3D PRINTED SKELETON CLOCK

SP2 Assembly Notes

Instructions for building a 3D printed skeleton clock with large exposed gears

Steve Peterson
17-Oct-2020

Contents

Tables

Figures

Revision History

01-Oct-20	Original version
06-Oct-20	Added option to print the brass shaft passing through winging drum (gear8_shaft)
17-Oct-20	Added gear reference chart

Description

This document describes the construction of a 3D printed pendulum clock with large exposed gears. It is a complete redesign of my 3D printed pendulum clock at https://www.thingiverse.com/thing:3524448 Nearly every part has been optimized for easier printing and better visibility of the gears. Future enhancements may include different sizes, a grasshopper escapement, or a conversion to a wooden gear clock.

The primary goal of this clock was to create a visually impressive timepiece. It needed to be accurate and have a long runtime to be a useful clock. I believe this clock achieves those goals. The design incorporates feedback from builders of my first clock and additional enhancements as I learn more about 3D printing and clock design.

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. The challenge is to make everything work elegantly and accurately.

The clock described here was printed on a Prusa MK3S and should also fit nicely on a Creality Ender3 or other similar sized machines. Future smaller versions of the clock may be more appropriate if you have a print bed smaller than 210x250mm or 220x220mm. Components are available with both metric and imperial sizes so the clock can be built using components available anywhere in the world.

Clock gears are defined by the size and shape of the teeth. This clock uses 10 diametral pitch gears (10DP or MOD 2.54) which means that a 10 tooth gear will have a diameter of 1 inch or 25.4mm. The 54 tooth gears in this clock are 5.4 inches at the pitch circle with an overall size of 5.6 inches. My original pendulum clock uses 20DP gears with each gear being around half the size as this design. The larger tooth size in this clock is very easy to print. It also creates a more impressive looking clock.

The gear tooth profile started as a 14.5 degree pressure angle gear and optimized further using a concept called “fancy gears” described at http://garysclocks.sawdustcorner.com/fancy-gears.html The basic premise is that clock gears operate with different criteria than most other gearing applications. Clock gears turn in one direction so only one edge of each gear tooth is engaged. The other edge can have any shape as long as it does not interfere with the neighboring teeth. This allows optimizing for 3D printing. One surface of each gear tooth is defined as the active edge. The inactive edge was placed a constant distance away to produce the cleanest possible printed gear. The rim and spoke widths were also adjusted to print smoothly using a standard 0.4mm nozzle.

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 are completely solid when printed using 4 perimeters.

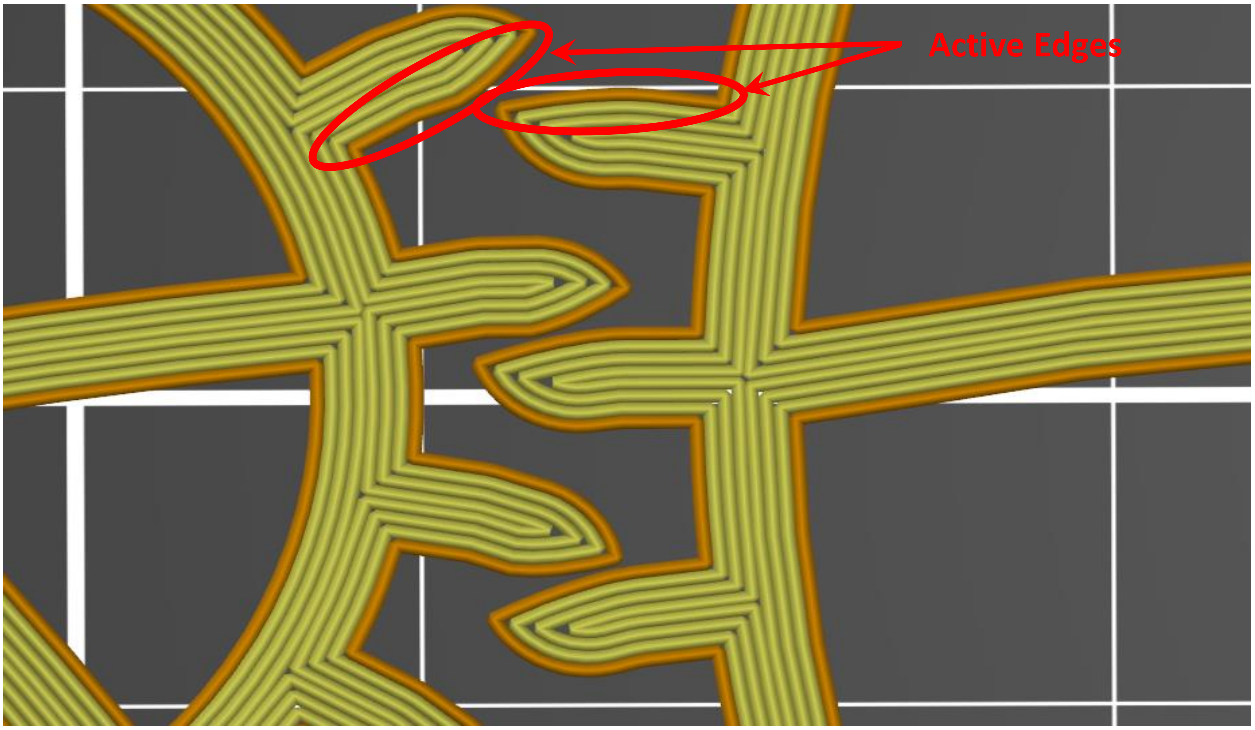

Figure 1 Sliced gears after optimization

The escapement and pallet 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.

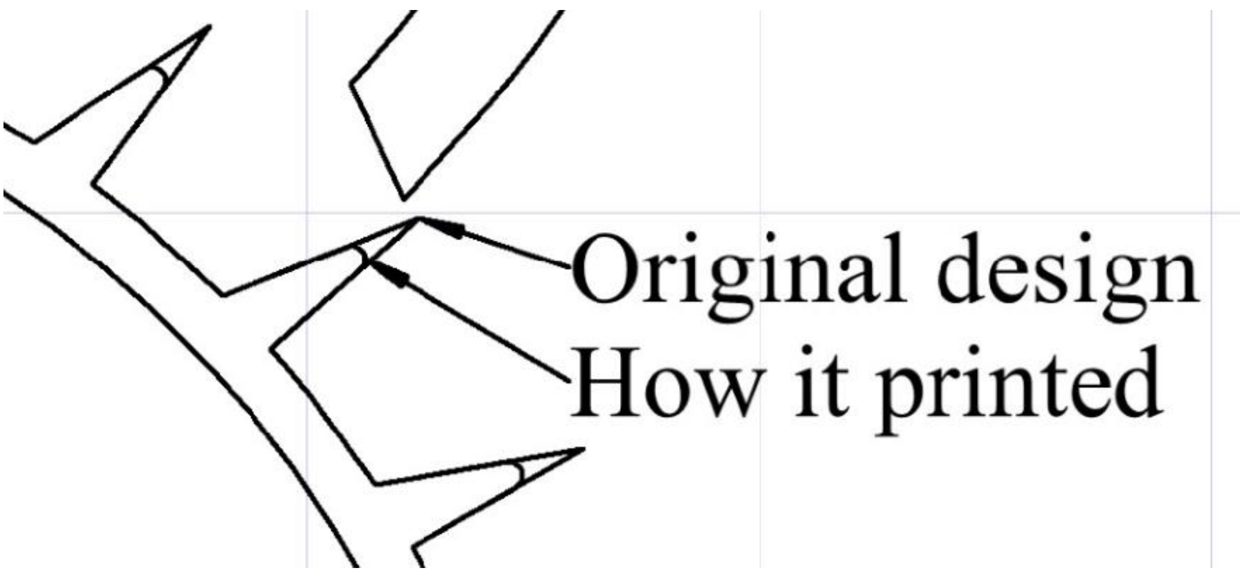

Figure 2 Traditional Deadbeat Escapement

The teeth can be lengthened to compensate, but different printers might need different optimizations. The solution used by this clock is to widen the tips of the escapement teeth and extend a consistent width to the rim and spokes. The pallet width was reduced to provide the proper clearance. It may look different than a normal design, but the active surfaces are similar. The predictable length of the escapement teeth makes it very reliable in a 3D printed design. The consistent width allows everything to print using very uniform filament flow.

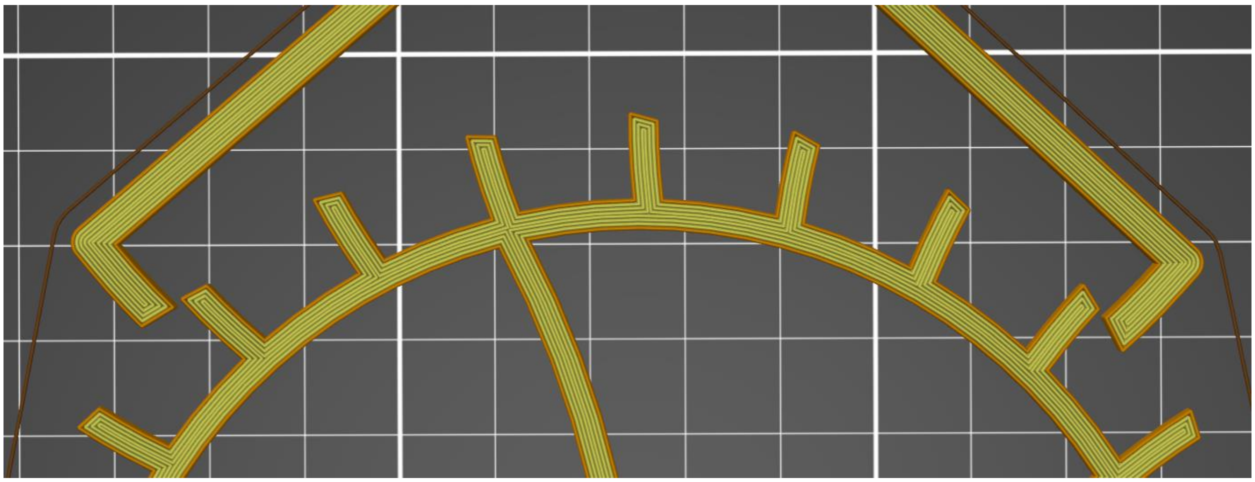

Figure 3 Escapement and pallet slicer output

Gear Ratios

Many traditional clock designs use small pinions with 6 or 8 teeth, but involute gears have less friction if the pinions have at least 12 teeth. An extra gear set was added between the minute hand and the escapement to allow 12 tooth pinions throughout the clock. Gear tooth friction should be reduced considerably at the expense of needing one additional arbor. The arbors have a very little friction because of the small diameter, so this is a good tradeoff.

Adding 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 24.48” long pendulum with a 25 tooth escapement. The rest of the gear train was adjusted for the clock to keep perfect time with beats 4556 beats per hour. The pendulum length looks proportional to the clock with this configuration.

Here are the gear ratios used in this clock and the labels used in the assembly documentation. Some of the STL file names will make sense from looking at this diagram. For example, gear 4 is an assembly with multiple pieces. Gear4_54_18 includes the 54 tooth gear and the 18 tooth pinion. Gear4_18 is a smaller component with only an 18 tooth pinion.

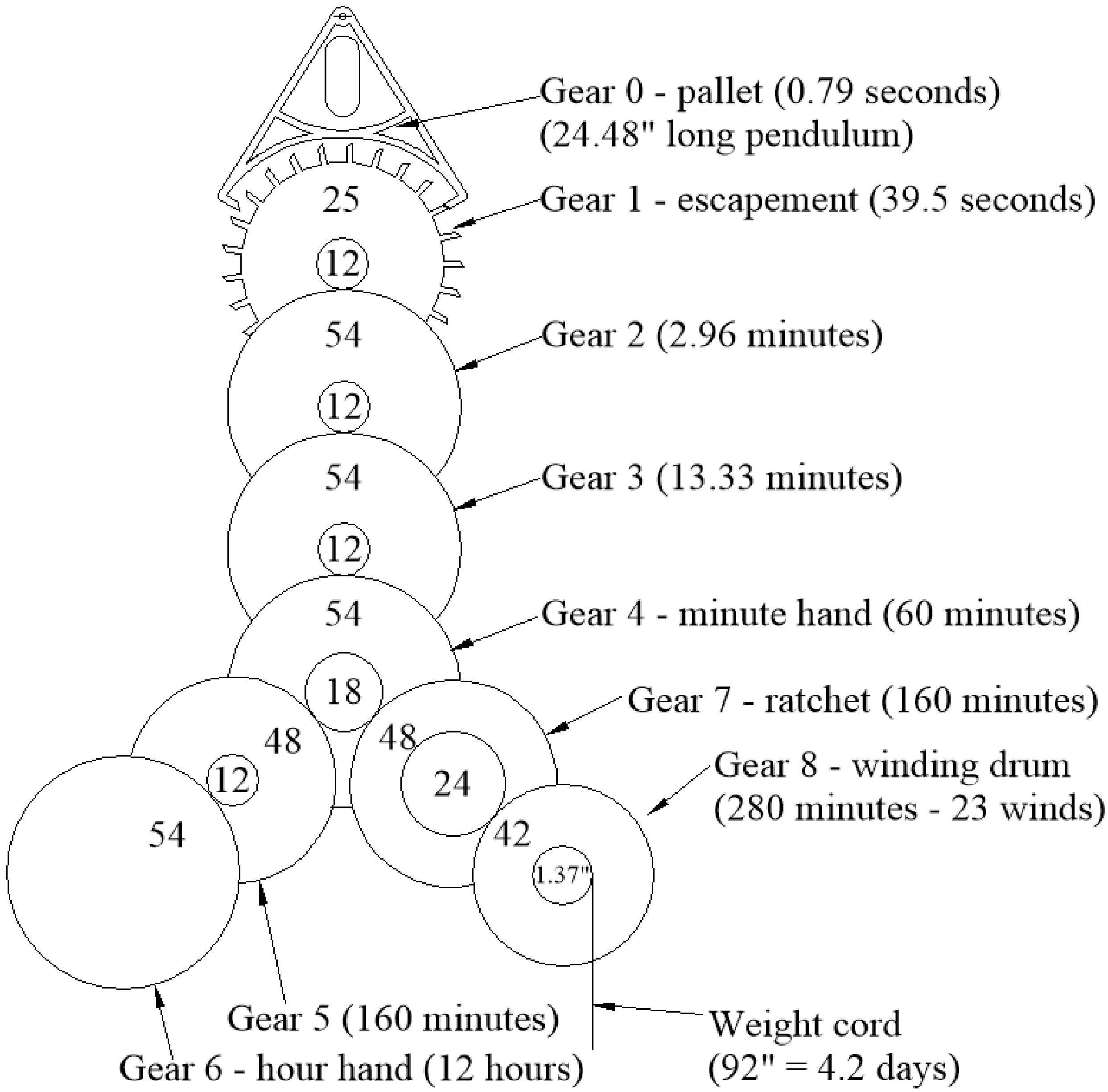

Figure 4 Clock gear ratios

The clock has been designed to support a 4 day runtime between winds with a reasonable sized drive weight. A clock with lighter weight 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 to 4 days. I think the tradeoff is worth it to have a more impressive looking clock. Four days is still a very respectable runtime.

Printing the Parts

The total print time for all of the components is around 150 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. Gears and pinions print together with the pinions forming on the center hub using 45 degree angle surfaces to print without needing supports.

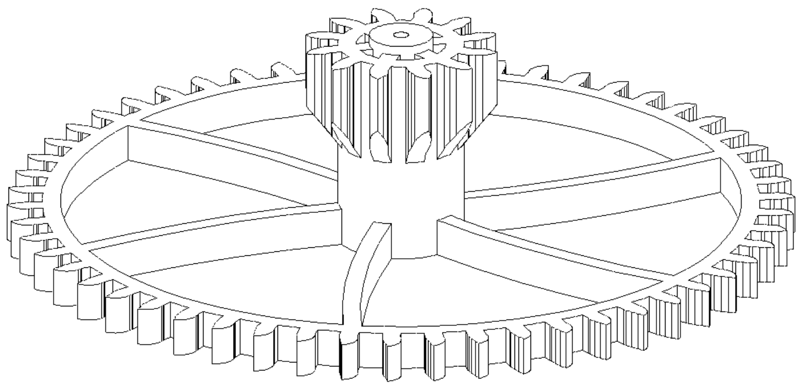

Figure 5 Gear profile example

The front frame integrates the dial and numbers into a single print using multiple colors for better visibility. The dial is the largest component that cannot be easily split. It sets the minimum printer bed requirement of around 210x220mm. The upper portion of the frame is added to the dial to create an 18 inch tall overall size. The segmented frame provides an upgrade path for future enhancements without needing to print the entire clock.

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 print slightly better with 5 perimeters. Others look slightly better with up to 10 perimeters. The gear design ends up creating a nearly solid object with 4-5 perimeters, so 10 perimeters does not add much extra material but it creates smoother top surfaces. 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 purple silk 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.

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 many gears are so large that it is difficult to fit more than one on the build plate at a time.

Some of the parts are included with both imperial and metric sized components. Select the version appropriate for the materials available in your country. Imperial components have "_imp" added to the file names and metric components have "_met" added.

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

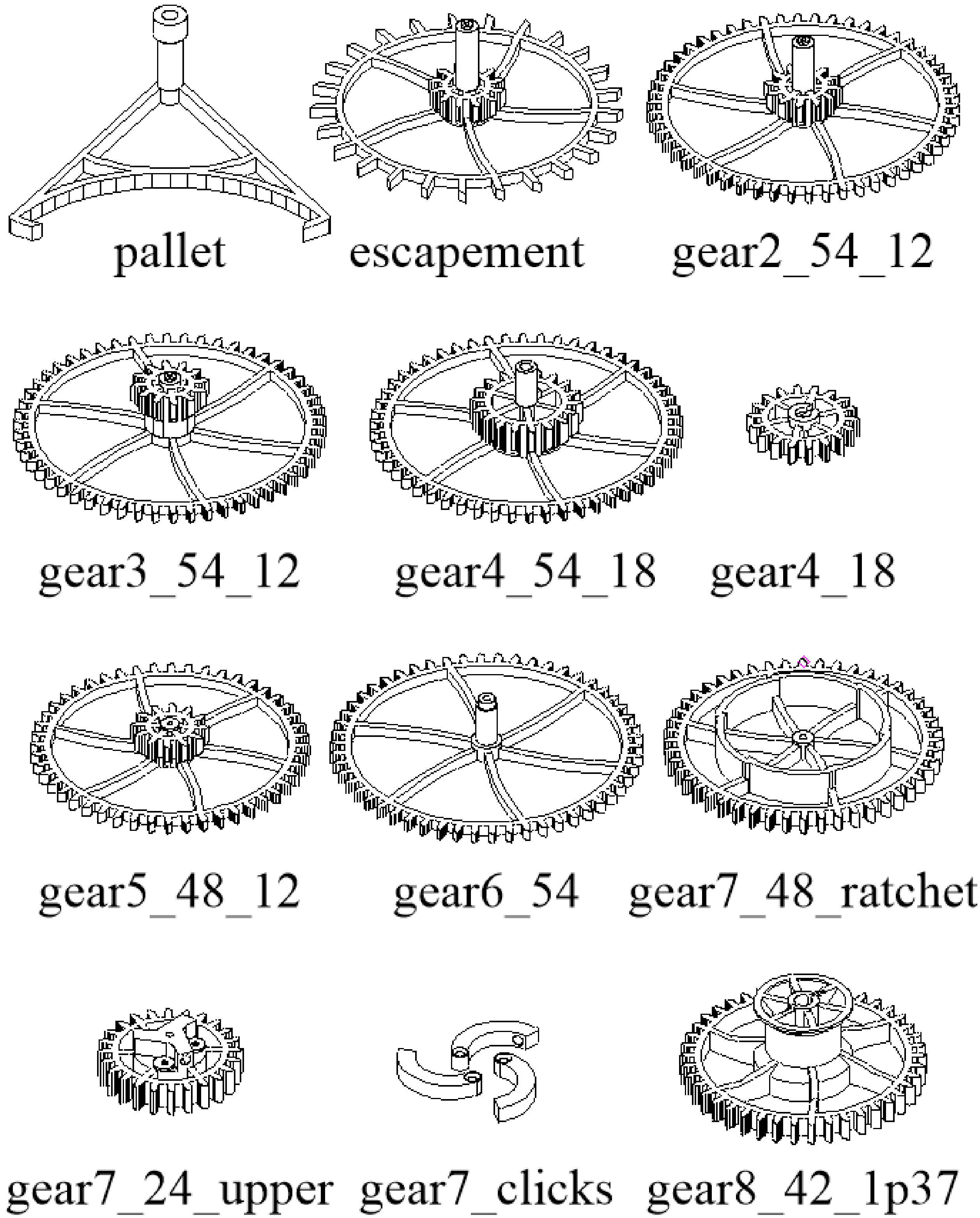

Figure 6 Gear reference chart

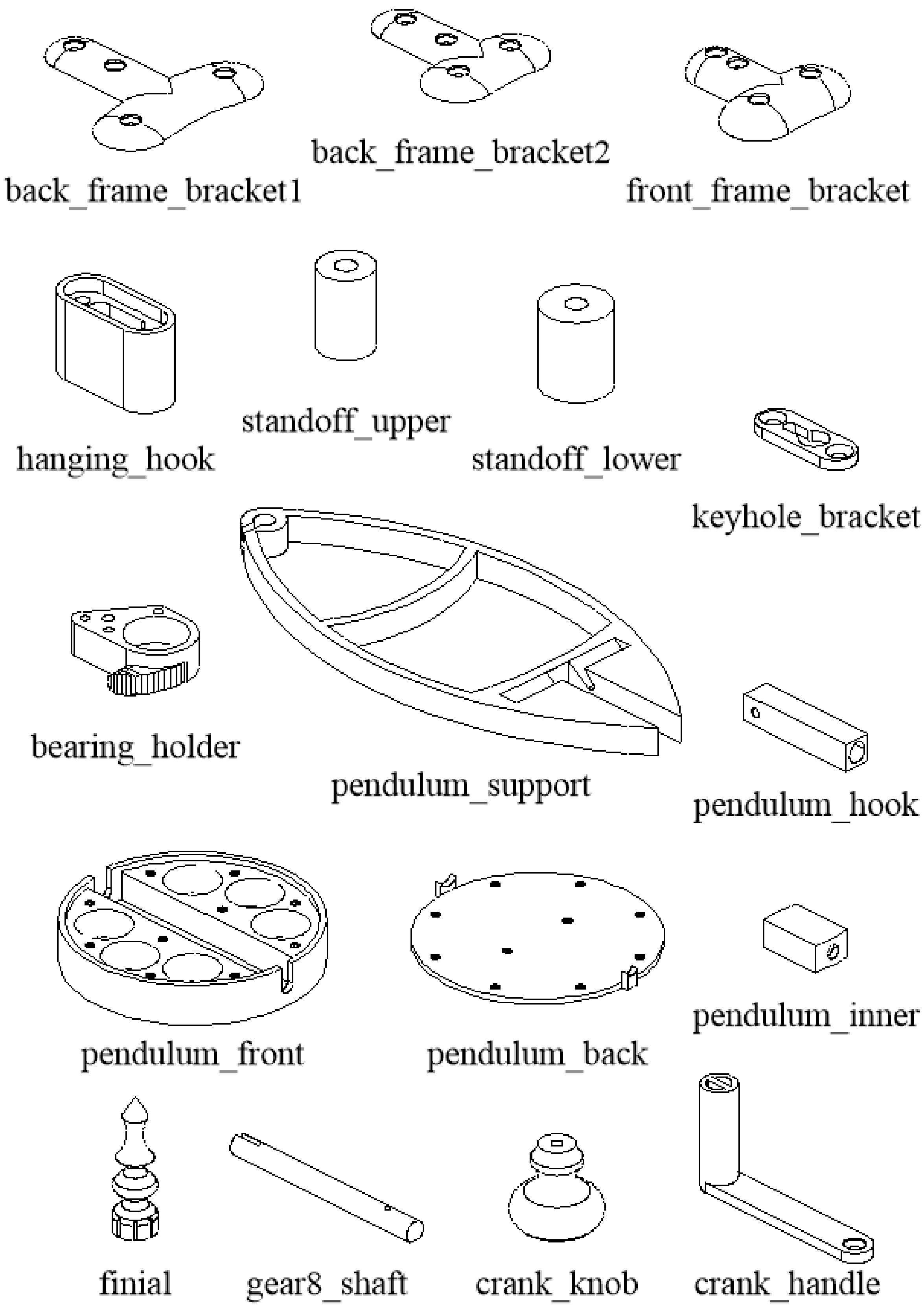

Figure 7 Additional parts reference

File Name	Metric, Imperial	Color	Print	Time	Filament	Notes
back_frame_upper	Yes	Tan	1	9h 48m	30.30	
back_frame_lower	yes	Tan	1	17h 34m	63.24	
back_frame_bracket1	yes	Tan	1	1h 5m	3.14	
back_frame_bracket2	yes	Tan	1	0h 51m	2.29	
hanging_hook	yes	Tan	1	2h 54m	6.82	
standoff_upper		Tan	1	1h 23m	2.77	
standoff_lower		Tan	2	1h 29m	3.86	
keyhole_hanger		Tan	0	0h 21m	0.64	See note 1
front_frame_upper	yes	Tan	1	4h 31m	13.69	
front_frame_lower	yes	Tan, Ivory, Black	1	15h 44m	60.27	
front_frame_bracket	yes	Tan	1	1h 23m	3.54	
bearing_holder	yes	Tan	1	1h 13m	3.05	
pallet		Gold	1	3h 25m	8.12	10 perimeters
escapement		Gold	1	3h 55m	9.78	
gear2_54_12		Gold	1	4h 13m	10.68	
gear3_54_12		Gold	1	4h 42m	12.10	
gear4_54_18	yes	Gold	1	5h 5m	13.79	
gear4_18	yes	Gold	1	1h 26m	3.75	
gear5_48_12		Gold	1	3h 36m	9.33	
gear6_54	yes	Gold	1	3h 8m	8.31	
gear7_48_ratchet	yes	Gold	1	5h 1m	15.17	
gear7_24_upper	yes	Gold	1	3h 36m	10.00	
gear7_clicks		Gold	3	0h 23m	1.06	
gear8_42_1p37		Gold	1	7h 35m	20.77	
gear8_shaft		Tan	0	0h 32m	1.50	See note 2
hands	yes	Black	1	1h 16m	2.26	10 perimeters
pendulum_support		Black or Tan	1	3h 51m	13.23	5 perimeters
pendulum_hook		Black or Tan	1	0h 30m	1.40	
pendulum_front		Gold	1	5h 52m	17.77	
pendulum_back		Gold	1	1h 7m	4.56	
pendulum_inner		Any	1	0h 31m	1.19	
finial		Black	1	1h 6m	1.38	
weight_shell_2p8		Gold	1	17h 52m	46.47	See note 3
weight_bottom_2p8		Gold	1	1h 32m	6.13	See note 3
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 34m	2.05	
misc_spacers	yes	Gold	1	3h 42m	7.07	
		Total	**41**	**148h 18m**	**448.54**	

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 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 filled weight shell should weigh around 8 pounds or 3.6 kg. There are several options to achieve the desired weight. The default is to use the 2.8" diameter shell filled with lead shot. The shell could be filled with less dense material if it was made larger in diameter or taller. STL files for a 3.2" diameter shell are included that weigh about 8.5 pounds when filled with BBs. The weight shell body is also provided in a split format to print in two pieces if your printer is not tall enough, although the normal version is 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_2p8 is the 2.8" full height weight shell, weight_shell_top_half_2p8 is the 2.8" diameter top half and weight_shell_bottom_quarter_3p2 is the 3.2" diameter quarter height bottom portion. Etc.

Print File Options

Several printed parts have multiple print 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
All Parts	metric	*_met	"_met" in the part name
	imperial	*_imp	"_imp" in the part name
Weight Shell	2.8" diameter	weight_*_2p8	Small diameter weight shell to be filled with lead shot
	3.2" diameter	weight_*_3p2	Large diameter weight shell for use when filled with lower density material such as BBs (or sand?)
Weight Shell	full height	weight_shell_2p8 (or _3p2)	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	misc_spacers	All the misc spacers in one file
	individual files	misc_spacer_0a (or _0b, _1, etc.)	Individual spacers
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 most important option is support for either metric or imperial sizes of the metal hardware. This is identified by file names with "_met" for metric or "_imp" for imperial sizes. Files without "_met" or "_imp" are common to both options. Obviously, you only need to print one copy. If you use metric sized metal hardware, then print the common files and the files with "_met" extensions.

The weight shell has many options depending on the printer size and material used to fill the shell. I have had the clock running with as little as 5 pounds, but the pendulum swing was small and the clock would stop if it was slightly out of beat. It becomes much more reliable with additional drive weight. The minimum recommended weight is 7 pounds (3.2kg) with a target of 8 pounds (3.6kg). 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 misc_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.

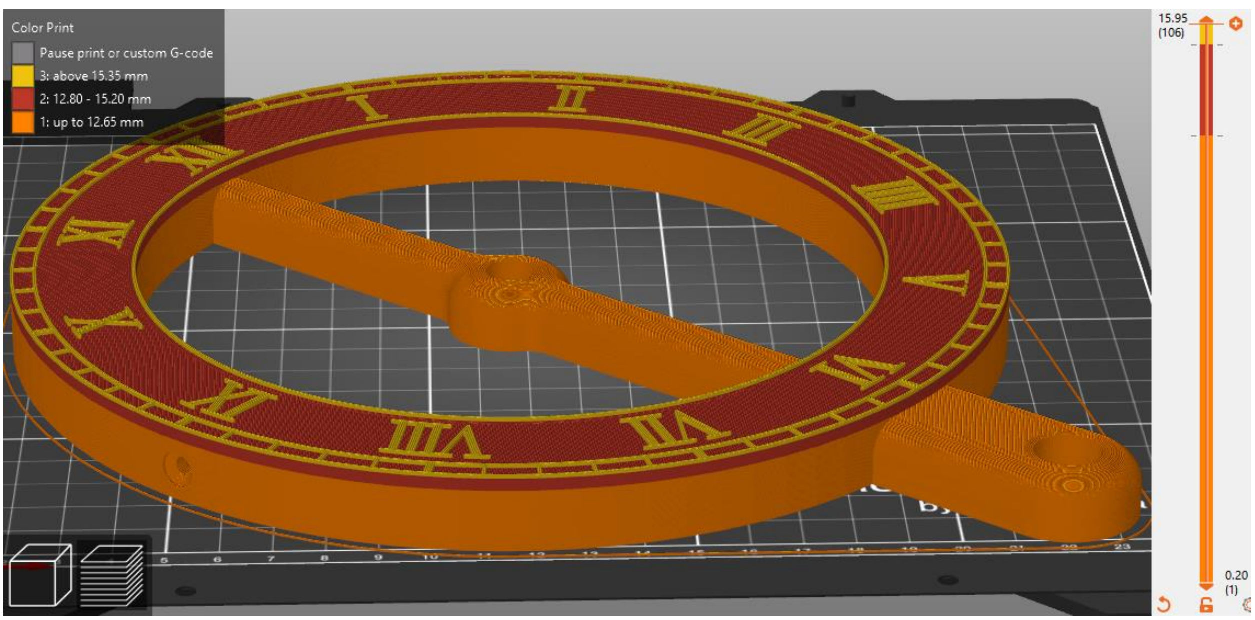

Figure 8 Layer changes for front frame

There are several options for the clock hands. I am still experimenting to find ones that look good with high visibility. Different designs can be added to the clock without having to take the clock apart. Some look best with a color change for some highlights.

The swing gauge is useful for determining the swing amplitude and also for balancing the escapement trip positions. It needs a color change at 1.40mm.

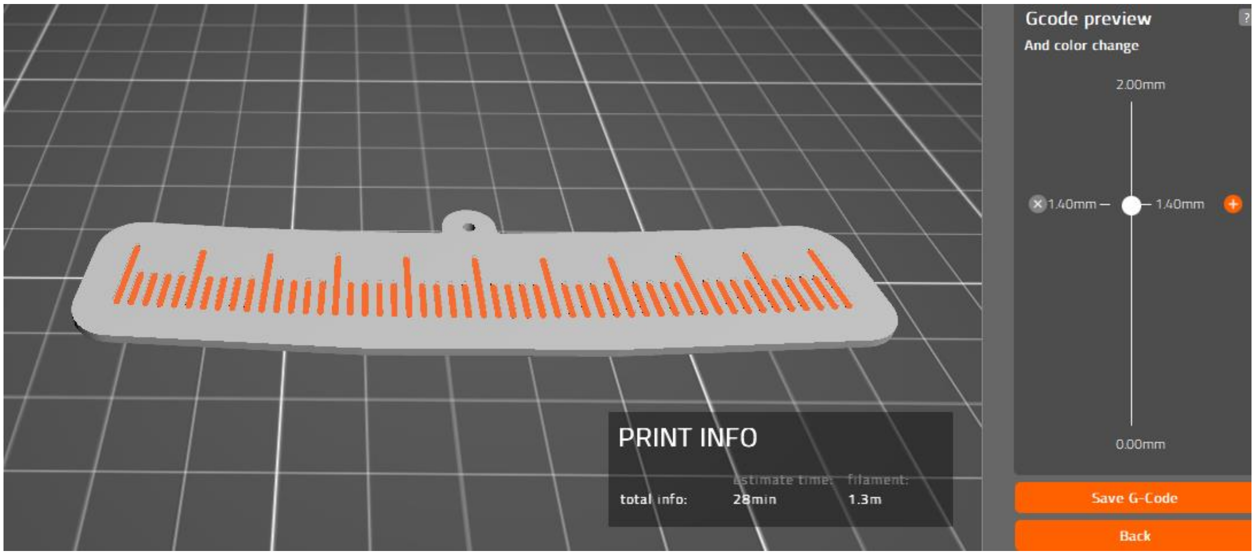

Figure 9 Swing gauge color highlights

The finial below the pendulum bob has a friction nut inserted to set the pendulum length and adjust the time. A friction nut is used to hold the position until you want to change it. It 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.

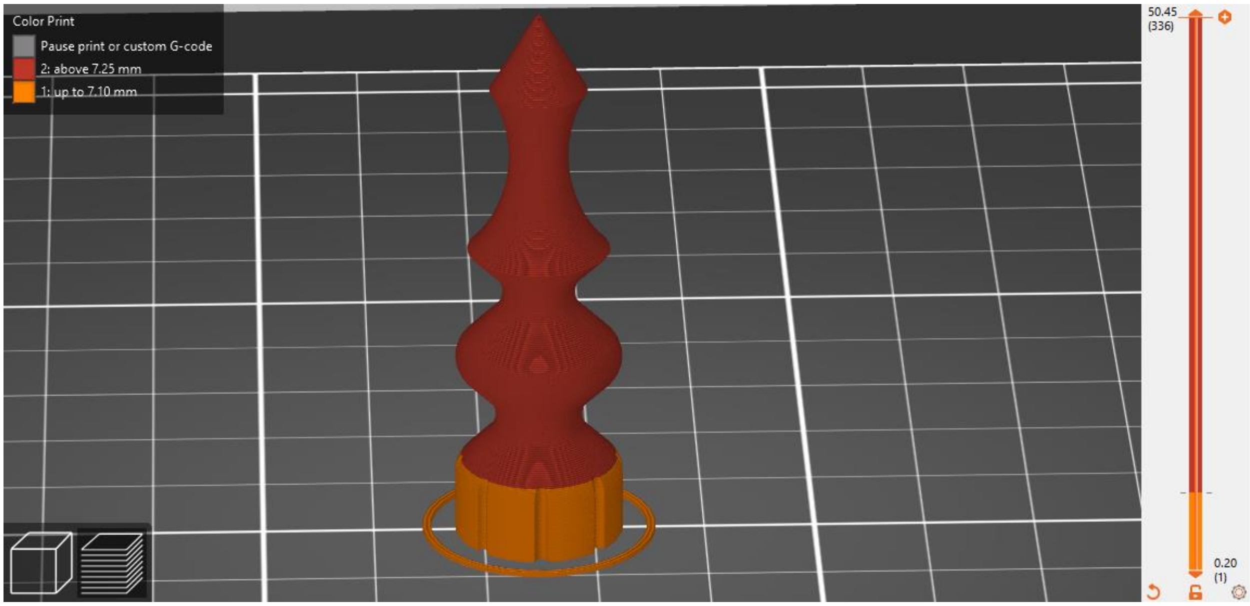

Figure 10 Pause finial at 6.95mm to insert nylon locknut

Some components are so small that they were grouped into a single file called misc_spacers_met (metric) or misc_spacers_imp (imperial). 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. They are grouped into a single file for easy printing and they also exist as separate files if you want to print them individually.

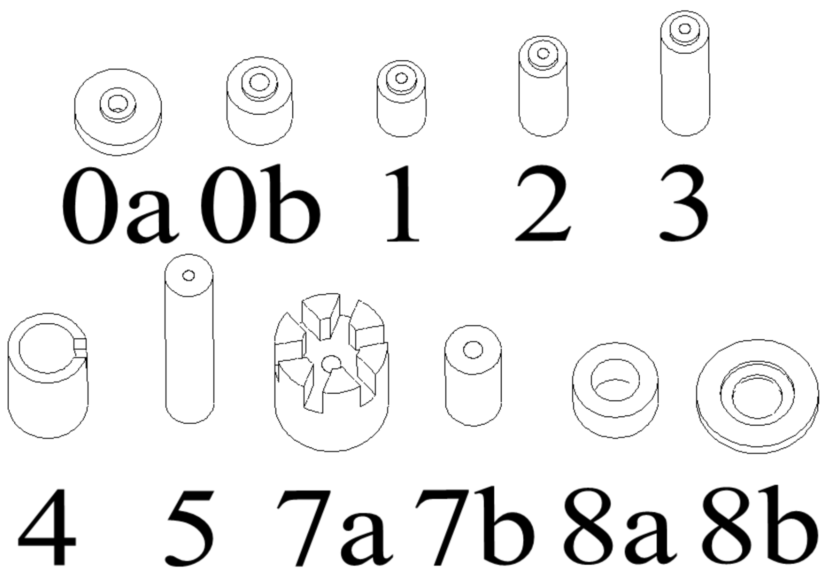

Figure 11 Misc_spacers

Additional Components

This clock is mostly 3D printed with a few hidden metal components to reduce friction at critical locations. A 100% 3D printed clock would have significantly shorter run times. Many of the 100% printed clock designs posted on the internet have run times as low as a few hours or minutes. Using some metal components allows this clock to become a useful timepiece. 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 supports both imperial and metric components for most parts. Sizes listed in this document are usually imperial (followed by the metric equivalent in parenthesis). Many parts can be substituted with the closest size of either type. 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.

Qty	Component Imperial or (metric) sizes	McMC Part No. (imperial)	Notes
23	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
36" (1m)	1/8” (3mm) stainless or brass rod	89535K16	See cut metal parts list
18" (0.5m)	1/16” (1.5mm) music wire	89085K85	See cut metal parts list
3" (75mm)	6-32 (4x0.7mm) threaded rod	90034A049	Can use a screw with the head cut off
19.5” (0.5m)	0.275” (7mm) carbon fiber tube		From an archery arrow, can use a wooden dowel as an alternative
1	6-32 (4x0.7mm) nylon insert locknut	90631A007	
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
8 lb. (3.6kg)	lead shot	9030K22	Can use ~11000 BBs with larger diameter weight shell
3	608 bearing	6153K111	Stainless or ceramic balls work best
2	R2 bearing 1/8x3/8x5/32 (623 bearing 3x10x4mm)	57155K349	ABEC 3 or better if available, open is best, rubber seals are OK
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. My first clock used short lengths of 1/8” stainless steel tubing to create bushings around the music wire arbors. The stainless steel tubing seemed to be difficult for many people to find, so I designed this clock with arbors running directly in PLA. Experiments show that this works good enough with considerably less effort than the stainless steel tubing. Friction increases slightly with a huge simplification during assembly.

Most of the descriptions in this document use imperial sizes. Both metric and imperial sizes are listed in the cut metal parts diagram to be used as a cross reference if you are using metric components. The lengths of most components are not super critical. Slightly shorter than the listed sizes are usually fine.

The 19.5” 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 1/8” 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 1/8” 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.

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 6-32 threaded rod is used at the bottom of 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 reduced so it fits into the carbon fiber tube is a good alternate source.

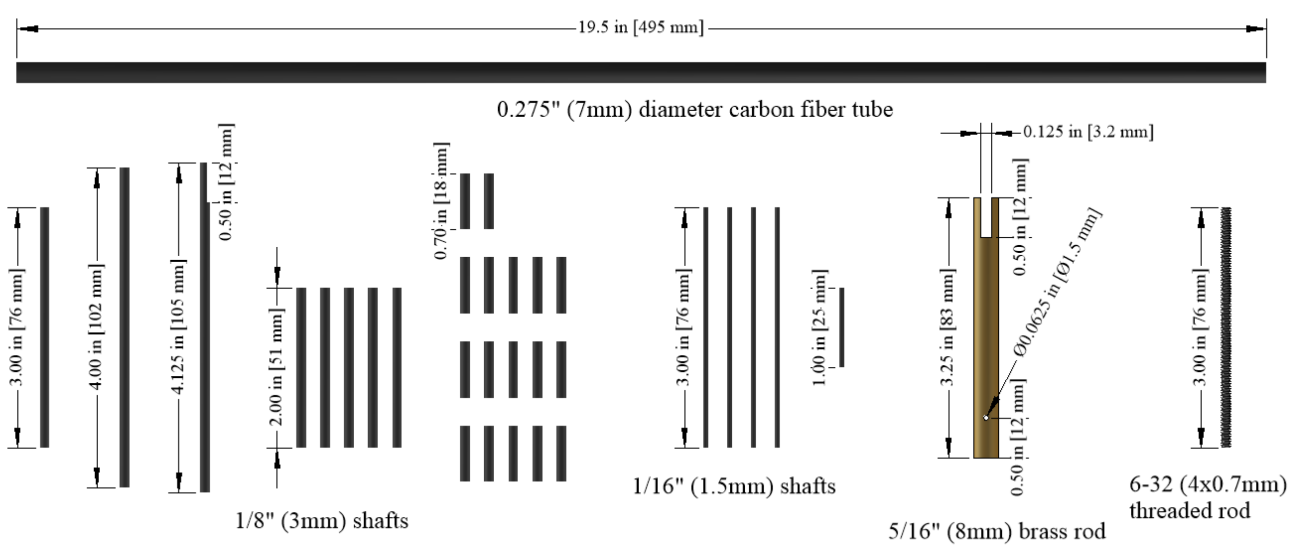

Figure 12 Cut metal parts

Additional parts needed are shown below. Threads are built directly in the plastic components, so the listed screw sizes are reasonably important. The bearings fit pre-printed pockets in the frame.

The 608 bearings are a very common size used in skateboard wheels. The smaller 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 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 too thick when wrapped 25 times around the winding drum.

The keyhole hanger is available at my 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.

In addition, glue is needed to attach the ends onto the pendulum shaft. Two part epoxy is preferrable, although other glues may also work.

Figure 13 Additional components

Back Frame

The clock frame is so large that it needs to be split into multiple components with brackets and screws to hold it together. Pins are used to keep everything aligned. The following descriptions use imperial sized components. Substitute the appropriate metric sized parts if needed. The assembly process is exactly the same.

Insert two 1/8" x 2" shafts into the alignment holes in back_frame_upper_imp (or_met) and back_frame_lower_imp (or _met). Press back_frame_bracket1 and back_frame_bracket2 into position over the six 3/4" alignment pins. The pins should be snug to properly align the frame. Add eight 6x3/4" wood screws to hold everything together.

The hanging_hook_imp (or _met) supports the entire weight of the clock so it was made fairly robust with four 3/4" 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. The standoff_upper goes near the top and the two standoff_lower's are near the bottom. Use 6x3/4" wood screws. These standoffs have no force, they simply hold the clock away from the wall.

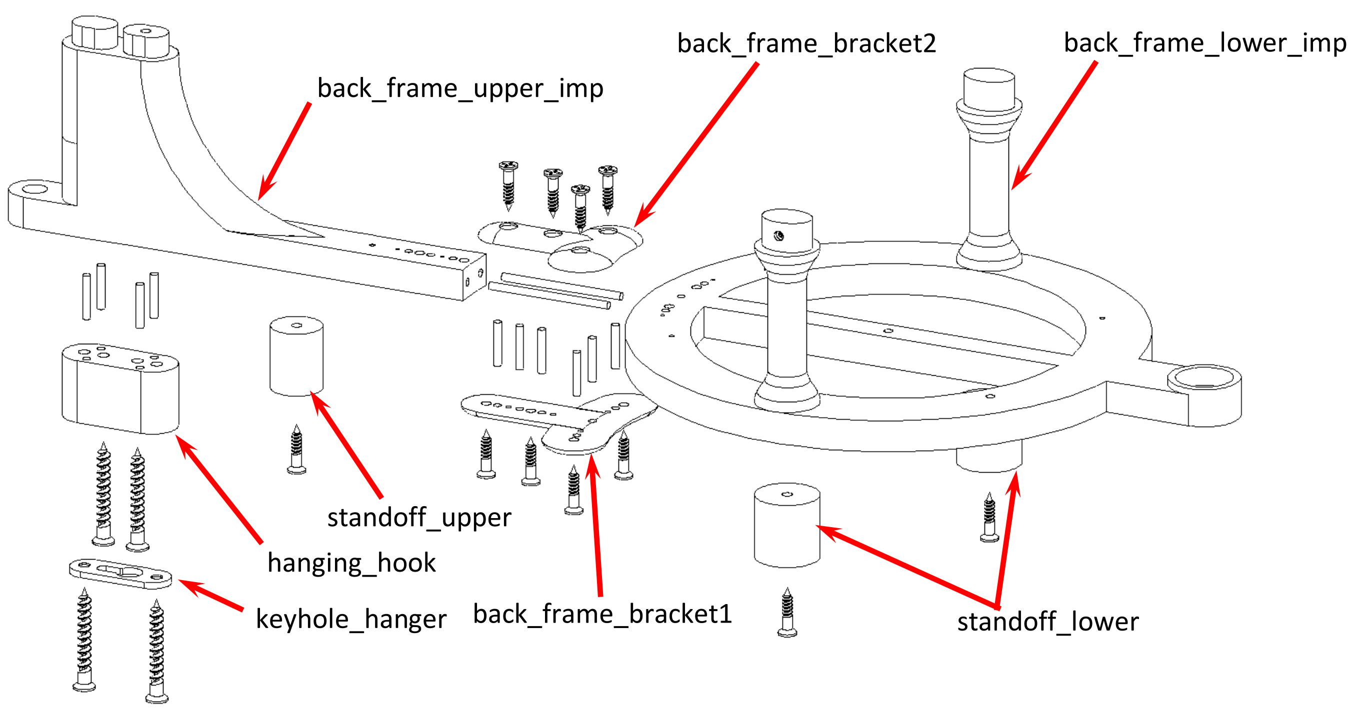

Figure 14 Back frame assembly

Front Frame

The front frame also gets assembled from components. Insert two 1/8" x 2" shafts into the alignment holes in front_frame_upper_imp (or _met) and front_frame_lower_imp (or _met). Add four 3/4" alignment pins and attach the front frame bracket using four 6x3/4" wood screws.

Place one of the 608 bearings and the misc_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 3/4" alignment pins and a 6x3/4" wood screw.

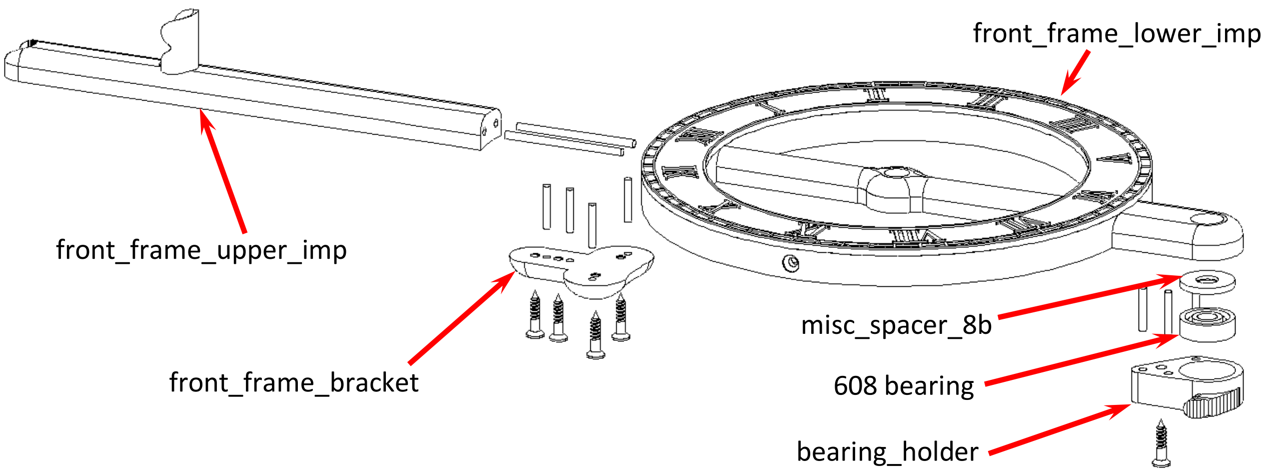

Figure 15 Front frame assembly

Attach the winding key knob to its handle with a 6x3/4" wood screw. Tighten the screw then back it off slightly so the knob spins freely.

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 three smaller standoffs should also be sitting flush with the wall. Add shims (washers) behind the lower standoffs if needed. Alternatively, scale the Z-height of the lower standoffs to get everything to sit perfectly flush against the wall. You should be able to pull down on the frame using around 10 pounds (4.5kg) of force with minimal deflection visible.

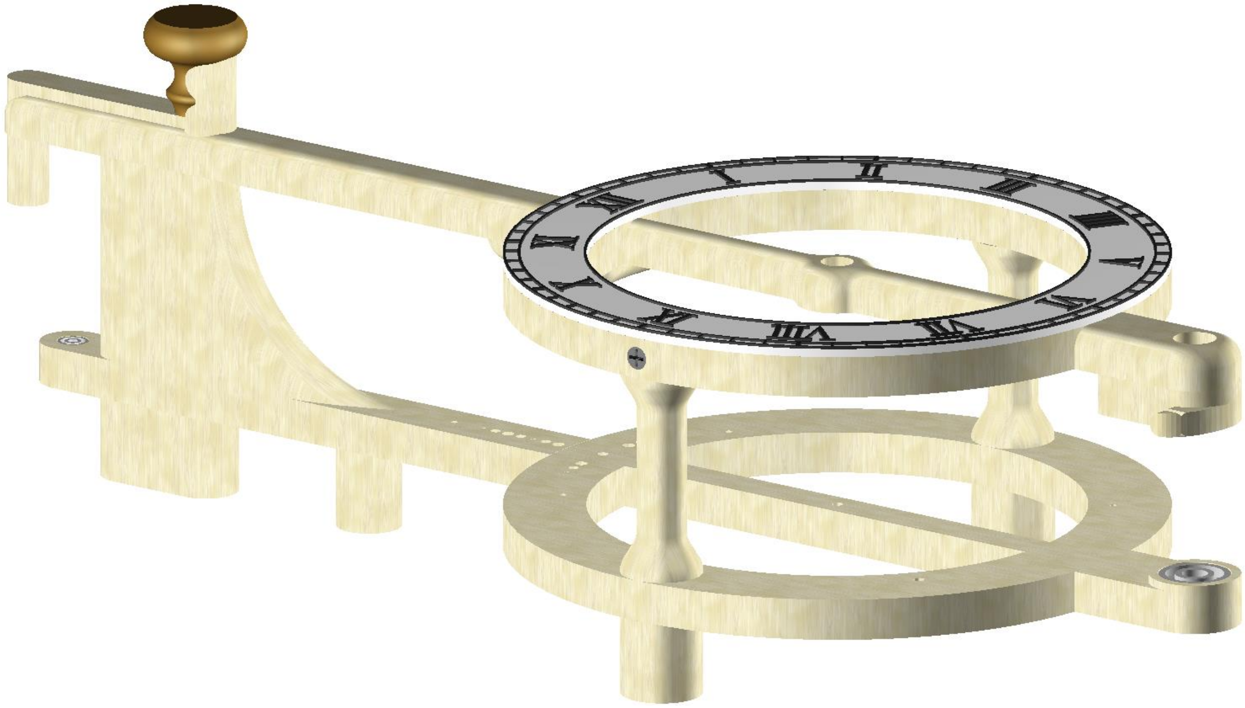

Figure 16 Completed Frame

Winding Drum and Ratchet

Slide the brass rod into the winding drum (gear 8_42_1p37) and push it into position with the 1/16" by 1" pin fitting into the slot. It is OK if it is a tight fit. This component never needs to be taken apart.

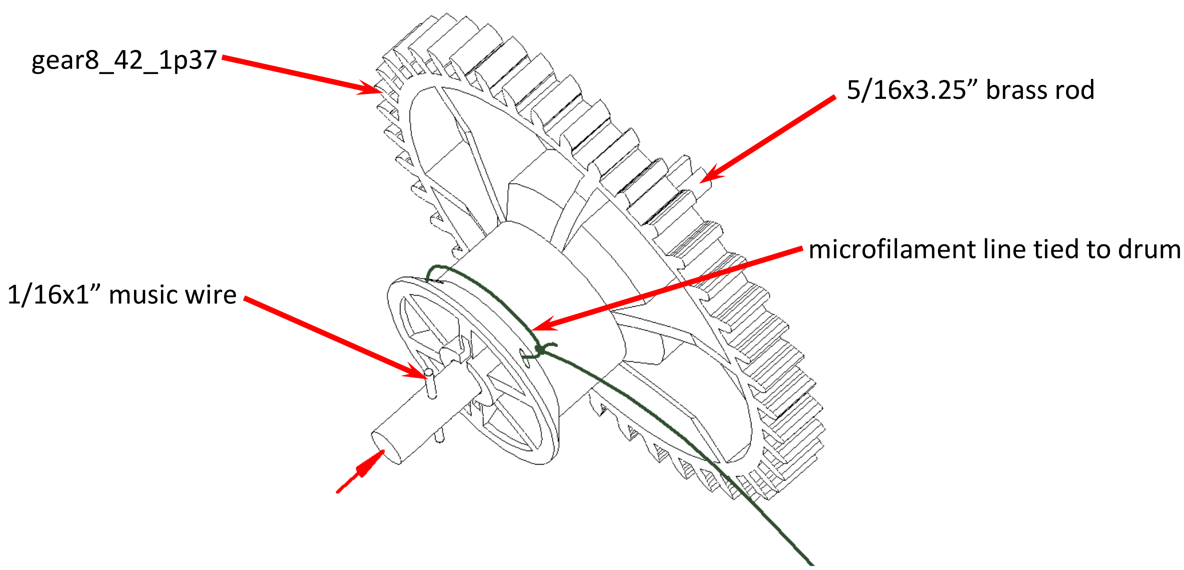

Figure 17 Winding drum assembly

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_clicks) 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 1/8x3” rod. Misc_spacer_7a 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.

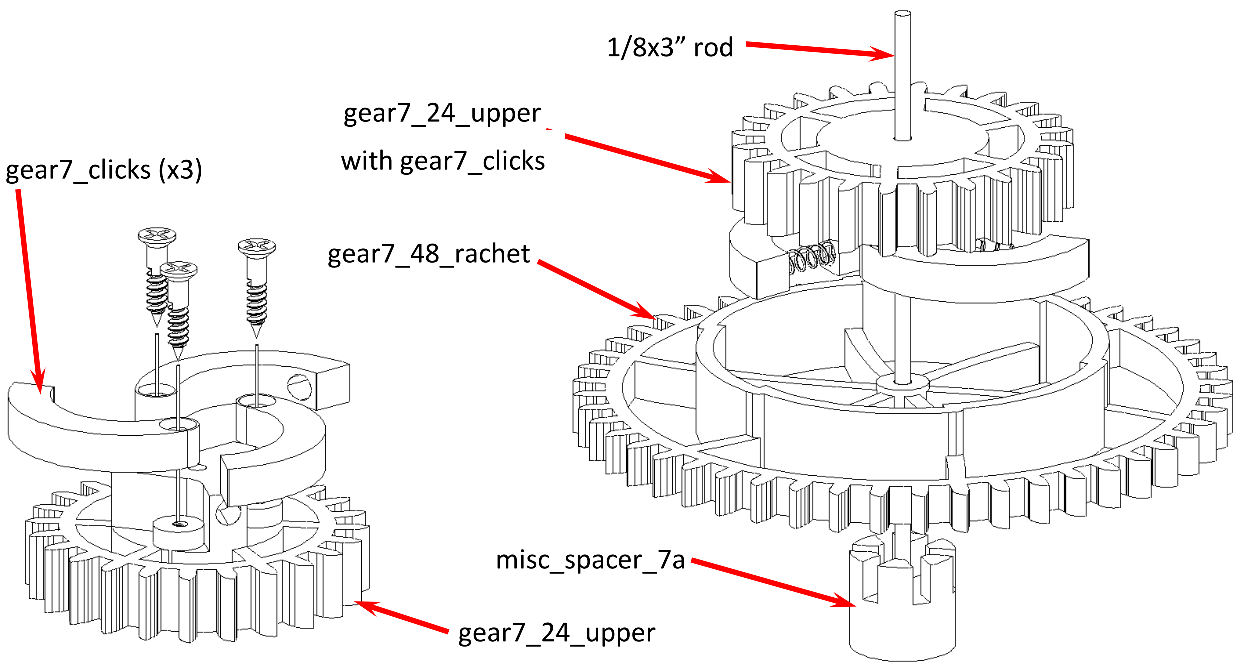

Figure 18 Ratchet assembly

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 2.25" from the lower end of the minute hand arbor. The top of the shaft collar is at 2.45". Gear4b_18 should slide over the shaft collar and set screw. Add misc_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 upper gear should rotate on the arbor with a small amount of resistance.

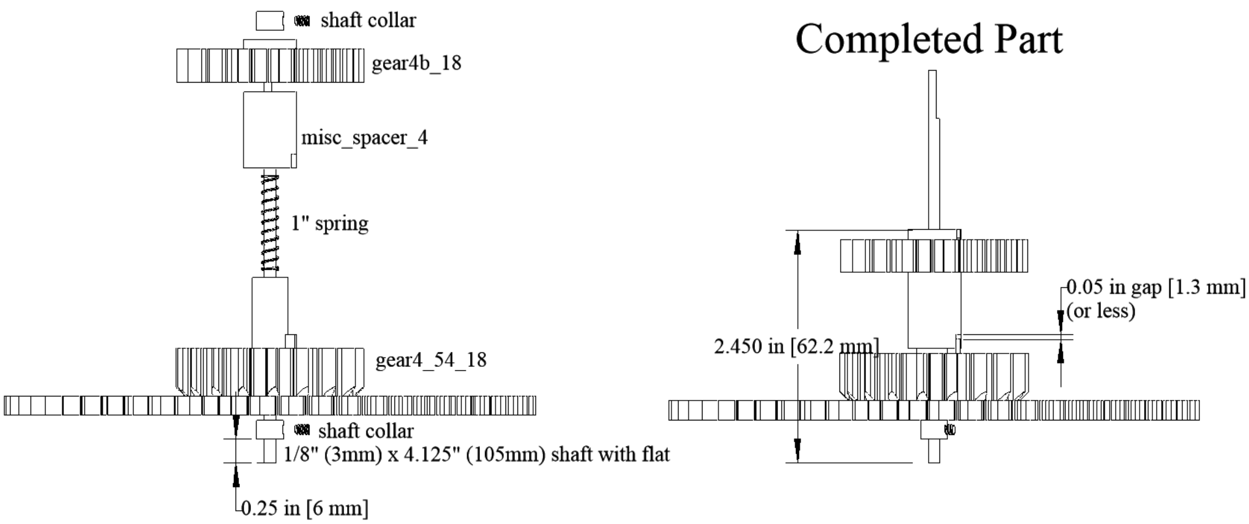

Figure 19 Minute hand assembly

Pendulum

The pendulum shaft is glued up from several components. The carbon fiber tube is cut to 19.5" in length and end pieces 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 1/8" by 2" rod is centered at the top end. 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.

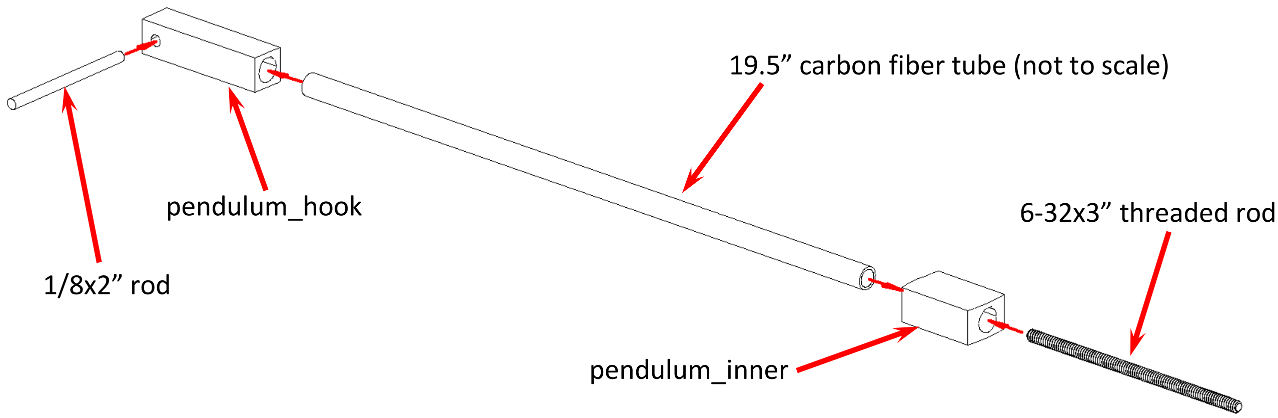

Figure 20 Pendulum shaft

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.

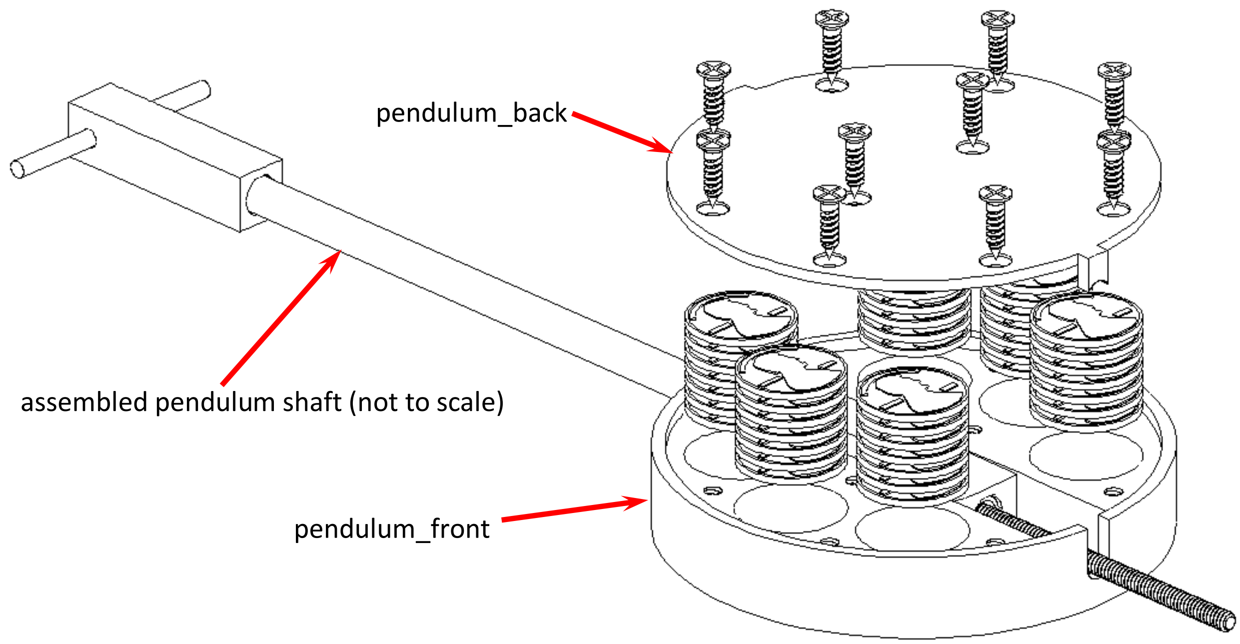

Figure 21 Pendulum bob

Add the finial to the end of the threaded rod. The final position will be determined later when adjusting the time.

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, misc_spacer_0a (with the narrow side down), and two shaft collars with set screws. Slide the pallet over the shaft collars. Add misc_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.

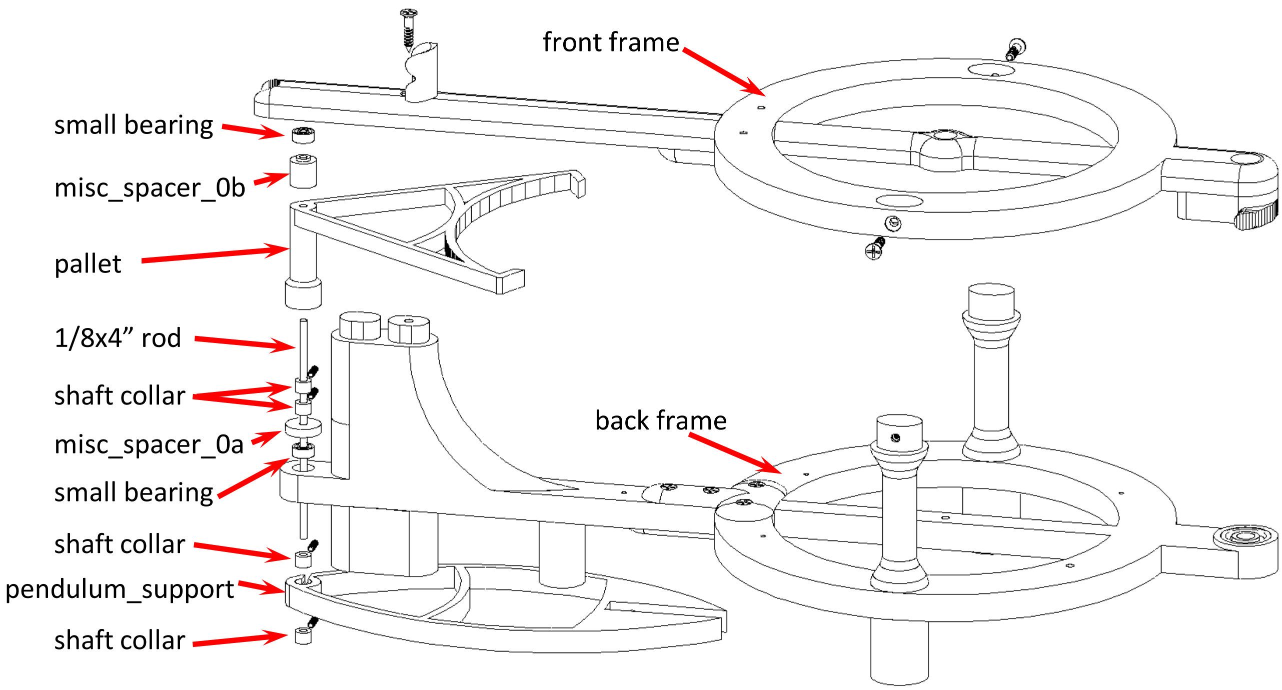

Figure 22 Pallet and pendulum support assembly

The completed assembly is shown below. The pallet straddles the large support rib and the pendulum support wraps around the upper standoffs. The pendulum support is centered within the gap behind the back frame.

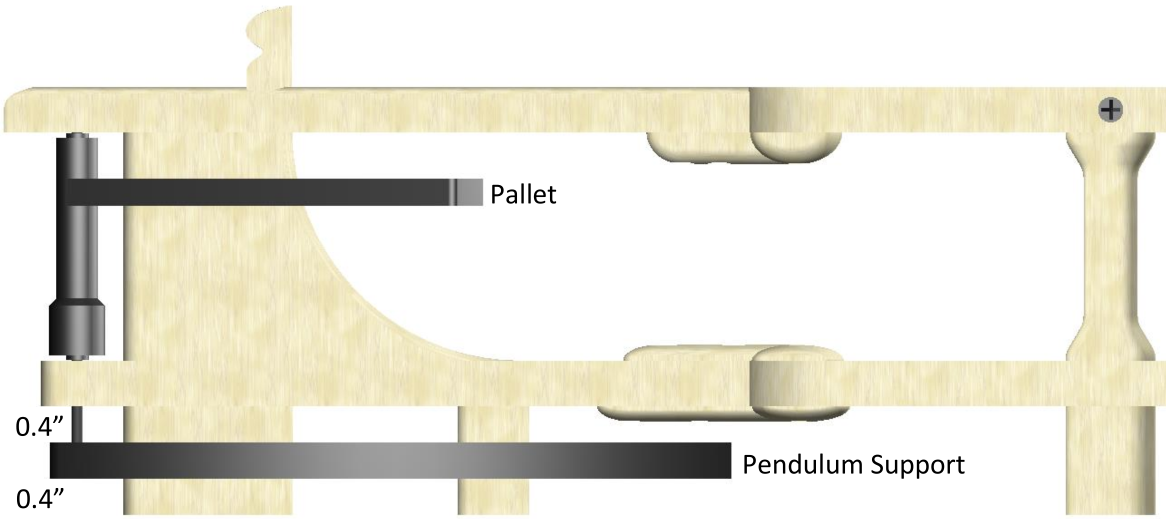

Figure 23 Pallet and pendulum support side profile

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 8 pounds (3.6kg) created using a 2.8” diameter shell by 7.6” tall. The clock might run using a smaller weight, but a slightly larger amount is more reliable. There are multiple files that can be used to create different size weight shells. The 2.8” shell needs to be filled with lead shot to hit the desired weight. The 3.2” shell can use lower density material such as BBs. It takes around 11000 BBs to fill the larger diameter shell.

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 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. The weight shell should weigh a bit over 8 pounds.

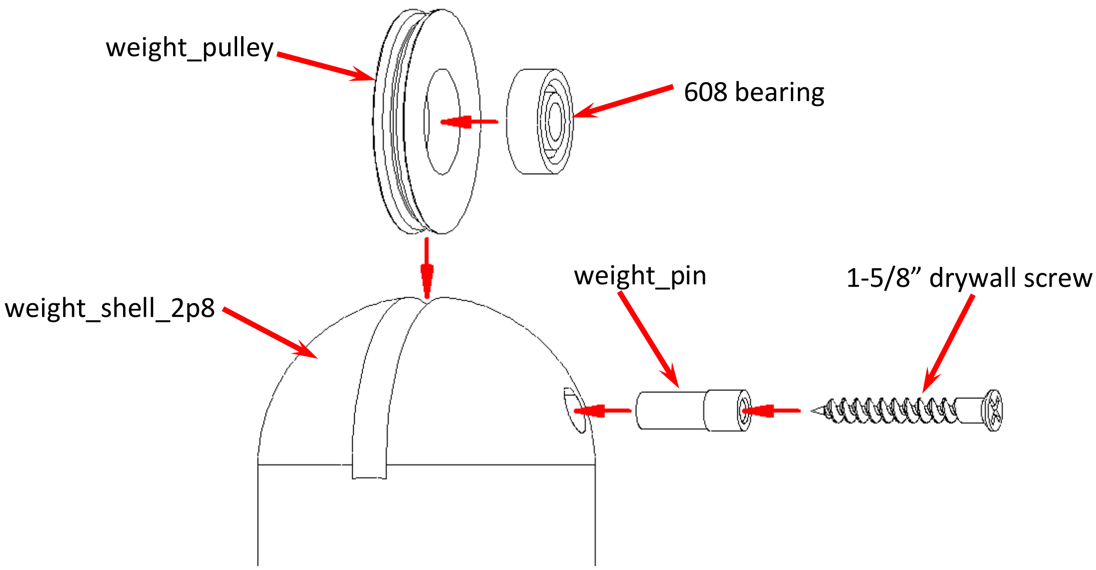

Figure 24 Top portion of weight shell

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.

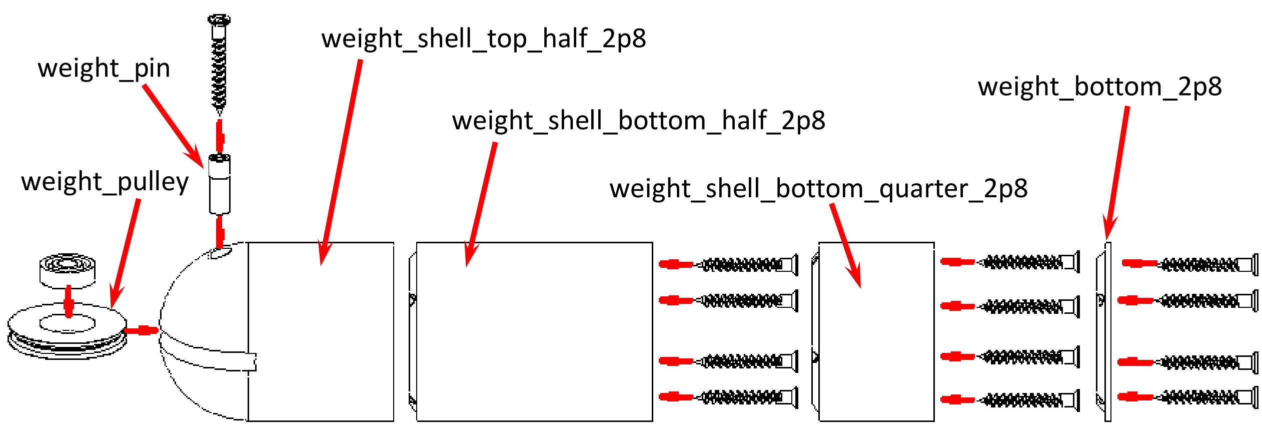

Figure 25 Split component weight shell

Building the Clock

Reducing friction is very important in a mechanical clock. This clock uses around 8 pounds of weight falling 46" every 4.2 days. The clock will tick 459270 times in 4.2 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.

Final Assembly

The rest of the clock can now be assembled. An assembly video will be posted to go along with these printed instructions.

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.

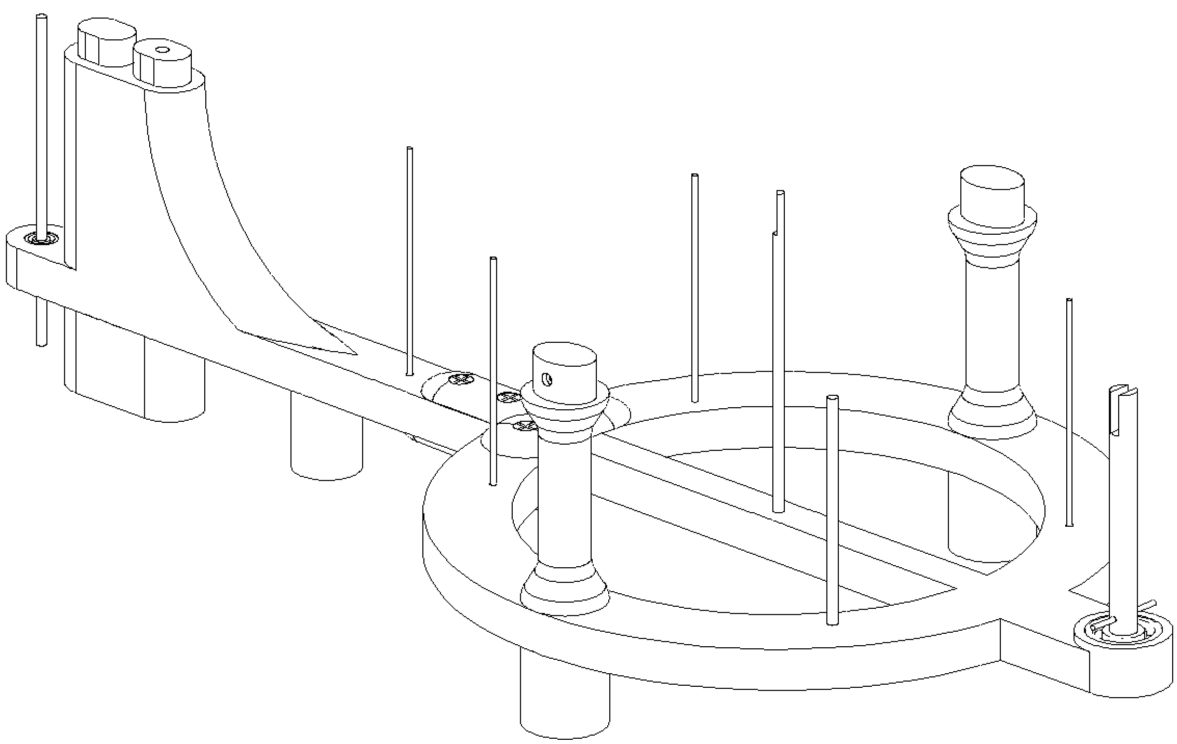

Figure 26 Back frame with arbors

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 misc_spacer_7b onto the gear 7 arbor.

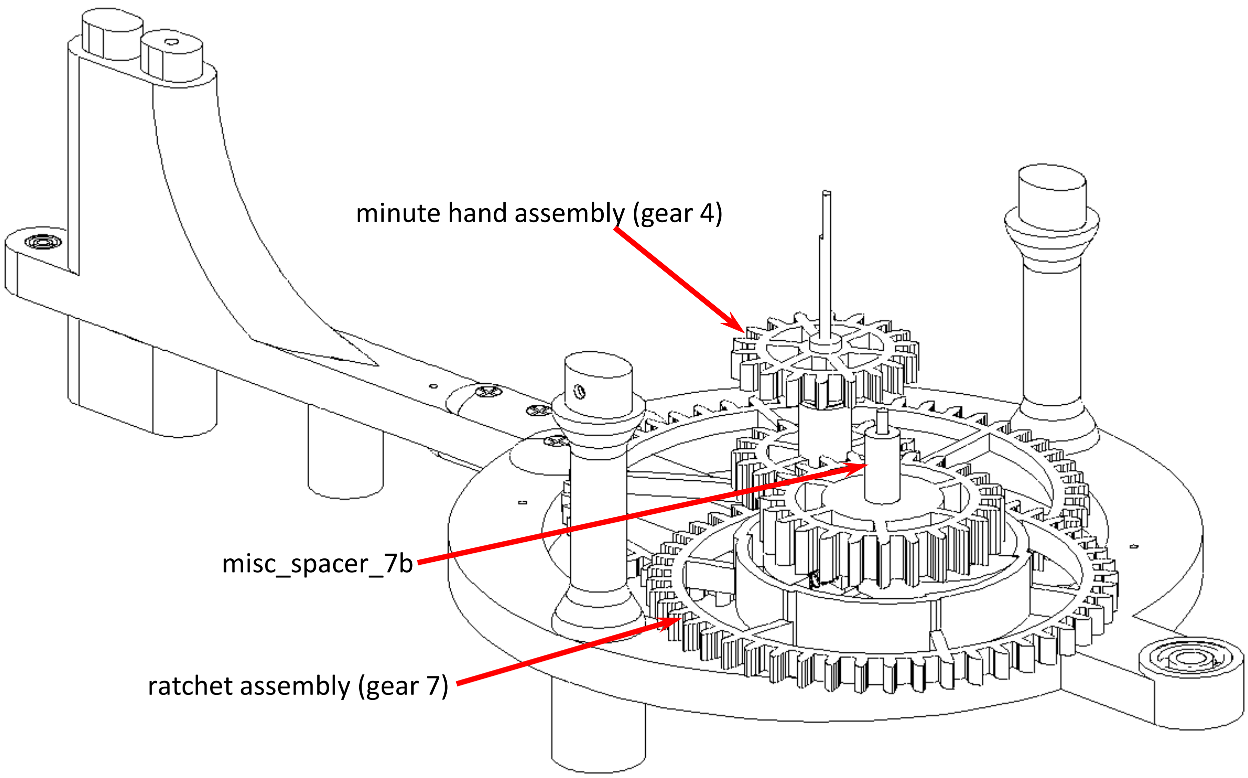

Figure 27 Gears 4 and 7

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 misc_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 misc_ 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 misc_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.

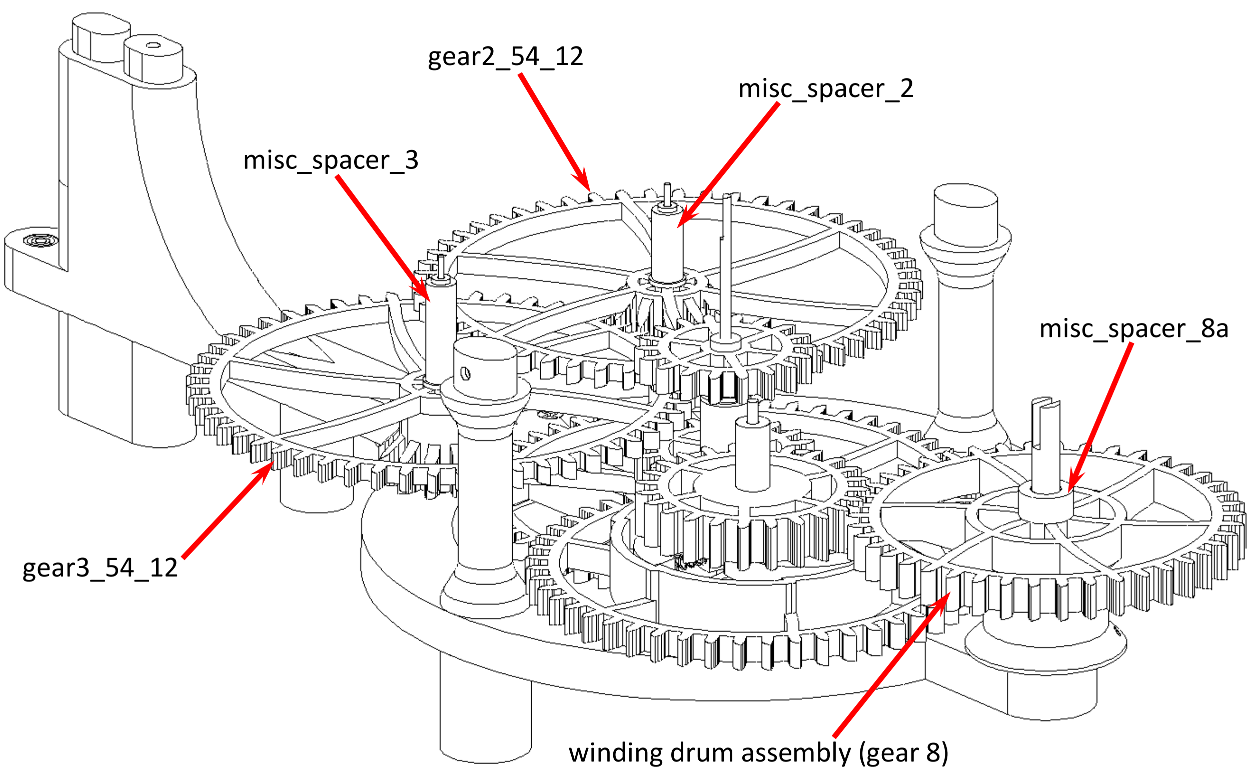

Figure 28 Gears 3, 2, and 8

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 misc_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.

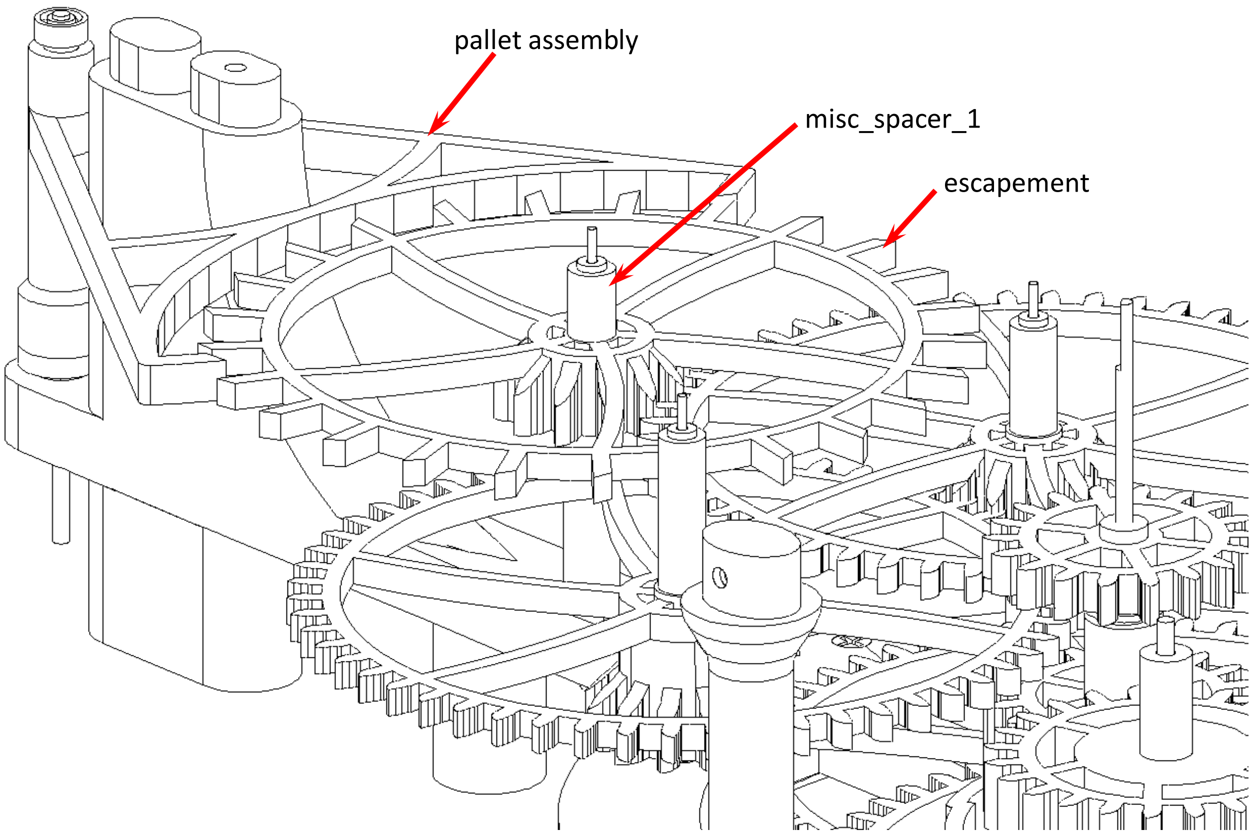

Figure 29 Pallet and escapement

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 misc_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.

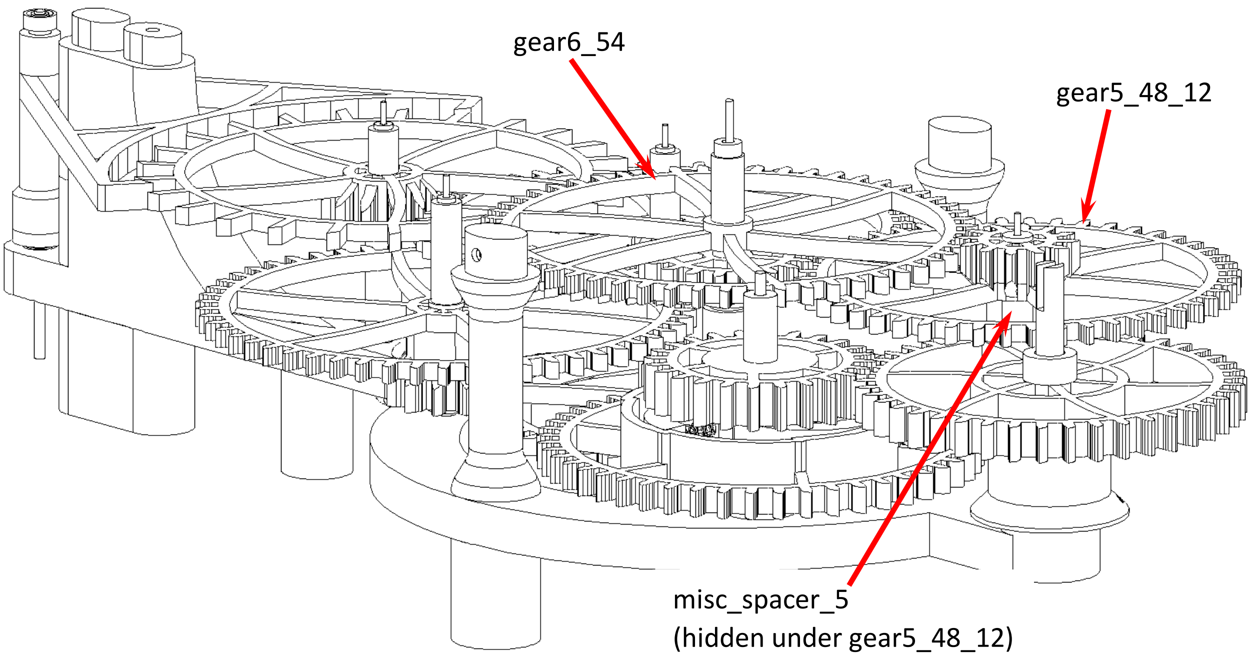

Figure 30 Gears 5 and 6

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.

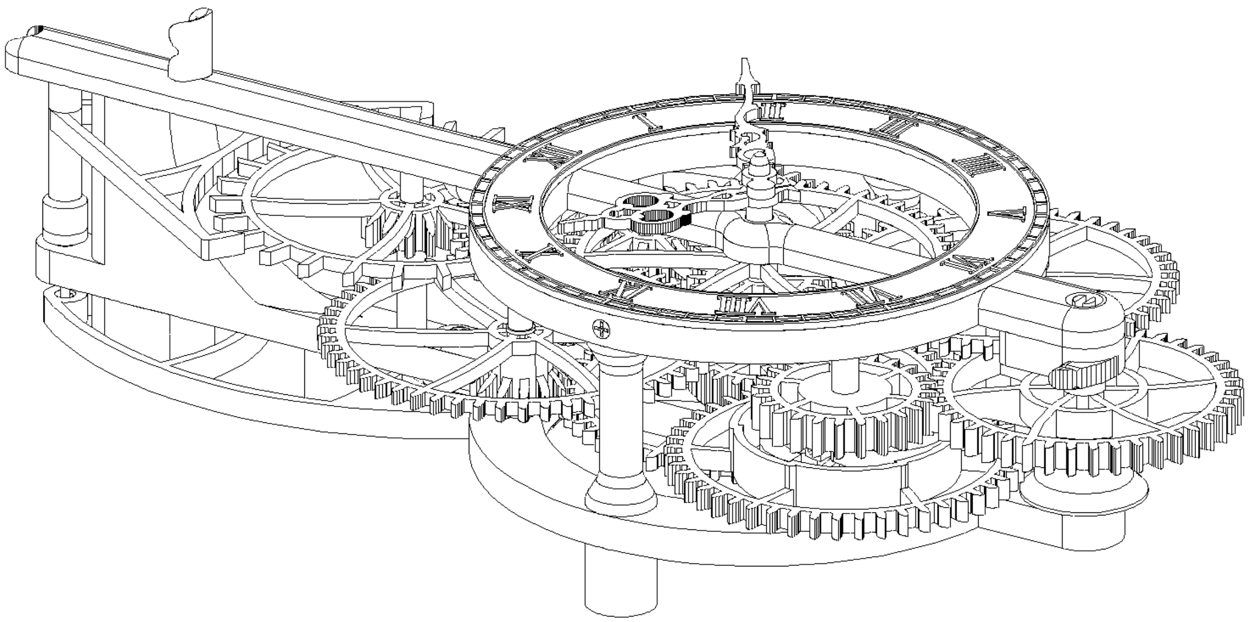

Figure 31 Assembled clock

Testing the Clock

Mounting the Clock

The clock mounts on the wall using a single screw driven into a wall stud. I use something around an 8x1-1/4" or a 10x1-1/2 pan head wood screw. Placing the screw 72" from the floor will give 46" of drop on the weights for more than 4 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 14 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 16-20 ounces for this experiment.

You can also remove the pallet and watch the gear movement with the small (~14 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 second 3D printed pendulum clock and by far my favorite. 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 current clock design. It needs a bit of fine tuning before it can be released. The second image is a rendering of the current design as it may look after porting to use wooden gears.

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