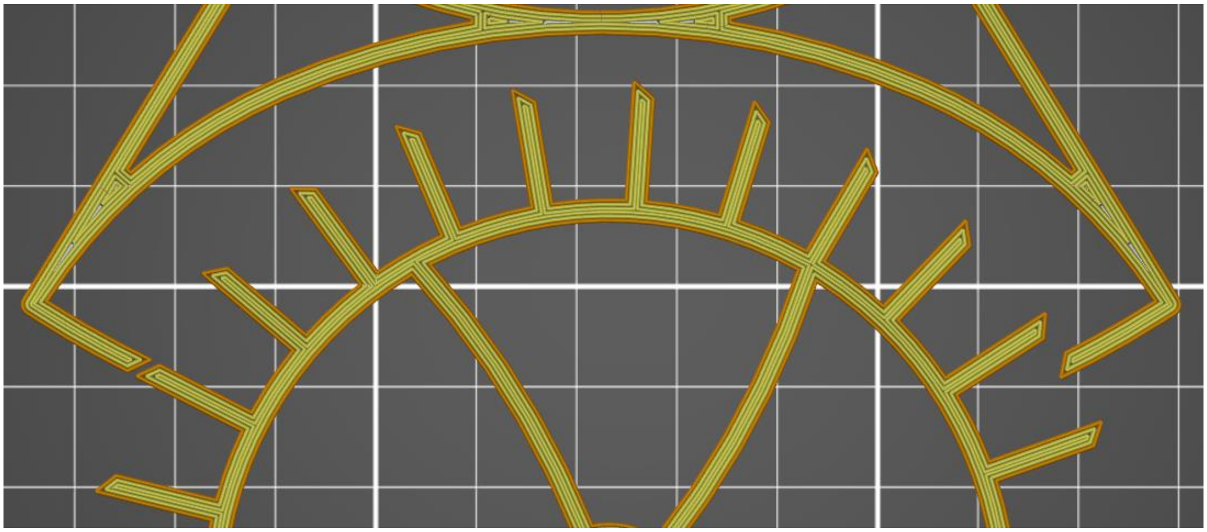

Figure 3 Escapement and pallet slicer output

Another optimization in this clock takes advantage of the printer's ability to create complex shapes as a single component. Pinions are positioned along the shaft and printed together with the larger gears. Angled surfaces are used so the pinion is formed without needing supports. The large body of the main gear has enough surface area to provide great adhesion.

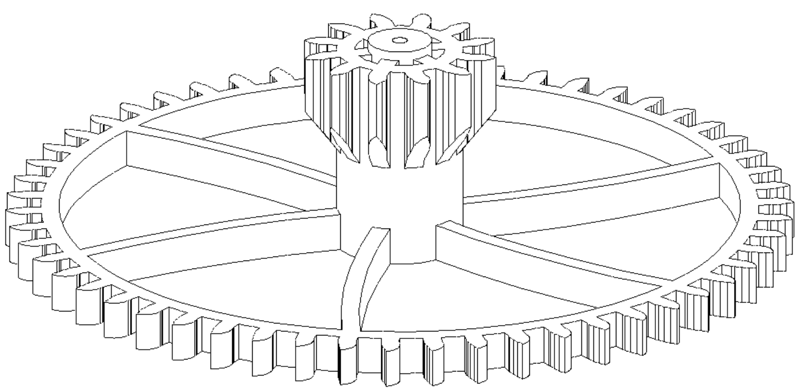

Figure 4 Gear profile example

The frame is a single integrated component that holds the clock together. I deviate from the mindset that a 3D printed clock needs to be 100% printed and use metal components where they provide a benefit. Metal screws and shafts are used in a few key locations. Ball bearings are used to support the weight shell and pendulum. These minor metal components are mostly hidden so the clock appears to be completely 3D printed, but performs like a traditional brass clock. They are used to create a clock with a five day runtime, so the tradeoff is worth it.

The dial is optimized to use layer based color changes to create a highly visible clock face. The dial is raised above the frame using a white color change. Another color swap is added for the jet black numbers. I like the look of a traditional clock, so the dial incorporates roman numerals. The widths of the dial features were optimized to print cleanly using 2 or 4 passes of a standard 0.4mm nozzle.

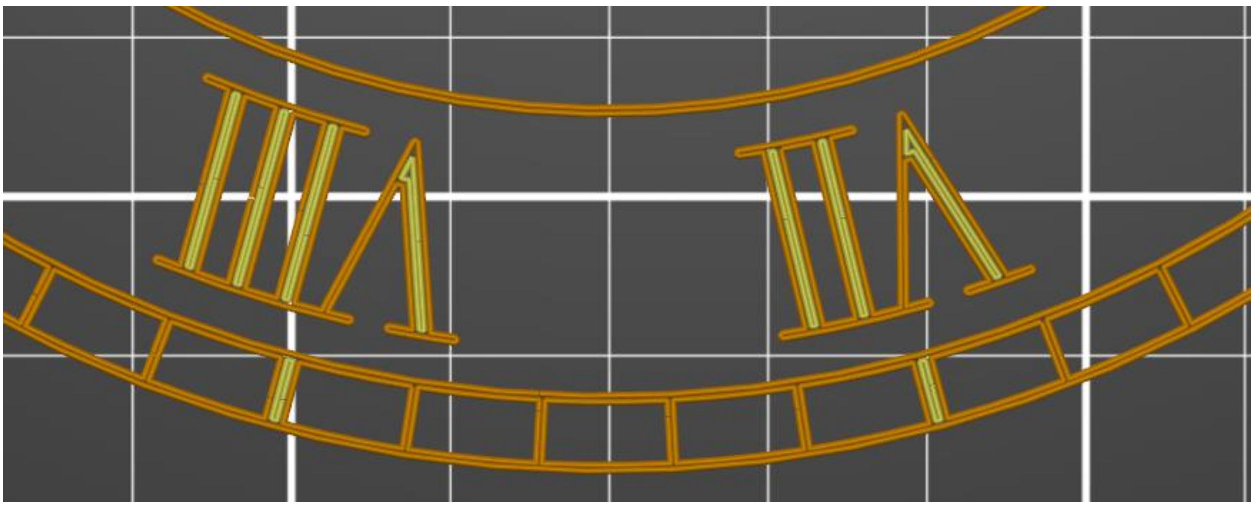

Figure 5 Dial lettering optimizations

Gear Ratios

Many traditional clock designs use small pinions with 6 or 8 teeth, but involute gears have less friction with 12 tooth pinions. The larger pinions can be accommodated by adding one additional arbor between the minute hand and the escapement.

The extra gear set allows flexibility with the escapement size and pendulum length. I am not a fan of 39" long pendulums in anything smaller than a grandfather clock. The gear train in this clock was designed to support a 20.98" long pendulum with a 27 tooth escapement. The rest of the gear train was adjusted for the clock to keep perfect time with beats 4920.75 beats per hour. This keeps the pendulum length proportional to the rest of the clock.

Here are the gear ratios used in this clock and the gear names used in the assembly documentation. For example, gear 4 is a multi-gear assembly that drives the minute hand. Gear4_54_18.stl is a 54 tooth gear and an 18 tooth pinion sitting in position number 4. Gear4_18.stl is a smaller component at position 4 with an 18 tooth pinion.

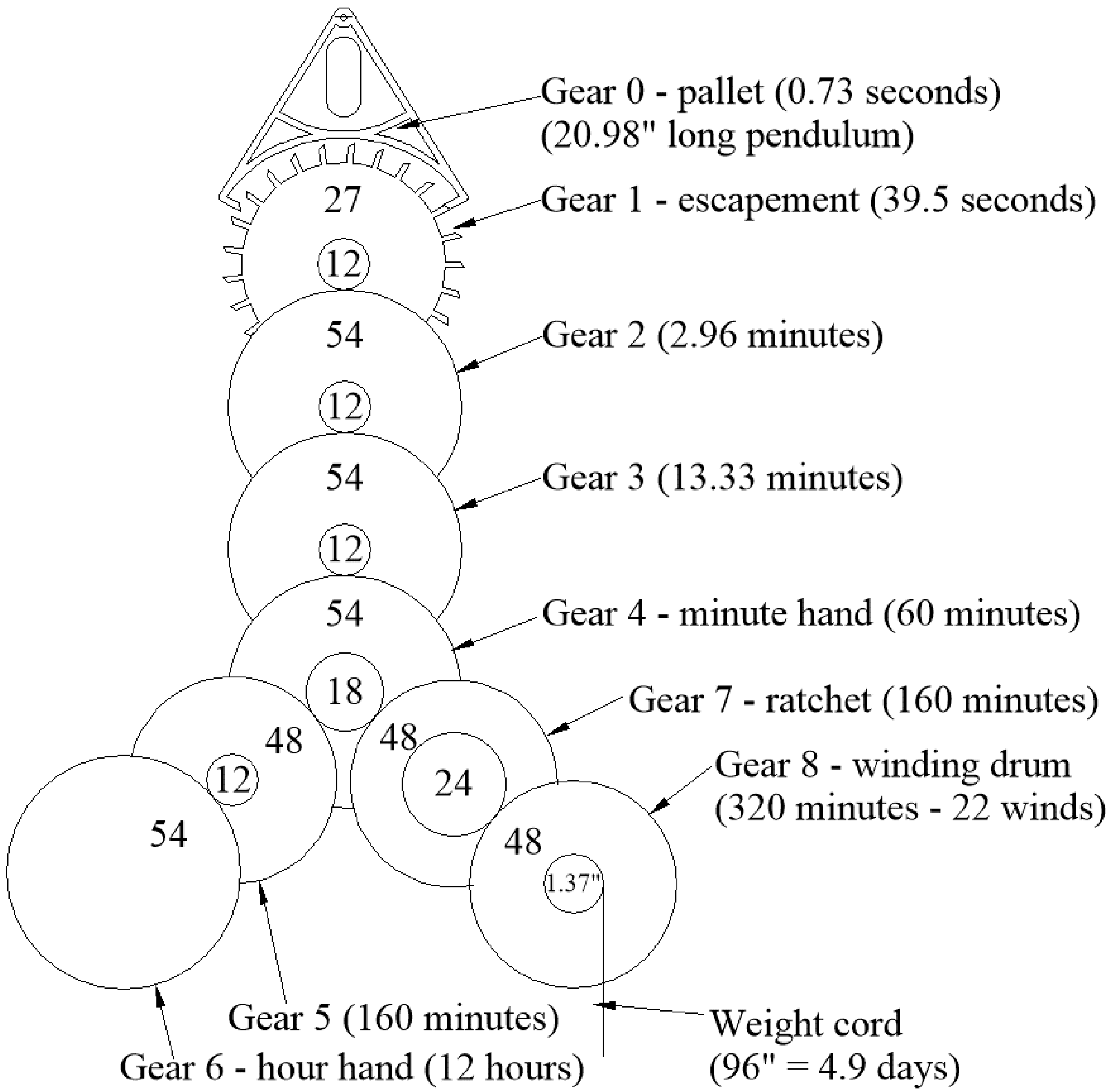

Figure 6 Clock gear ratios

The clock has been designed to support nearly five days of runtime between winds with a reasonable sized drive weight. A clock with smaller gears could be designed with a longer runtime. In fact, my first 3D printed clock has an 8 day runtime. It had a more complex assembly process involving stainless steel bushings at every pivot point to reduce friction. This clock is significantly easier to build, but the heavier gears and slightly increased pivot friction lowers the runtime slightly. I think the tradeoff is worth it to have a more impressive looking clock. Five days is still a very respectable runtime.

Printing the Parts

The total print time for all of the components is almost 120 hours. This may seem like a lot of time, but you will be creating a piece of art that will last for many years. All parts are oriented to print flat on the build plate with the preferred surface at the bottom. Supports are not needed for any components.

The front frame integrates the dial and numbers into a single print using contrasting colors for visibility. This component cannot be split easily split, so it sets the minimum printer size requirement of around 175x175mm.

I print most parts with 0.15mm layers, 4 perimeters, 10 top layers, 8 bottom layers, and 30% cubic infill. This creates a frame that is strong enough to support the weight shell without sagging. A few parts look slightly better with additional perimeters. I use 0.15mm layer heights, although most parts can probably print just as well with 0.20mm layers. Random seam positions are good.

The gears look best using a bold color to make them stand out. Gold or bronze are good for making gears that look like brass. Silk PLA in almost any color has a good look. The clock on the cover picture was printed using silk gold PLA. The frame should be printed using a neutral color with a light colored dial and dark highlights for the numbers. The colors listed below are only suggestions. Feel free to substitute other colors as desired. I use PLA exclusively, although it may be possible to use different materials.

The print times were reported in PrusaSlicer 2.2.0 in normal mode with 0.15mm layer heights. It is OK to combine multiple parts into one long print job, although some parts are so large that it is difficult to fit more than one on the build plate at a time.

The following diagrams will be useful for identifying names and shapes of gears and other objects.

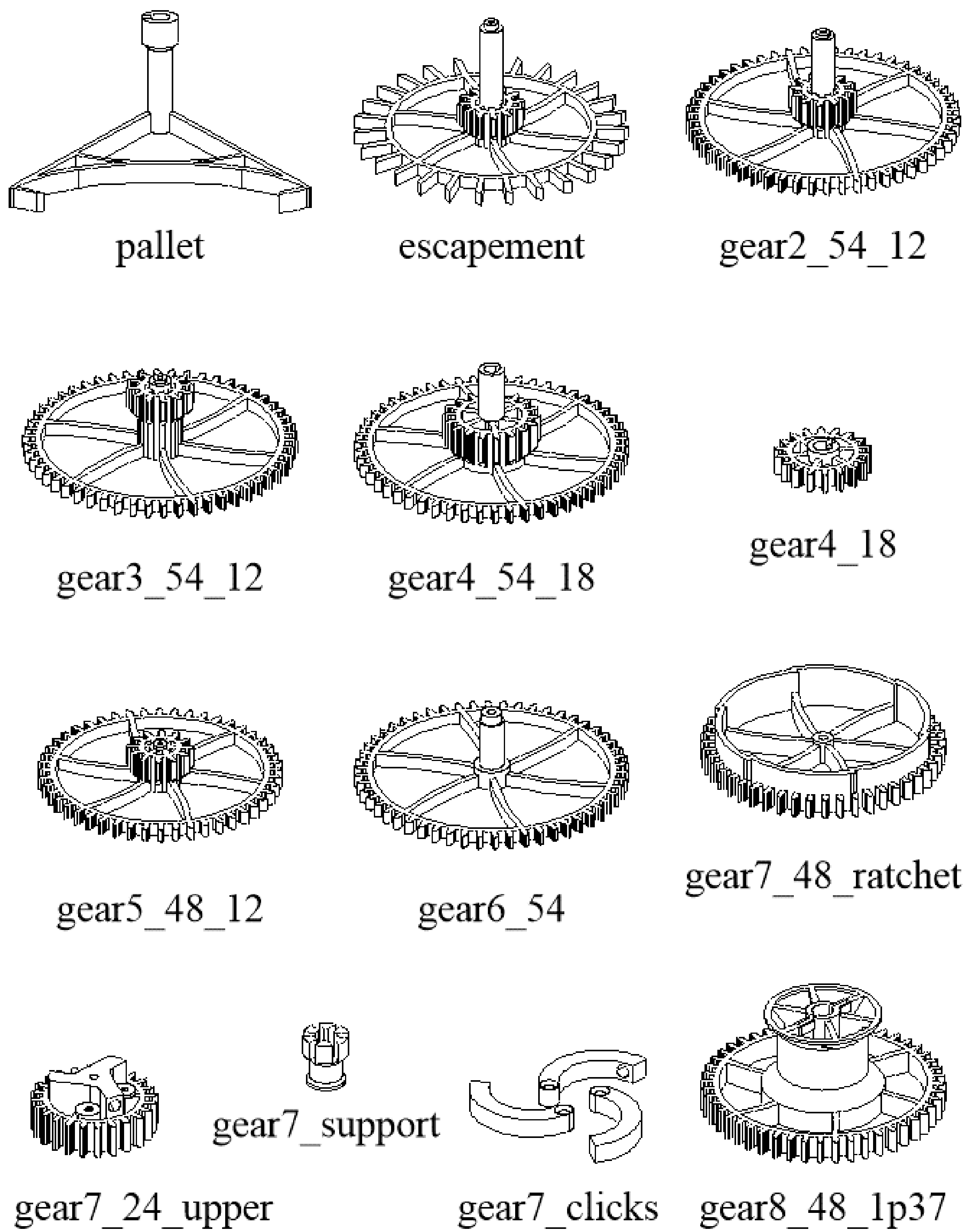

Figure 7 Gear reference chart

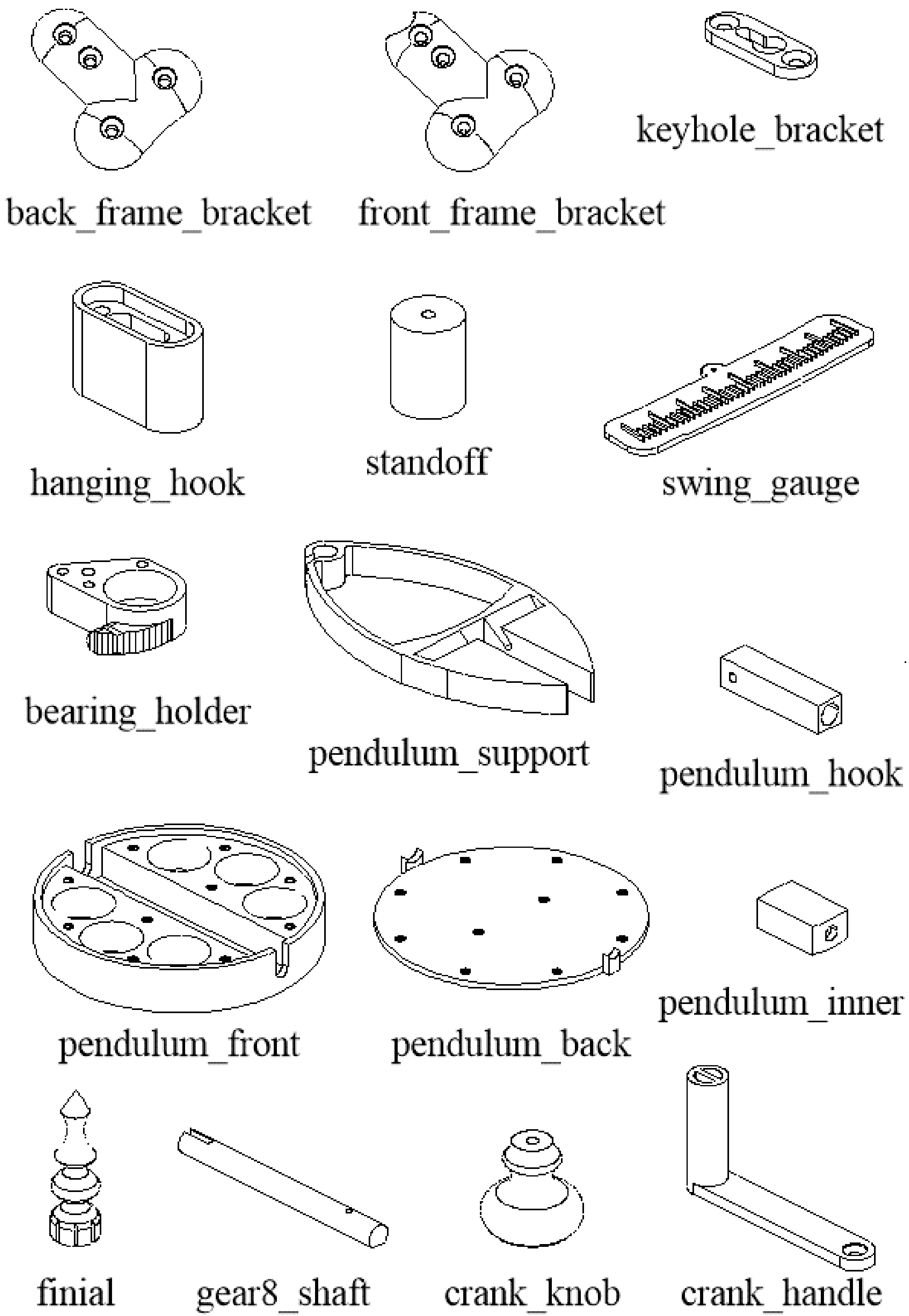

Figure 8 Additional parts reference

File Name	Color	Print	Time	Filament	Notes
back_frame_upper	Tan	1	8h 18m	25.04	
back_frame_lower	Tan	1	13h 53m	47.21	
back_frame_bracket	Tan	1	0h 57m	2.46	
hanging_hook	Tan	1	2h 52m	6.81	
back_frame_standoff	Tan	2	1h 25m	3.29	
keyhole_hanger	Tan	0	0h 18m	0.64	Optional (see note 1)
front_frame_upper	Tan	1	3h 51m	10.91	
front_frame_lower	Tan, Ivory, Black	1	11h 58m	43.99	
front_frame_bracket	Tan	1	1h 23m	3.46	
bearing_holder	Tan	1	1h 13m	3.05	
pallet	Gold	1	2h 11m	4.47	
escapement	Gold	1	2h 49m	6.35	
gear2_54_12	Gold	1	2h 49m	6.37	
gear3_54_12	Gold	1	2h 59m	6.78	
gear4_54_18	Gold	1	3h 23m	7.81	
gear4_18	Gold	1	0h 50m	1.80	
gear5_48_12	Gold	1	2h 10m	5.20	
gear6_54	Gold	1	2h 5m	4.99	
gear7_48_ratchet	Gold	1	2h 48m	8.06	
gear7_24_upper	Gold	1	2h 50m	6.79	
gear7_click	Gold	3	0h 24m	1.04	
gear7_support	Gold	1	0h 50m	1.03	
gear8_48_1p37	Gold	1	5h 13m	13.95	
gear8_shaft	Tan	0	0h 34m	1.35	Optional (see note 2)
hands	Black	1	0h 57m	1.44	8 perimeters
pendulum_support	Black	1	2h 6m	6.38	
pendulum_hook	Black	1	0h 28m	1.26	
pendulum_front	Gold	1	5h 52m	17.77	
pendulum_back	Gold	1	1h 7m	4.56	
pendulum_inner	Gold	1	0h 31m	1.19	
finial	Black	1	1h 6m	1.36	See note 3
weight_shell_2p6	Gold	1	16h 15m	42.02	See note 4
weight_bottom_2p6	Gold	1	1h 15m	4.92	
weight_pulley	Gold	1	0h 49m	2.88	
weight_pin	Gold	1	0h 19m	0.38	
crank_handle	Gold	1	1h 26m	2.57	
crank_knob	Gold	1	1h 26m	3.14	
swing_gauge	Ivory, Black	1	0h 31m	1.86	
spacers	Gold	1	2h 41m	4.75	
Total		**40**	**116h 13m**	**323.92**	

Table 1 Printed Components

Note 1: The keyhole hanger is a metal part available at my local hardware store. A printed equivalent is provided, although the metal version is preferable since the entire clock hangs on this component. Make it as strong as possible if you use the printed version. Use 100% infill or increase the number of top/bottom layers so it prints completely solid.

Note 2: The 8mm (5/16”) brass rod holding the winding drum may be difficult to fabricate. A printed version is provided, although the metal version is preferred. Tests show the printed version to be strong enough to support the weight shell and allow winding the clock. Print using 10 perimeters so it is completely solid using long straight filament flows.

Note 3: The finial is provided with both metric (finial.stl) and imperial (finial_imp.stl) sized components. Either one is acceptable, depending on the availability of metal hardware. The metric version uses a 4x0.7mm threaded rod and nylon insert locknut. The imperial version uses a 6-32 threaded rod and nylon insert locknut. Alternatively, you could skip the nylon insert locknut and scale the finial to thread directly onto the threaded rod.

Note 4: The filled weight shell should weigh around 6.5 pounds or 3.0 kg. There are several options to achieve the desired weight. The default is to use the 2.6” diameter shell filled with lead shot. A larger 3.0” diameter weight shell is included that could reach the target weight using less dense material such as BBs. The weight shell body is provided in a split format to print in two pieces if your printer is not tall enough, although the normal version will be slightly heavier. There is also a quarter height bottom portion that can be stacked to increase the weight slightly. The file names should make sense. For example, weight_shell_2p6 is the 2.6” full height weight shell, weight_shell_top_half_2p6 is the 2.6” diameter top half and weight_shell_bottom_quarter_3p0 is the 3.0” diameter quarter height bottom portion, etc. There is a bit of margin in the drive weight. My clock runs on 5.0 pounds, is reliable using 6.5 pounds.

Print File Options

Several printed parts have multiple file options. The intent is to provide different options for makers with different printers or access to different non-printed components. Here is a description.

Component	Option	File Name	Description
Weight Shell	2.6" diameter	weight_*_2p6	Small diameter weight shell to be filled with lead shot
	3.0" diameter	weight_*_3p0	Large diameter weight shell for use when filled with lower density material such as BBs (or sand?)
Weight Shell	full height	weight_shell_2p6 (or _3p0)	Full height weight shell in one piece
	half height	weight_shell_top_half_* weight_shell_bottom_half_*	Weight shell split into two pieces The bottom half can be used as a large extension to add extra weight
	quarter height	weight_shell_bottom_quarter_*	Quarter height weight shell used as an extension to add a small amount of additional weight
Misc Spacers	one file	spacers	All the spacers in one file
	individual files	spacer_0a (or _0b, _1, etc.)	Individual spacers

Finial	metric	finial	Default option using a 4x0.7mm threaded rod and nylon insert locknut
	imperial	finial_imp	Optional finial support using a 6-32 threaded rod and nylon insert locknut
Winding Key Shaft	metal	NA	Winding key shaft using brass rod This option will be the strongest
	printed	gear8_shaft	Printed winding key shaft
Hanging Hook	metal	NA	Metal hanging hook - this option is the strongest
	printed	hanging_hook	Printed hanging hook if you can't find the metal version

Table 2 Print Options

The weight shell has many options depending on your printer size and material used to fill the shell. My clock runs easily with 5.0 pounds, but the pendulum swing is improved with additional drive weight. The minimum recommended weight is 6.0 pounds (2.7kg) with a target of at least 6.5 pounds (3.0kg). Anything above 10 pounds (4.5kg) increases the risk of the frame sagging. You can use any combination of weight shell components to achieve the desired weight.

The spacers are all grouped into a single file for convenience. They can be printed as a group or individually.

Color Changes

The front frame has an integrated dial that needs a color change at 15.35mm to highlight the numbers. Another color change can be added at 12.80mm to add light color dial. My clock starts with a tan base layer, with a change to ivory at 12.80mm, and black at 15.35mm for the numbers. PrusaSlicer has a really easy method for adding layer changes.

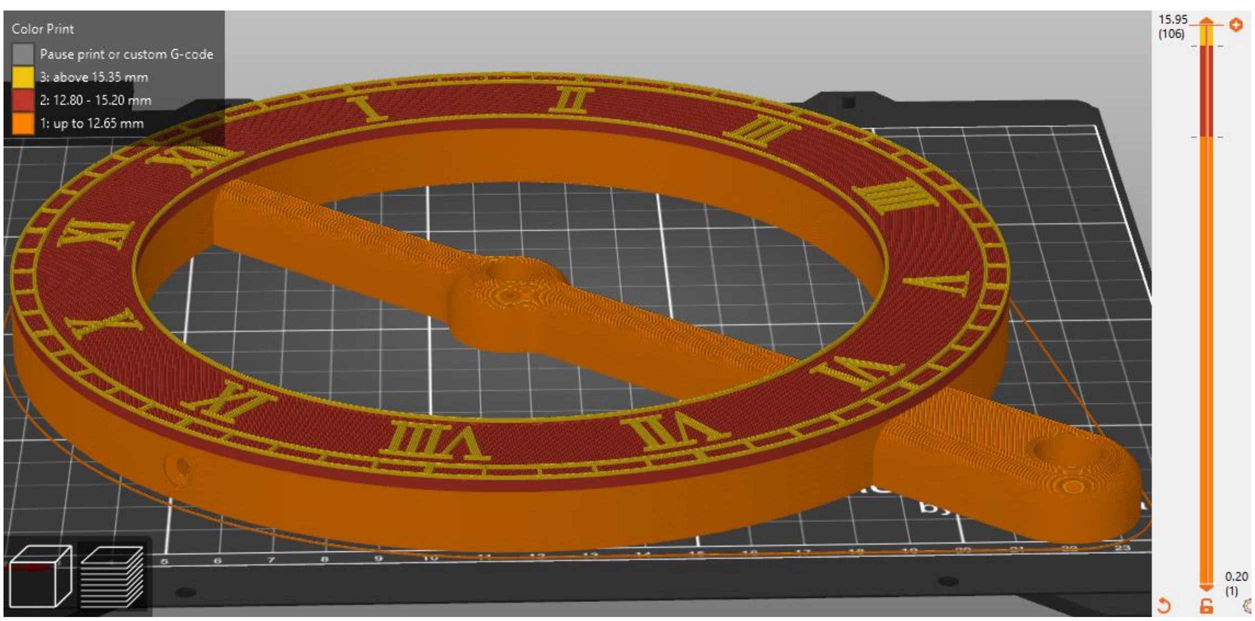

Figure 9 Layer changes for front frame

The swing gauge is useful for determining the swing amplitude and also for balancing the escapement trip positions. It needs a color change at 2.00mm.

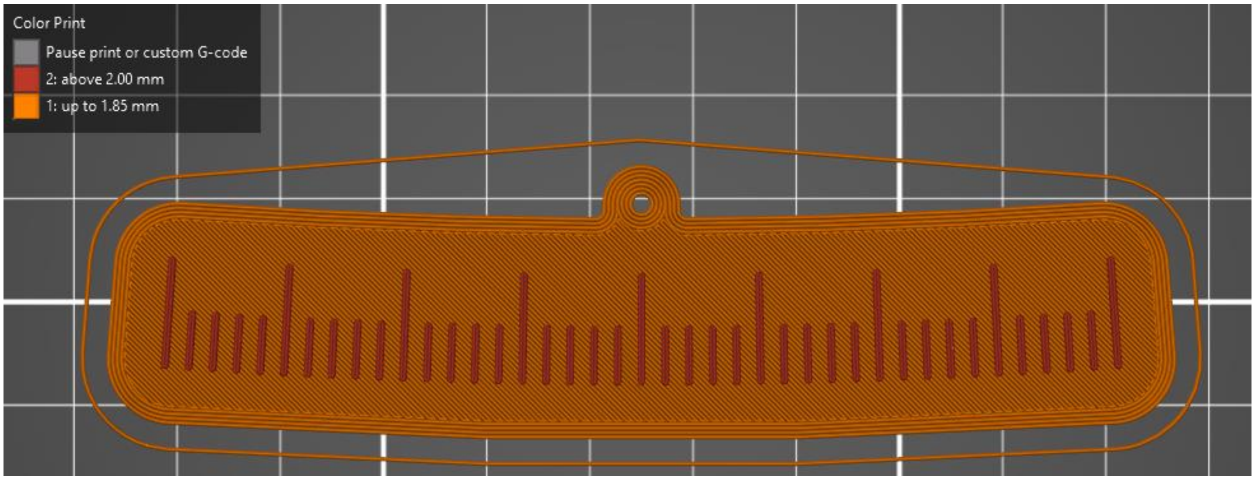

Figure 10 Swing gauge color highlights

The finial below the pendulum bob has a friction nut inserted to allow you to change the pendulum rate when needed and hold the position all other times. Note that you need to use the proper file depending on your nylon insert locknut. Finial.stl uses a 4x0.7mm nut and finial_imp.stl uses a 6-32 nut. The finial is a single color component with a pause at 7.25mm to drop in the 6-32 or 4x0.7mm nylon insert locknut and continue printing. Treat this as a color change even though the color stays the same. Remove the filament and re-insert the same color. The finial is tall enough to benefit from a brim if you have adhesion issues.

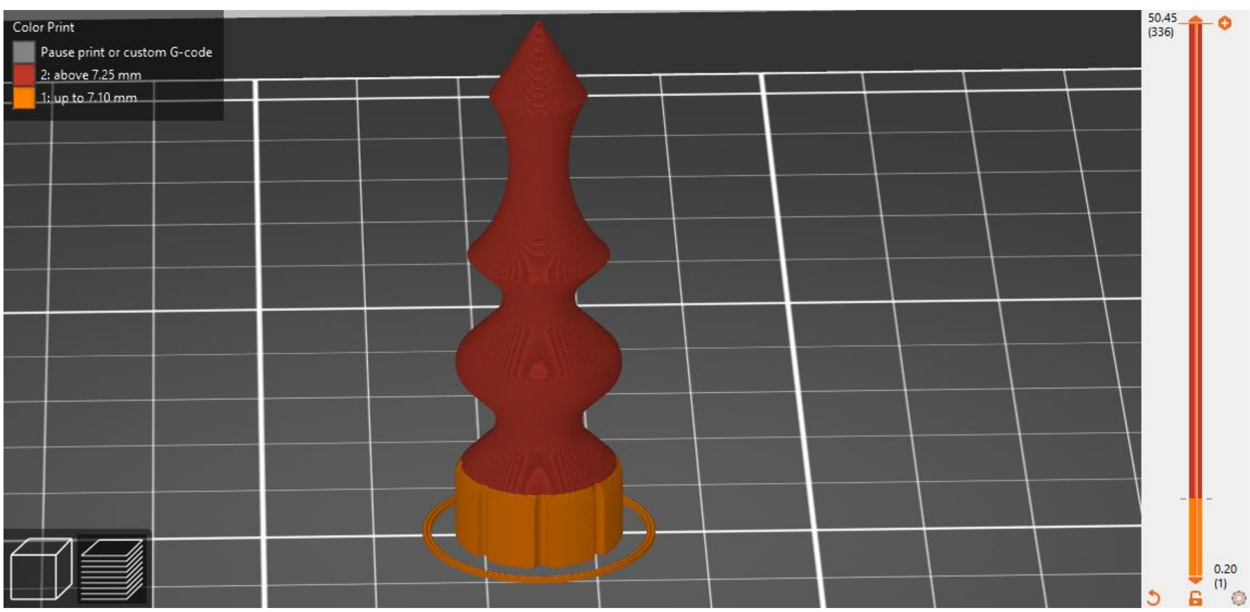

Figure 11 Pause finial at 6.95mm to insert nylon locknut

Some components are so small that they were grouped into a single file called spacers.stl. The following diagram shows what they look like along with the corresponding arbor number. Arbor 0 is the pallet and arbor 1 is the escapement. The numbers on the remaining spacers match the file names for the gears. The spacers also exist as separate files if you want to print them individually.

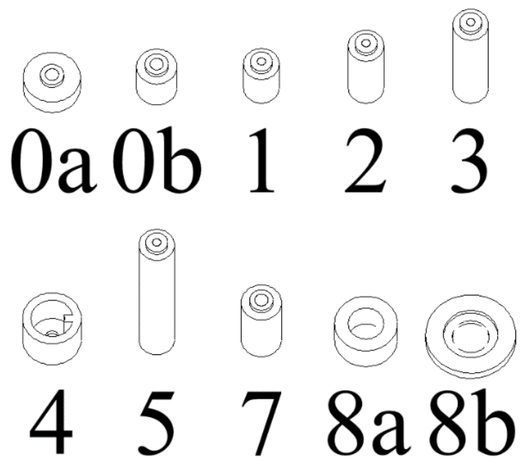

Figure 12 Spacers

Additional Components

This clock is mostly 3D printed with a few hidden metal components to reduce friction at critical locations. Many 100% printed clock designs on the internet have run times as low as a few hours or minutes. Using a few select metal components allows this clock to become a useful timepiece with a long runtime. The arbors use music wire or steel rods. Ball bearings are used anywhere there is weight being supported. The weight shell uses skateboard bearings and the pendulum uses small ball bearings. A few steel screws are also used, but they are hidden as much as possible.

The following non-3D printed components are required. Part numbers from McMasterCarr are provided for some parts although most can be found at your local hardware store. The clock was designed to primarily use metric components that should be easily available worldwide.

A few parts can use either imperial or metric sizes. For example, the design uses a 5/16" or 8mm brass rod to support the weight drum. 5/16" is 0.3125" and 8mm is 0.31496". Both will fit inside the 8mm hole of a 608 bearing, but the 5/16" rod is a tiny bit easier to assemble. Some 8mm brass rod needs to be sanded down to fit into the bearing. 5/16" brass rod nearly always fits.

The arbors are designed with enough tolerance to support 1.5mm, 1.6mm, or 1/16" diameter music wires. Any of the sizes should work.

The 3mm diameter stainless or brass rod is important to match printed component hole sizes. It might be possible to drill out the holes to use 1/8" rod if you use a minimum of 4 perimeters.

Lengths are usually given with both metric and imperial sizes.

Qty	Component sizes (alternate sizes in parenthesis)	McMC Part No.	Notes
18	6x3/4” flat head wood screw	90031A151	Metric equivalent is ~19mm long
10	4x1/2” flat head wood screw	90031A110	Metric equivalent is ~12mm long
9	6x1-5/8” drywall screw	99136A300	Metric equivalent is ~41mm long
3.25" (83mm)	5/16” (8mm) brass rod	8953K138	Mild steel or aluminum could be substituted (or use printed version)
36" (1m)	3mm stainless or brass rod	1274T42	See cut metal parts list
18" (0.5m)	1/16” (1.5mm) music wire	89085K85	See cut metal parts list
3" (75mm)	4x0.7mm (6-32) threaded rod	94595A216 (90034A049)	Can use a screw with the head cut off
1	4x0.7mm (6-32) nylon insert locknut	93625A150 (90631A007)	Use metric or imperial finial to match
19.0” (0.5m)	0.275” (7mm) carbon fiber tube		From an archery arrow, can use a wooden dowel as an alternative
6	1/8" (3mm) brass wheel collar		Great Planes GPMQ4305 or DuBro DUB139 (imperial and metric versions appear to be identical)
10' (3m)	microfilament fishing line		I use PowerPro Spectra Fiber braided fishing line 65 lb. test, Eq Dia 16
6.2 lb. (2.8kg)	lead shot	9030K22	Can use ~9000 BBs with larger diameter weight shell
3	608 bearing	6153K111	Stainless or ceramic balls work best
2	623 bearing (3x10x4mm)	7804K128	ABEC 3 or better if available, open is best, removable rubber seals are OK (McMC version has difficult to remove metal shields, try to find elsewhere)
1	keyhole hanger		Hillman 122211 or use printed version
4	click pen springs		

Table 3 Non-printed Parts

Component Pre-Assembly

Metal Parts

Most of the gears in this clock use music wire arbors. There is enough tolerance in the design that either 1/16”, 1.5mm, or 1.6mm diameter music wire should work. There is very little friction because of the small diameter.

Most of the descriptions in this document list imperial lengths because all my rulers are imperial. I attempted to list both metric and imperial lengths in the cut parts list. The lengths of most components are not super critical. Slightly shorter than the listed sizes are usually fine.

The 19.0” carbon fiber tube comes from an archery arrow. Carbon fiber has incredibly low thermal expansion so the clock should keep excellent time. A wooden dowel would also work.

The minute hand arbor uses a 4.125” long section of 3mm stainless steel or brass rod. It needs a flat filed at one end to prevent the minute hand from slipping on the arbor. Various additional lengths of 3mm rod are also required. The short segments are used as alignment pins to hold the frame together. I buy them pre-cut in bulk, although it is easy to cut them using a hacksaw. Round over the edges by rotating them against a grinder or belt sander. A small pin vice is useful here.

The 1/16” music wire is used for the arbors. I buy them in 36” lengths at the local hobby shop where they sell small metal parts. They come hardened so they are quite strong for such a small diameter. Clean up the ends by rotating them while gently touching them to a bench grinder or sanding disk.

The 5/16” brass rod needs a small amount of prep work before inserting into the weight drum. Aluminum or mild steel could be substituted if needed. One end needs a 1/8” wide slot about 0.5” deep. It can be cut with two passes from a hacksaw and hand filed to final shape. The printed winding key needs to easily slide over the end. Keep filing until it fits. A 1/16” hole is drilled 0.5” from the other end for a 1/16” by 1” music wire pin. A printed version of this part is included as gear8_shaft if you want to skip the fabrication of this part, although the metal version would be stronger.

The 4x0.7mm threaded rod is used below the pendulum for adjusting the time. It will be glued into one end of the carbon fiber rod. A 3” long screw with the head cut off or reduced so it fits into the tube is a good alternate source.

Sorry about the mixture of metric and imperial lengths in the following descriptions. My last clock used both metric and imperial sized components. This clock was simplified to use mostly metric diameter components, but some of the descriptions use imperial lengths.

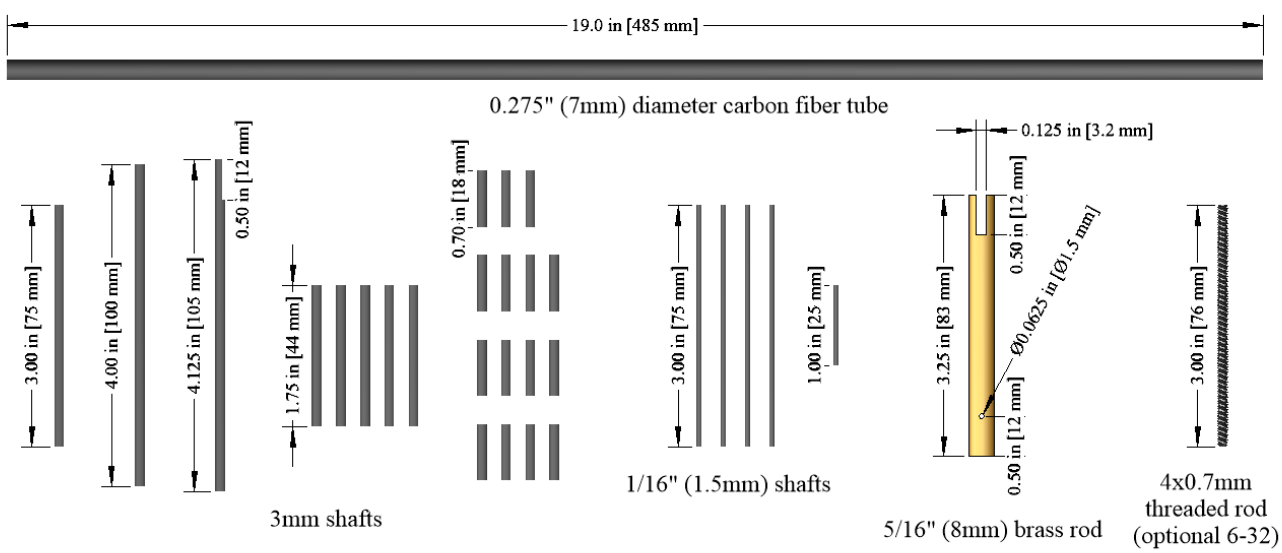

Figure 13 Cut metal parts

Additional parts needed are shown below. Threads are built directly into some of the plastic components, so the listed screw sizes are reasonably important. I have not heard any complaints from metric countries that they have difficulty finding appropriately sized screws.

The 608 bearings are a very common size used in skateboard wheels. The smaller 623 bearings are the most critical because they support the pendulum. Too much friction here will not allow the clock to work well. Select ABEC 3 or higher quality bearings if available. Stainless steel races with stainless or ceramic balls are nice because they will not rust. All of the factory grease needs to be removed using solvent, so open (unshielded) bearings are the best choice. The next best option is rubber seals because they are usually easy to remove using a small pin. Metal shielded bearings are a last resort since the shields are difficult to remove. I purchase bearings from eBay and can often find hybrid ceramic skateboard bearings for around US$1.00-1.50 each in lots of 10.

The bearings should spin freely after the seals are removed and the factory grease is removed. The operating speeds are so slow that there is no harm in running them dry. You can add a drop or two of dry Teflon bike chain lube to the bearings if desired. Make sure any solvent in the Teflon lube is compatible with your 3D printed material. It seems to be OK for PLA.

The microfilament fishing line has been working great in my clocks for several years. It has an amazing strength in a very small diameter. You can also find cord specifically designed for use in clocks. Other small cord should also be OK as long as it is strong enough to support the weight shell and not so large that it builds up when wrapped 25 times around the winding drum.

The keyhole hanger is available at the local large box building supply store. A 3D printed version is included with the STL files if you need it. Print it at a high density to make it as strong as possible. The metal version is preferred.

I use lead shot that is reclaimed from firing ranges, although it is getting harder to find. Used lead shot appears to cost around $2-3 per pound in 25-pound lots. The weight shell has options to print larger diameters or taller if you want to use lower density fill material.

Figure 14 Additional components

Back Frame

The clock frame is so large that it needed to be split into multiple components with brackets and screws to hold it together. Pins are used to keep everything aligned.

Insert two 3x44mm shafts into the alignment holes in back_frame_upper and back_frame_lower. Press back_frame_bracket into position using four 3x18mm alignment pins. The pins should be snug to properly align the frame. Add four 6x3/4" wood screws to hold everything together.

The hanging_hook supports the entire weight of the clock so it was made fairly robust with four 3x18mm alignment pins. Two 1-5/8" drywall screws attach the hanging hook to the back frame and two more drywall screws hold the keyhole hanger in place. The screw holes are printed with built-in threads to fit 1-5/8" drywall screws with 9 threads per inch. They should screw in easily without fear of breaking. The keyhole hanger is 0.59" by 1.65". My local hardware store carries the item as "Hillman 122211 Keyhole Fastener". A 3D printed version of the hanger is included with the files if needed.

Standoffs provide clearance for the pendulum to swing behind the clock. Two standoffs are located near the center of the lower frame. Use 6x3/4" wood screws. These standoffs have no force, they simply hold the clock away from the wall.

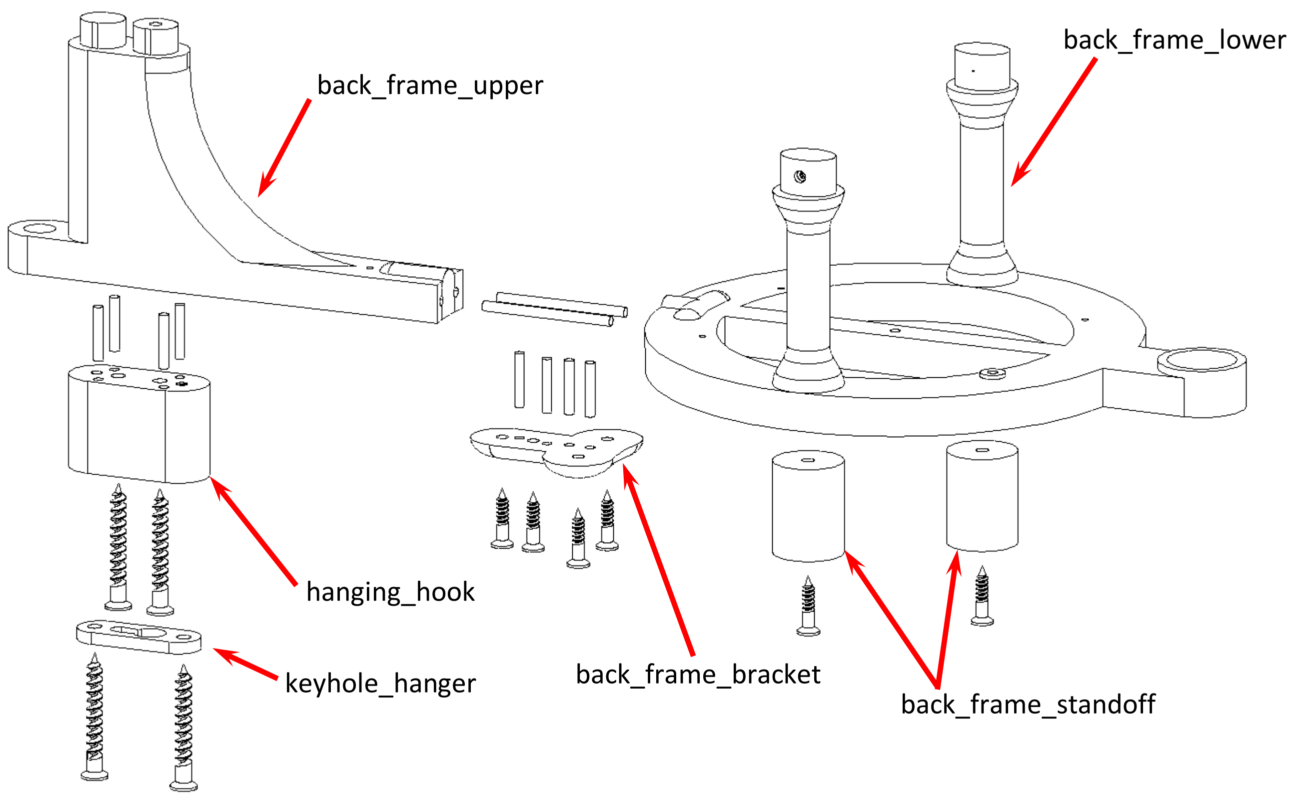

Figure 15 Back frame assembly

Front Frame

The front frame also gets assembled from components. Insert two 3x44mm shafts into the alignment holes in front_frame_upper and front_frame_lower. Add four 3x18mm alignment pins and attach the front frame bracket using four 6x3/4" wood screws.

Place one of the 608 bearings and spacer_8b into bearing_holder. The spacer should be positioned to provide clearance around the center hub of the bearing. The bearing holder attaches behind the front frame with three 3x18mm alignment pins and a 6x3/4" wood screw.

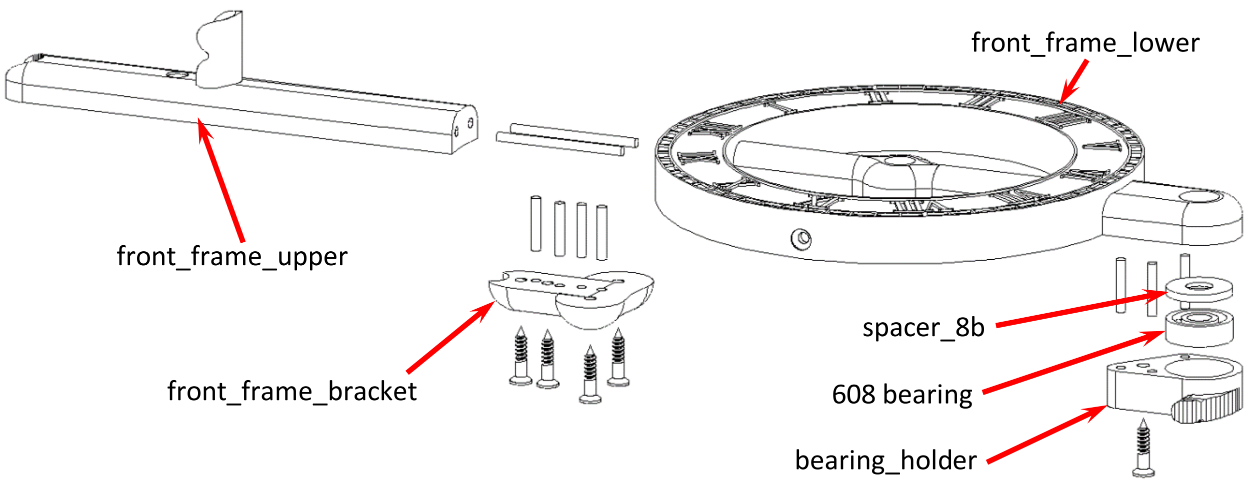

Figure 16 Front frame assembly

Test that the two halves of the frame go together easily and can be attached with three 6x3/4" wood screws, two from the sides and one near the top. There is no need to over-tighten these three screws since they are only acting like pins to hold the frame in place. You may be taking the frame apart many times before the clock is finished and you don't want to strip these threads.

You could test the strength of the frame hanging on the wall at this point. The entire clock is supported by the keyhole hanger and a single 8x1-1/2" or 10x1-1/2" pan head screw. Put the screw into a wall stud around 72" (1.8m) from the floor. Adjust the screw depth so the frame sits snug against the wall to prevent the clock from sagging. The standoffs should be sitting flush with the wall. Add shims (washers) behind the standoffs if needed. Alternatively, scale the Z-height of the standoffs to get everything to sit perfectly flush against your wall. You should be able to pull down on the frame using around 10 pounds (4.5kg) of force with minimal deflection visible.

Winding Drum and Ratchet

Slide the brass rod into the winding drum (gear 8_48_1p37) and push it into position with the 1/16" by 1" music wire pin in the slot. It is OK if it is a tight fit. This component never needs to be taken apart.

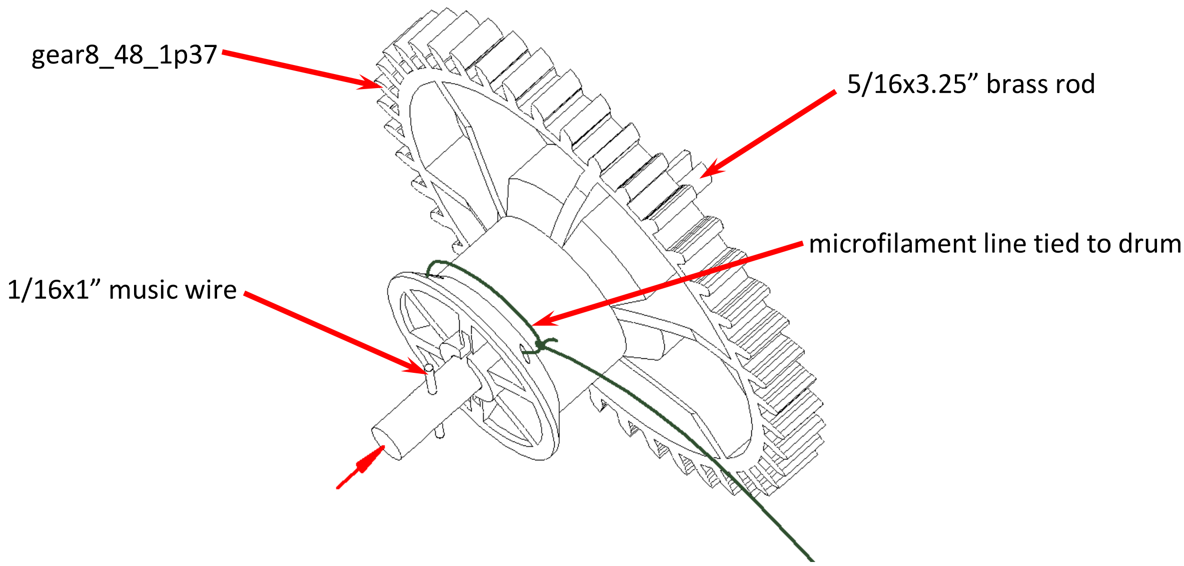

Figure 17 Winding drum assembly

Insert one end of the microfilament fishing line through the hole on the winding drum. Wrap it around the drum and tie the end. Tighten the knot and trim the end to around 0.25". Leave the line about 10-12 feet long. You can cut it to final length later. The brand I use is Power Pro Spectra Fiber Braided Fishing Line 65 lb. test with a diameter of 0.016". It seems to have a lot of strength for such a small diameter. It has been running for over a year without showing any wear, but I keep inspecting it and will replace it if needed. I certainly don't want the weight shell crashing to the floor in the middle of the night. There are cords specifically designed for clocks that would also be a great option.

The ratchet allows you to wind the clock. Attach the three clicks (gear7_click) to the ratchet center hub (gear7_24) with 6x3/4" wood screws. Tighten them until they are snug, then back them off until the clicks swing freely. Insert three springs from ball point pens into the holes. Add the assembled center hub with springs and the ratchet outer hub (gear7_48) to the 3x75mm rod. Gear7_support gets added to the bottom end. The ratchet should rotate easily in one direction. The springs only need to be strong enough to push the clicks into the outer ratchet. It will be noisy when winding if the springs are too strong. Adjust the spring length until the ratchet feels good.

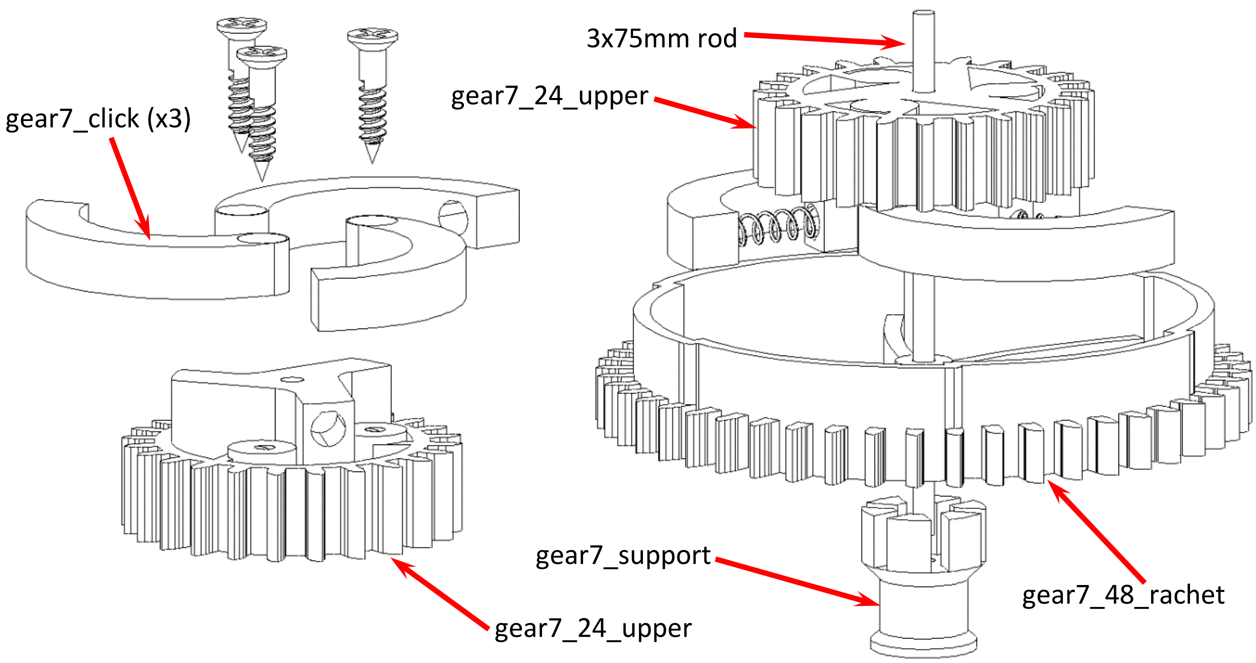

Figure 18 Ratchet assembly

Minute Hand

The minute hand arbor contains a friction clutch that slips when setting the time. A spring from a ball point pen provides the holding force. Power continues to be provided to the escapement though the large gear.

Assemble the minute hand arbor components from the top down. Place a shaft collar and set screw 1.675" from the upper end of the minute hand arbor. Gear4b_18 should slide over the shaft collar and set screw. Add spacer_4, a pen spring, gear4_54_18, and another shaft collar and set screw. Compress the pen spring so the gap is around 0.05" or less. The arbor should stick out the bottom by around 0.25".

Add the minute hand over the notched end of the arbor and turn it while holding the large gear. The large gear should rotate on the arbor with a small amount of resistance.

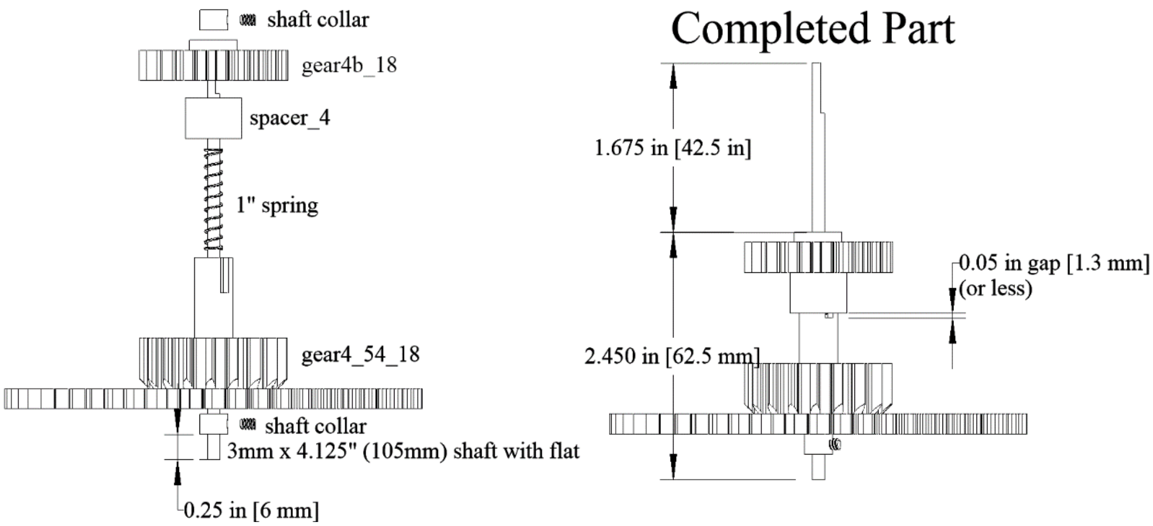

Figure 19 Minute hand assembly

Pendulum

The pendulum shaft is glued up from several components. The carbon fiber tube is cut to 19.0" in length and the ends are glued on using two part epoxy. Other types of glue may also work just as well. The bob is fairly light weight so there is very little strength needed to hold the end pieces on. The threaded rod at the bottom needs to be strong enough to hold its position when a nylon insert friction nut in the finial gets tightened.

Make sure the two ends are parallel to each other so the pendulum bob will sit flat against the wall. A piece of 3x44mm rod is centered at the top end of the pendulum hook. Glue it if needed to hold it in place. A 3" length of threaded rod is glued into the bottom end with at least 2" sticking out. Keep the rod centered and in-line with the shaft while the epoxy cures.

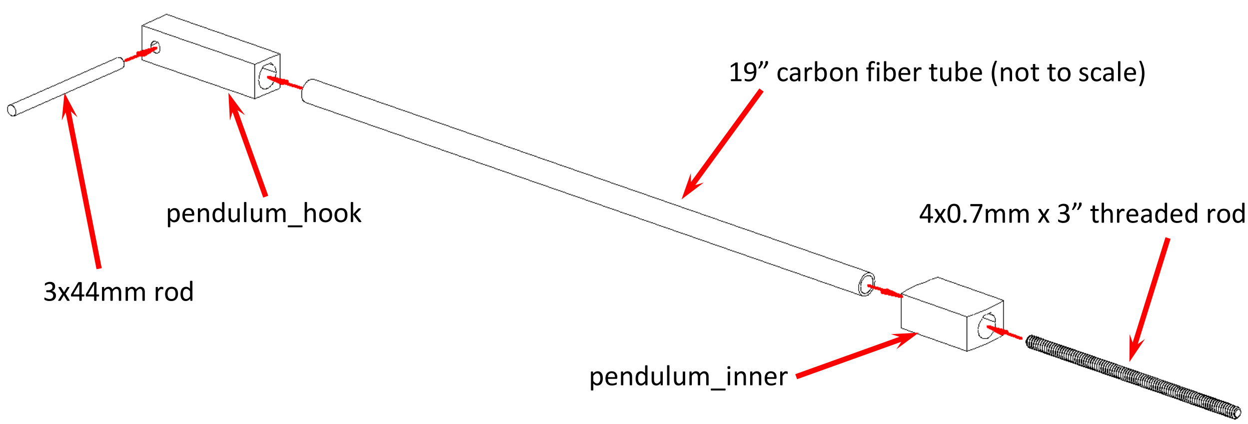

Figure 20 Pendulum shaft

The pendulum bob is a two-piece shell filled with pennies 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 needs to have enough momentum to continue swinging during minor disturbances and not so heavy that there is excess friction at the pivot point. The holes in the bob could be filled with washers, small rocks, or anything that fits. Pennies are cheaper than washers they fit nicely. Insert the pendulum shaft and attach the back of the bob using ten 4x1/2" wood screws. Ten screws are a bit of overkill, but they are hidden behind the pendulum so they are nearly invisible.

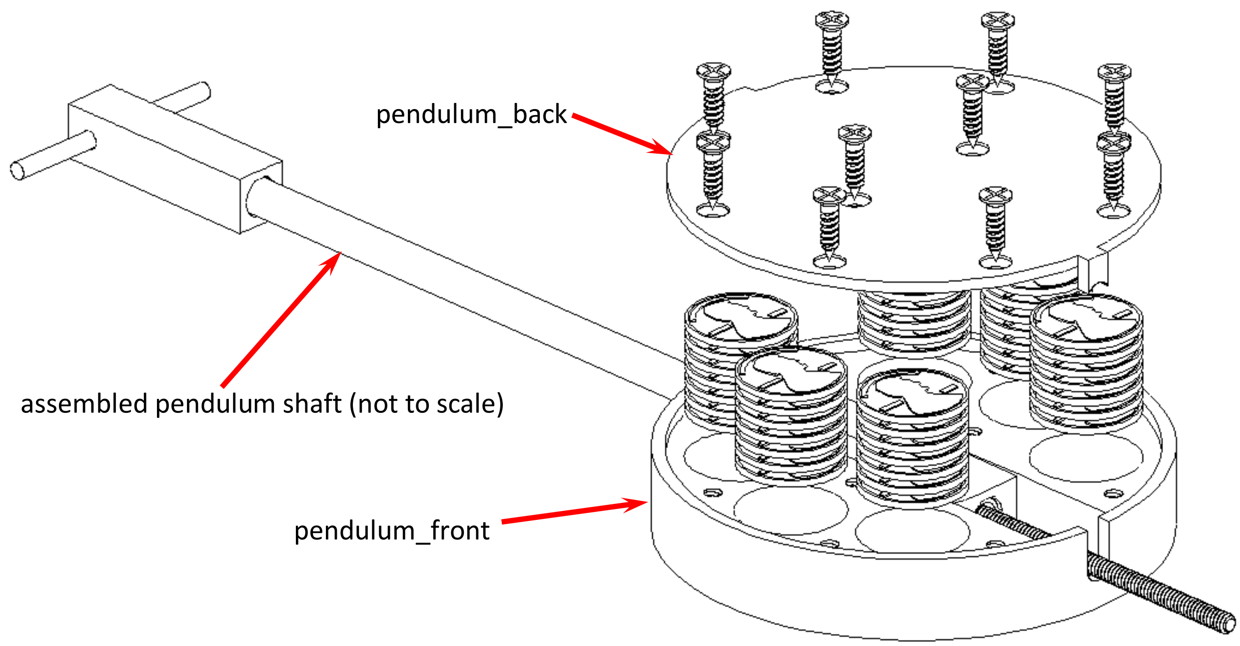

Figure 21 Pendulum bob

Add the finial to the end of the threaded rod. The final position will be determined later when adjusting the time. Start with the finial position near the center of the adjustment range.

This is a good time to test the pendulum operation by assembling the pallet and pendulum support. Insert a shaft collar and set screw from each side of the pendulum support. Long set screws work best here. Place the pendulum support at the end of the arbor and tighten the set screws. Insert the arbor through the hole on the back of the frame. Add a small bearing, spacer_0a (with the narrow side down), and two shaft collars with set screws. Slide the pallet over the shaft collars. Add spacer_0b and a small bearing.

Gently tighten the pallet set screws with the end of the arbor just extend past the upper bearing. Add the front frame by lining up the upper bearing and support posts. The arbor should extend about 0.8" through the back frame with the 0.4" thick pendulum support centered in the 1.2" space behind the frame.

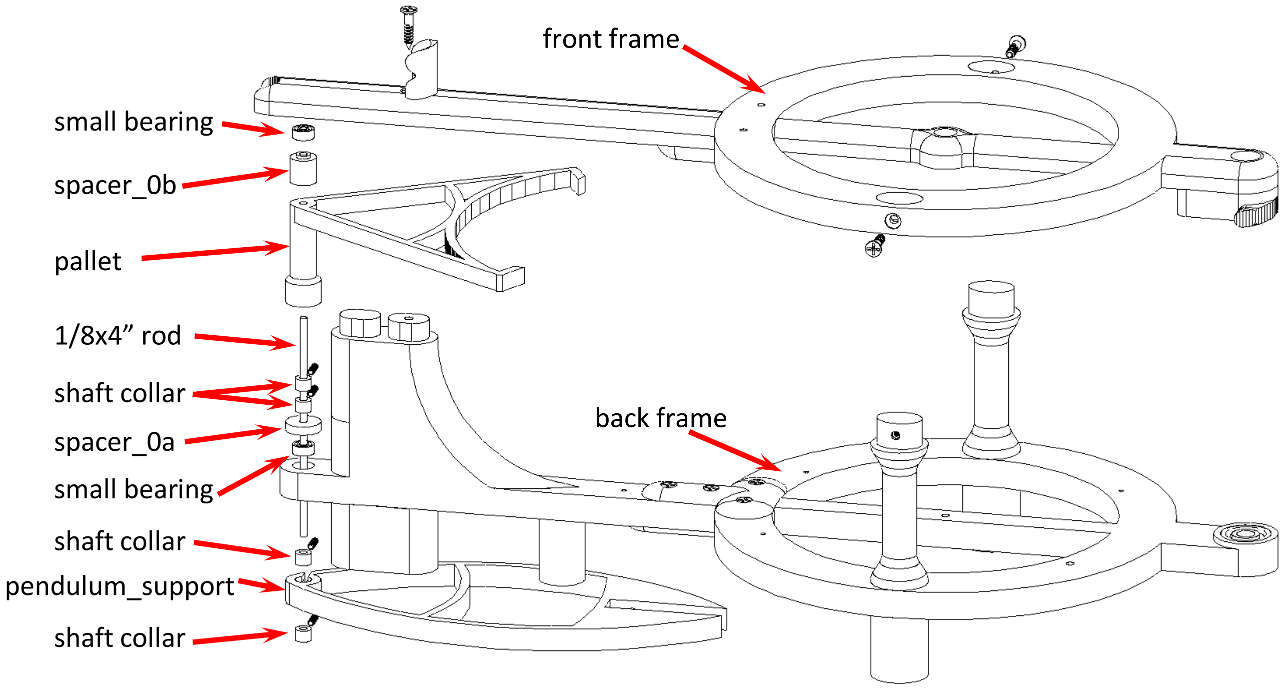

Figure 22 Pallet and pendulum support assembly

The completed assembly is shown below. Note that some of the pictures are borrowed from the large sized clock and there may be a few non-critical differences between this medium sized clock. For example, some pictures show an additional back standoff that doesn’t exist in this clock. The assembly procedure is the same and it should be easy to follow along.

The pallet straddles the large support rib and the pendulum support wraps around the hanging_hook. The pendulum support is centered within the gap behind the back frame.

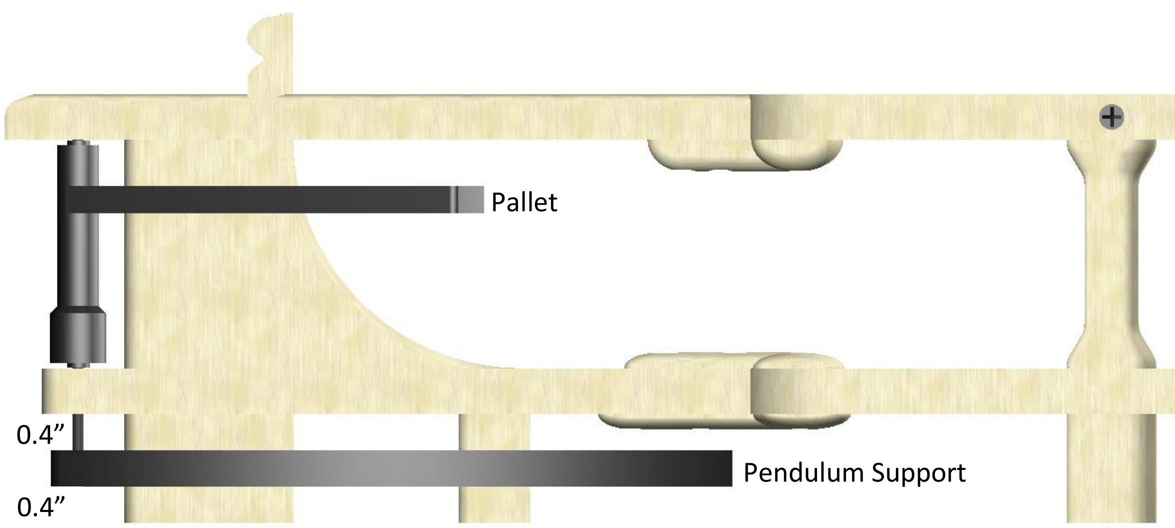

Figure 23 Pallet and pendulum support side profile

Hang the clock frame on the wall and add the pendulum to the hook in the pendulum support. Move the pendulum to one side and release it, timing how long it takes for the amplitude to reduce in half. The rate of decay is exponential, so if it takes two minutes for the swing to reduce from +/-4 degrees down to +/-2 degrees, it will take another two minutes down to +/-1 degree, and another two minutes down to +/-0.5 degrees. My clocks usually show a slight movement after 20 minutes of running the pendulum free swing test. Anything less than 10 minutes is an indication of too much friction in the bearings. Make sure the seals are removed and all factory grease has been cleaned out using solvent. Sometimes a batch of 10 bearings will have 1 or 2 gritty bearings. Select the best ones for the pendulum support.

Weight Shell

The weight shell is filled with lead shot that provide enough energy to keep the clock running. I tested multiple weights before settling on around 6.5 pounds (3.0kg) for this clock. The desired weight can be achieved using the 2.6” diameter shell filled with lead shot or the 3.0” diameter shell filled with BBs. I estimate around 9000 BBs. You might also be able to fill the weight shells with sand or gravel if you stack some additional sections to increase the height. The target weight should be at least 6.0 pounds (2.7kg). The clock might run using a smaller weight, but a slightly larger weight is more reliable.

There are multiple options to create different size weight shells. Select the smaller diameter if you have access to lead shot or the larger diameter for less dense material. Use the full height weight shell if your printer supports it. Otherwise, print the half height components and combine them. The quarter height portion can be added if your clock needs a small amount of additional weight to run reliably.

Insert a 608 bearing into the weight_pulley. It should be a reasonably tight fit to keep it from slipping sideways and binding. Add a drop of Teflon lubricant to the bearing and wipe off any excess. The pulley is positioned into the top of the shell with the weight_pin and a 1-5/8” drywall screw. Push the pin into position around the pulley and secure it in the weight shell. The pulley should spin freely.

Turn over the weight shell and fill it with lead shot (or BBs if using the larger diameter shell). It is a good idea to wear disposable gloves for this step to minimize exposure to lead. Plug the four screw holes before filling the shell to prevent lead from falling down the holes. Pack the weight shell with as much lead as it will hold. Secure the bottom cover to the weight shell using four 1-5/8” drywall screws.

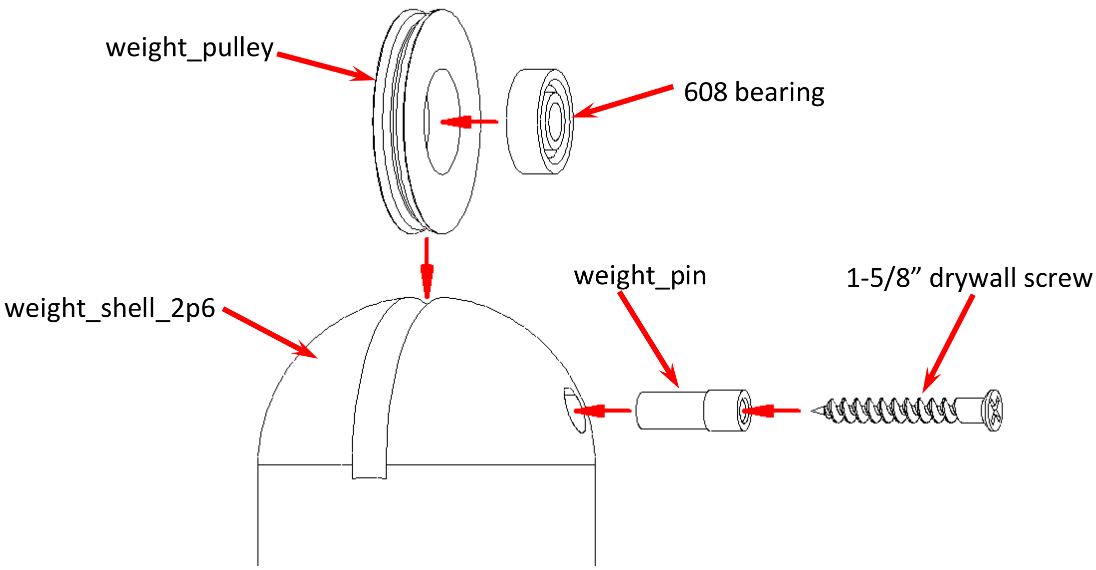

Figure 24 Top portion of weight shell

There are options to print a half height upper weight shell, and half or quarter height bottom weight shell components. The half height options were designed for printers that don’t support a 7.5” tall print. They can also be used to extend the length of the weight shell if you have lower density fill material. The quarter height extension can be used to add a small amount of additional weight. This will reduce the run time slightly because the weight shell will hit the floor sooner, but at least you will have a functional clock.

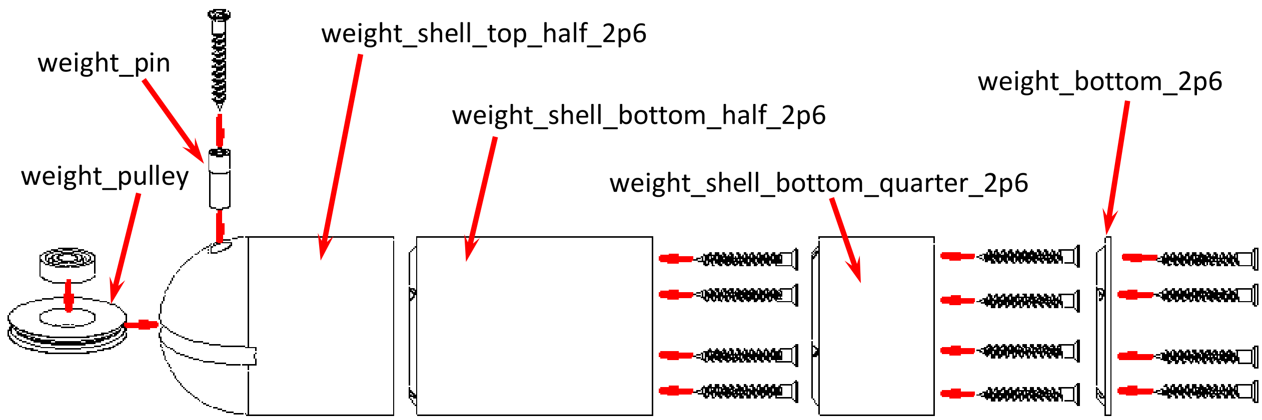

Figure 25 Split component weight shell

Building the Clock

Reducing friction is very important in a mechanical clock. This clock uses around 6.5 pounds of weight falling 48” every 4.9 days. The clock will tick 578680 times in 4.9 days, with the weight shell dropping about 0.0001” with each tick. The energy of the weight shell falling 1” needs to keep the pendulum swinging back and forth 5000 times. There is not a lot of excess energy to waste on friction.

I sometimes add dry Teflon lubrication to the moving parts of the clock. Just a tiny bit is needed. Use the tip of a toothpick and add a drop to the ends of the arbors. I also lubricated the escapement and pallet arms since they are continuously sliding past each other. It is generally considered a bad idea to oil an escapement because oil attracts dust that can scrape the surfaces. Dry Teflon lubricant doesn’t seem to leave behind a sticky surface to collect dust. It appears to be safe for PLA, but test it before adding it all over your completed clock. This step might be optional. My version of this medium sized clock is running great without any lubrication.

Final Assembly

The rest of the clock can now be assembled. Assembly videos have been posted on YouTube to go along with these printed instructions. They show assembly of the larger clock, but the process for this clock is almost identical.

The image below shows the back frame with arbors added for reference. They can be placed now or later as gears get added. Assembly starts with the lowest gears when the clock is sitting flat on the table.

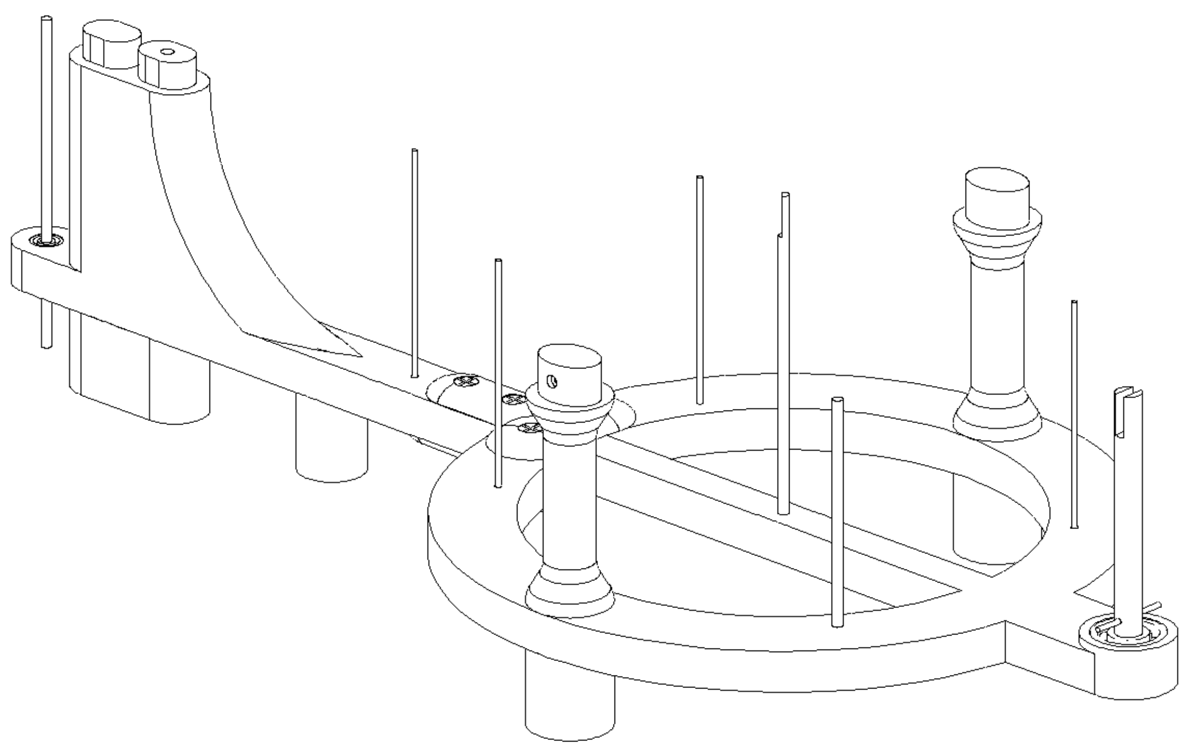

Figure 26 Back frame with arbors

Gears 4 and 7

The previously assembled minute hand assembly (gear 4) gets placed first. Add the ratchet assembly (gear 7) to the larger diameter pivot hole on the lower left. The two gears should mesh without any interference. Add spacer_7 onto the gear 7 arbor.

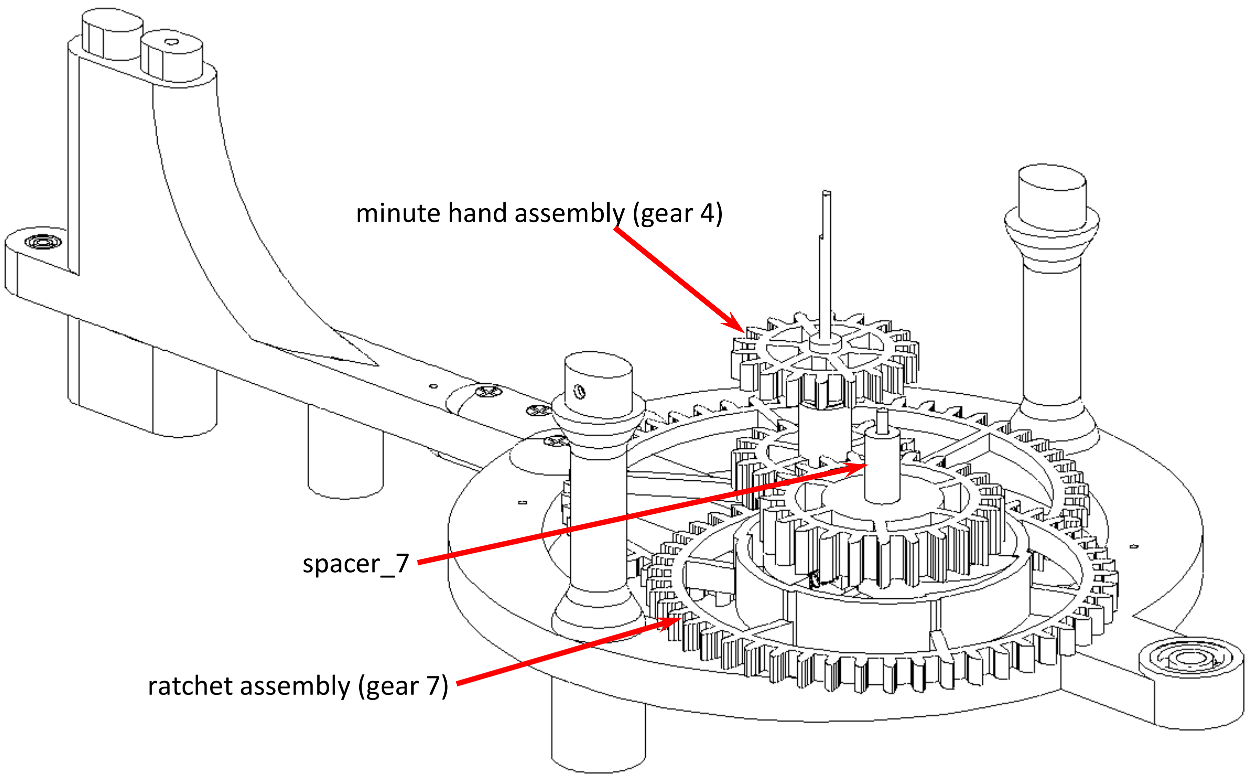

Figure 27 Gears 4 and 7

Gears 2, 3, and 8

Add 1/16" by 3" arbors into the holes at the 11 o'clock and 1 o'clock positions. Place gear3_54_12 onto the arbor so the pinion meshes with the bottom portion of gear 4. Add spacer_3 with the narrow end facing up. This reduced diameter helps reduce friction on the fast moving portion of the gear train.

Add gear2_54_12 and spacer_2 in the upper right pivot hole. Everything should mesh smoothly. You could add the front frame to double check that all gears spin easily.

Place a 608 bearing into the large bearing hole at the bottom of the frame and add the winding drum assembly plus spacer_8a. Gear 8 should already have about 10 feet of fishing line tied to it. Most of the line can be wrapped around the winding drum to keep it out of the way. The end should hang on the right side of the winding drum. Leave at a foot or two unwound for hanging the weight shell after the clock is mounted to the wall.

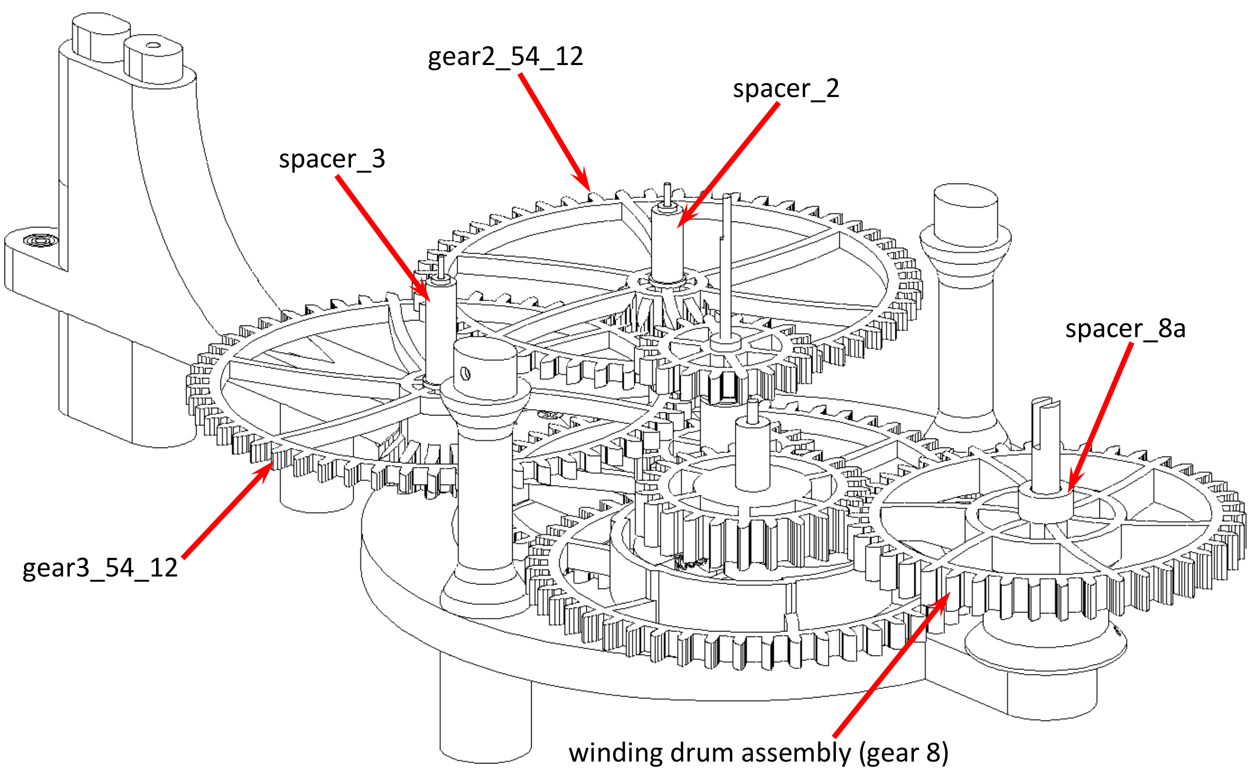

Figure 28 Gears 3, 2, and 8

Escapement and Pallet

The pallet and escapement can be added now. Add a 1/16” by 3” arbor for the escapement. Add the escapement and spacer_1 with the narrow end facing up.

The previously assembled pallet can be added back in. The arbor sticks out the back of the frame about 0.8” for attaching the pendulum support.

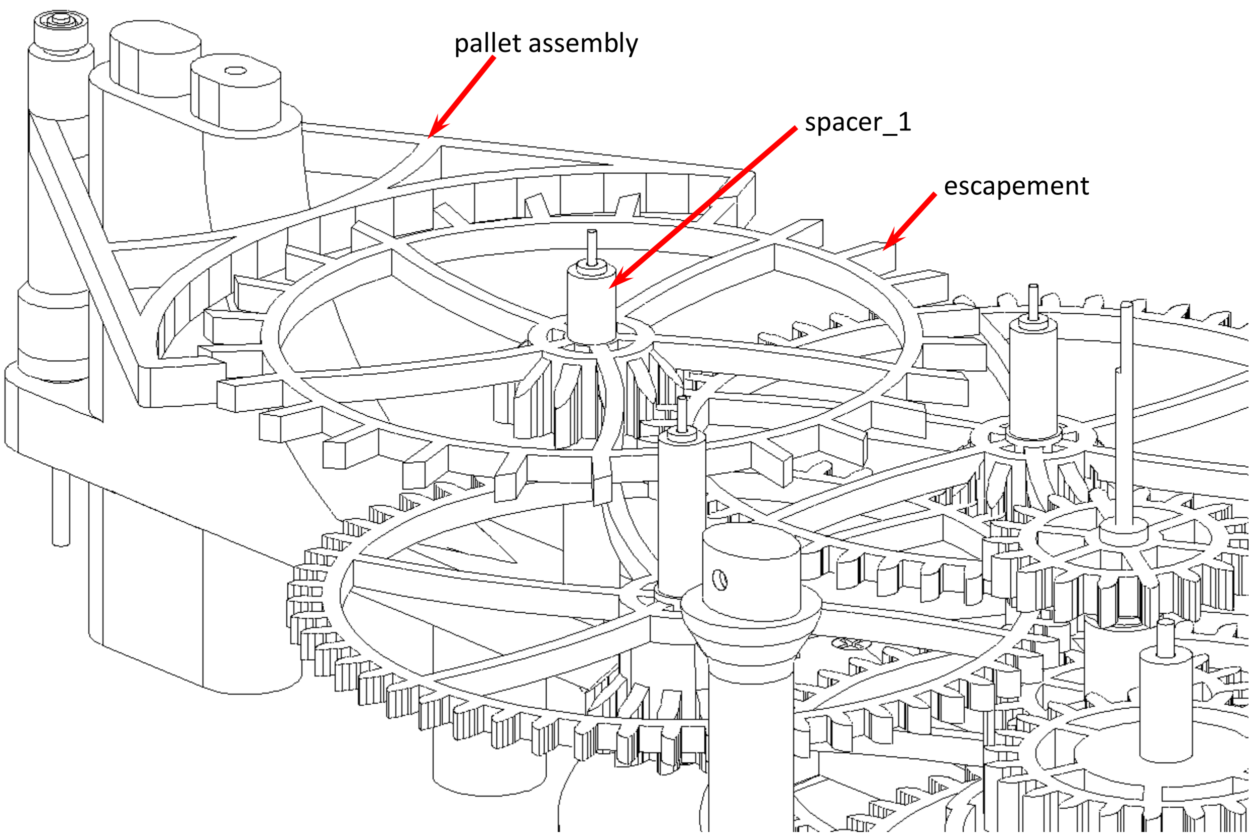

Figure 29 Pallet and escapement

Gears 5 and 6

Gears 5 and 6 are the final gears to add. Place a 1/16” by 3” arbor into the last remaining pivot hole. Add spacer_5 and place gear5_48_12 on the arbor. Gear6_54 fits over the minute hand arbor. Most of the arbors should stick up around 0.25” above their gear stack with the exception of the minute hand arbor and the winding drum.

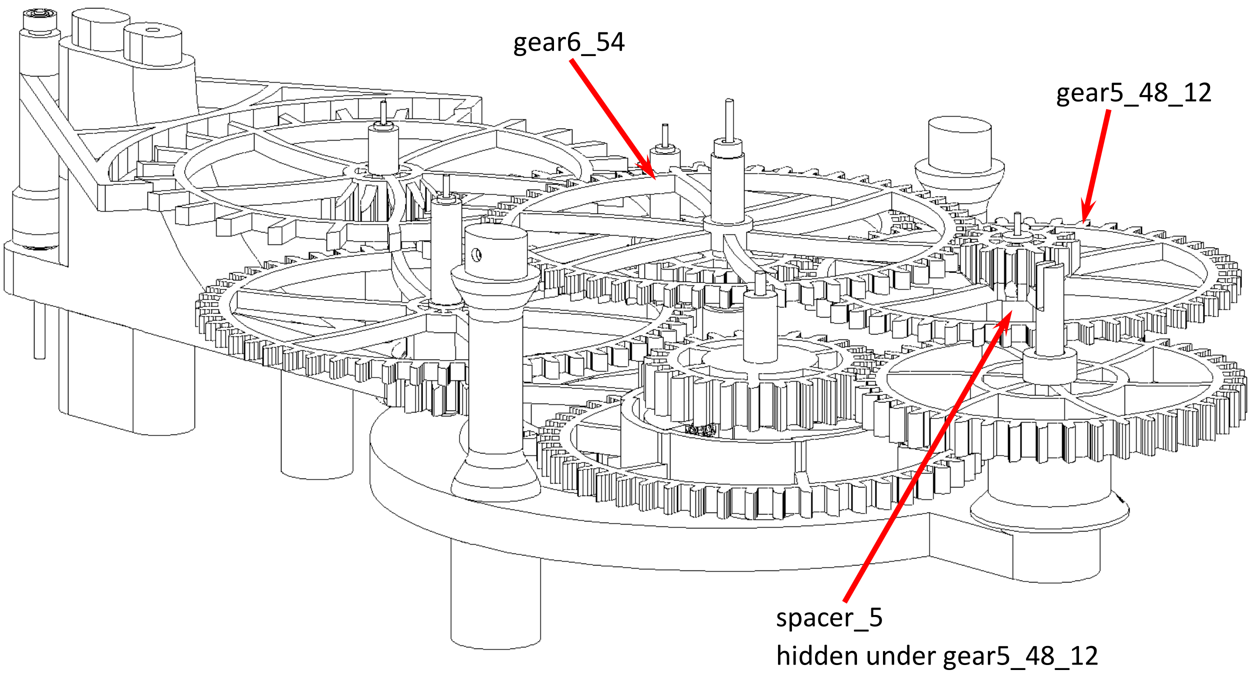

Figure 30 Gears 5 and 6

Front Frame

It is time to put the face on the clock. This step is a little tedious because there are 8 arbors and 3 support posts that all need to be positioned properly. I may have assembled and dis-assembled my clocks 100 times while fine tuning different parts. It is still tedious, so be patient.

Start in the lower corner and work towards the top. Place the front frame over the lower support posts and slide the front bearing over the winding drum arbor. The two halves will go together part way and stop on any arbor not lined up with its hole. Set the clock flat on a table and look from the sides to see which arbor is blocked. Move the blocked arbor into position and the frame should close a bit more. Keep adjusting arbors until everything lines up and the front frame drops into position. The frame is held together by three 6x3/4" wood screws, two from the sides and one at the top.

Add the hour hand onto the hub at the top of gear 6. It is a press fit and can be positioned in any direction. The minute hand has a flat and can only be positioned in one direction. Set the minute hand to the 12 o’clock position and move the hour hand to point to any full hour position. You should be able to change the time by rotating the minute hand and the hour hand should move accordingly.

Everything should be starting to look like a clock at this point.

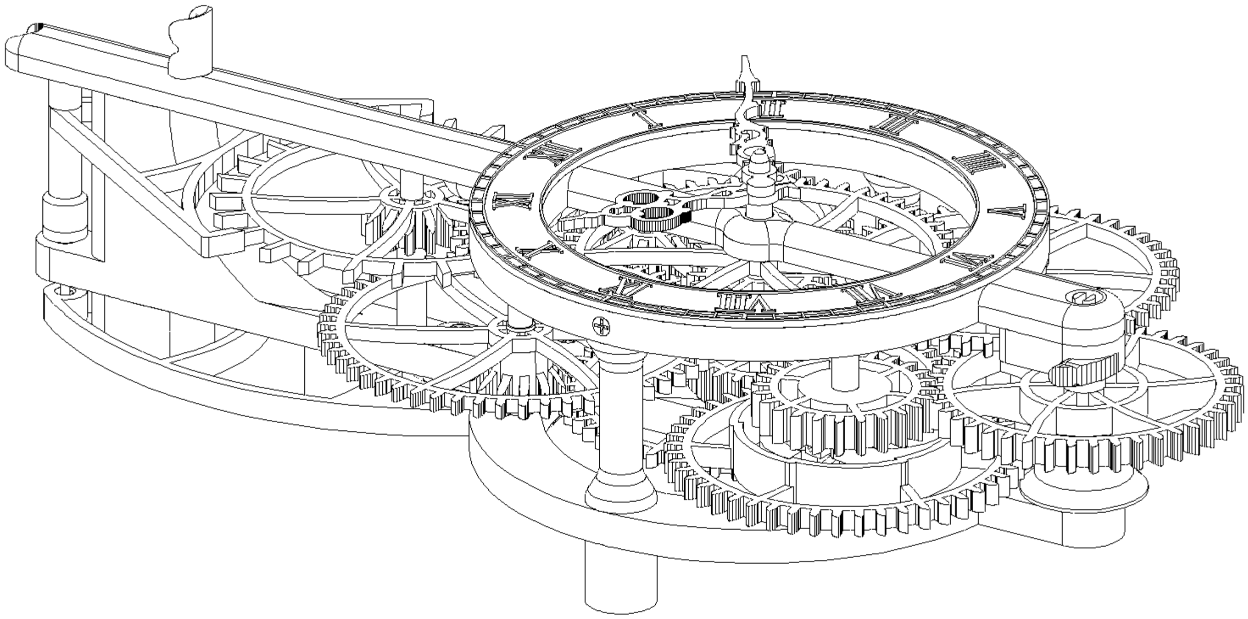

Figure 31 Assembled clock

Testing the Clock

Mounting the Clock

The clock mounts on the wall using a single screw driven into a wall stud. An 8x1-1/4" or a 10x1-1/2 pan head wood screw fits nicely into the keyhole hanger. Placing the screw 72" from the floor will give 48" of drop on the weights for almost five days of run time. Place the clock on the wall and adjust it to be level. Add the pendulum bob to the pendulum support.

Attach the swing gauge to the wall so it is centered below the tip of the finial. It may be best to just tape it to the wall for now and adjust the height after the final pendulum length is determined.

Tie a loop in the end of the winding cord and pass it through pulley in the weight shell. Hook the end on the tab sticking out from the bearing holder. Make sure that the cord stays in the weight_pulley groove. Lower the weight shell after the line is attached properly. 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 pallet 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………". The swing gauge helps to determine if it is balanced. Each tall line on the swing gauge corresponds to 1 degree of pendulum motion. The short lines are 0.2 degrees.

The clock should tick at around 1.5 degrees to the left and 1.5 degrees to the right of the mid-point. Loosen the set screws on the pallet slightly so they allow a small amount movement when the pallet is pushed when the pendulum is held steady. Tighten the set screws when the beat is balanced from left to right. You can also tilt the clock frame slightly to make a minor final adjustment.

Push the pendulum about 3 degrees to one side and release. The clock should continue ticking. The pendulum only needs about 1.5 degree of swing in each direction for the escapement to be functional. A bit of extra movement is desirable to keep the clock from stopping from a slight breeze. I like to see at least 2 degrees of swing in each direction. Adding additional weight would increase the swing and the clock should be a bit more reliable, although the clock gets slightly 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 length around 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 0.03" in change in pendulum length should change the rate of the clock by about a minute per day.

Imperial 6-32 threaded rod on the finial has 32 threads per inch, so one full rotation changes the length by 0.03125". One full rotation of the finial would change the rate by about a minute per day. There are 8 tick marks on the finial, so each tick adjusts the rate by approximately 8 seconds per day.

Metric 4x0.7mm threaded rod has a slightly smaller pitch of about 0.0276" per rotation. Each full rotation adjusts the time by around 55 seconds per day. Each small tick adjusts around 7 seconds per day.

The clock rate may change during the first week or two as the components settle into position. Then it should stabilize to a consistent rate. Wait to get past this break-in period before attempting the final timing adjustment. The carbon fiber pendulum rod should have really good temperature stability. My clock is usually accurate to about a minute or two 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. I usually press on the frame to hold it against the wall when winding the clock to prevent it from shifting. You may need to reset the beat after winding if the position shifted. It may be a good idea to halt the clock while winding to prevent the beat from changing.

Debugging

Once the clock is working properly, it should continue to work for many years. This clock has many features intended to make it a trouble free design. The large gears have loose tolerances and the frame strength has been increased to prevent sagging. These added features should make your clock as reliable as mine.

Start with the pendulum free swing test described previously when building the frame.

Manually move the pendulum back and forth to watch the escapement. If the clock is in beat, the escapement will release equally in either direction. I like to remove the weight shell and place a much smaller weight on the cord. My clock still shows escapement movement with around 10 ounces of weight. There is not enough energy to power the clock, but the escapement should continue rotating while manually moving the pendulum. Make sure to continue this test through a complete rotation of the escapement. There may be too much friction in the gear train if your clock needs more than 12-16 ounces for this experiment.

You can also remove the pallet and watch the gear movement with the small (~10 ounce) weight. You can remove the pendulum support arbor and tie the pallet out of the way, or take the clock apart and completely remove the pallet. The escapement should spin freely. It should start spinning again if you stop it at random times.

Add the weight shell back and observe the pendulum amplitude. There may be too much friction if the clock has less than 2 degrees of swing. You could take out all the gears and put back two at a time to see how they mesh. Test each pair of gears individually to see that they move smoothly with no noticeable friction. You can also try adding extra weight using the 1/4 height weight shell extensions to see if the clock improves. Also make sure the frame does not sag when adding the weight shell.

Final Comments

Designing this clock has been a lot of fun. It is my third 3D printed pendulum clock and it has been the most reliable. It started ticking as soon as it was assembled and has not stopped once. I like the bold look with gears extending beyond the frame.

I enjoy the challenge of looking at every component and deciding if there are any slight improvements to be made. Maybe I am a bit of a perfectionist, because it takes me a really long time to design each clock. I have never built a clock out of brass, although I am attempting a few wooden gear clocks.

Please feel free to support me by purchasing more of my designs. I hope to start a Patreon page at https://www.patreon.com/user?u=30981480 (Steve's Clocks) where I will explain the design process used in my various clocks.

Good luck with your clock build.

Steve

Here are a few of the other clocks I have built. Many of them will eventually be released for others to build. The first is a grasshopper escapement to replace the deadbeat escapement in the large clock design. It needs a bit of fine tuning before it can be released. The second image is a rendering of the clock as it may look after porting to a wooden gear design.

Figure 32 Grasshopper clock modification and a wood clock rendering

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

Figure 33 Wooden gear experiments

This is a family of desk clocks using an Arduino Nano and a stepper motor for the clock movement. The clock design is very straightforward, but documenting the small circuit board and Arduino programming is slowing down the release. I think I need to try something other than purple gears for a while.

Figure 34 Desk clocks

Here is the clock that started it all. It is posted to https://www.thingiverse.com/thing:3524448

Figure 35 Original Thingiverse design

All of my wall mounted pendulum clocks in one group. The clock described in this document is the middle clock.

Figure 36 All my wall mounted clocks