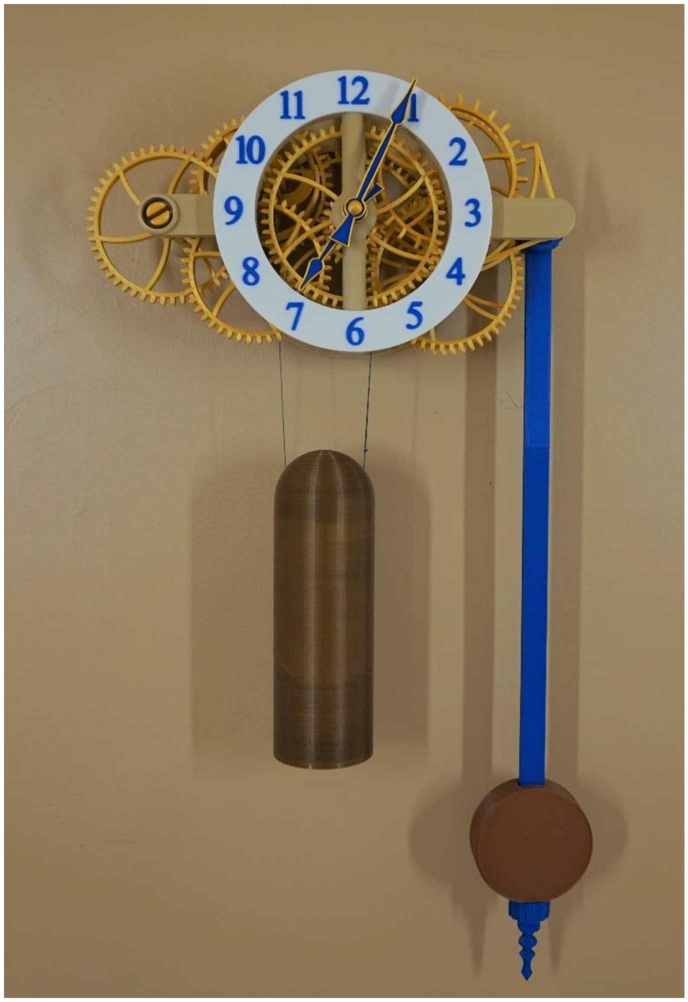

EASY BUILD SKELETON CLOCK

SP5 Assembly Notes

Instructions for building a medium size 3D printed skeleton clock
This design has been optimized for easy construction
Run time up to 32 days

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25-Feb-2021

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25-Feb-21 Original version

Description

This document describes the assembly of an easy to build 3D printed pendulum clock. The changes made to simplify construction also made it more efficient. This design is this the easiest of my clocks to build and it also has the longest runtime. This is a great starter clock.

The primary goal of all my designs is to create a functional clock that is also visually impressive. This clock is 11 inches wide with a 6 inch dial and fully exposed gears. Accuracy is within a few minutes per week. Three gear train options are provided with runtimes of 7.8 days, 10.1 days, 15.3 days, 21.3 days, and even as long as 32.2 days. A clock that only needs winding once a week is a very functional clock. Once every two weeks is even better. Once a month is incredible.

The secondary goal for this clock was to simplify the construction process. The use of non-printed parts has been minimized to just a few components, with a bill of materials that is half as complex as my other clocks.

The components are sized to print nicely on a Prusa Mini or any printer with a print area of at least 160x160mm. The light weight gears in this clock provide the longest runtimes with the best chance of creating a working clock. A larger version of this clock needs a printer the size of a Prusa MK3S (250x210) or Creality Ender3 (220x220). The heavier gears in the large clock result in shorter runtimes.

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.

This clock design started with the goal of reducing the number and types of non-printed components. It uses one size of ball bearings that are readily available worldwide. Two sizes of metal shafts and one screw size are used throughout the clock. The few additional parts include fishing line, BBs, springs from a ball point pen, and a few pennies for the pendulum bob. Everything else is 3D printed.

The gears in this clock are around 13.6 diametral pitch (13.6DP or MOD 1.86) which gives the largest 54 tooth gear a diameter of almost 4 inches.

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 always 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. These gears are designed so that the teeth, rim, and spokes are completely solid when printed using 4 perimeters in the large clock and 3 perimeters in this clock. The feature sizes were selected to print cleanly using a standard 0.4mm nozzle.

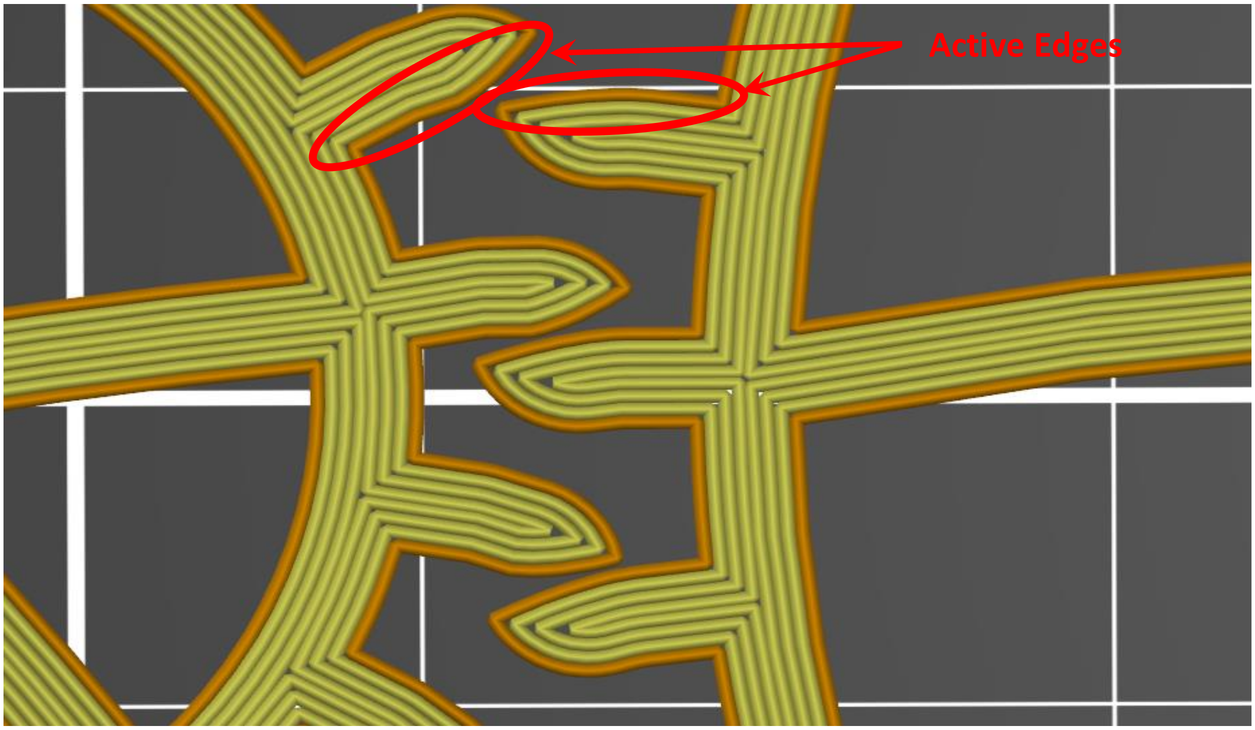

Figure 1 Sliced gears after optimization

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.

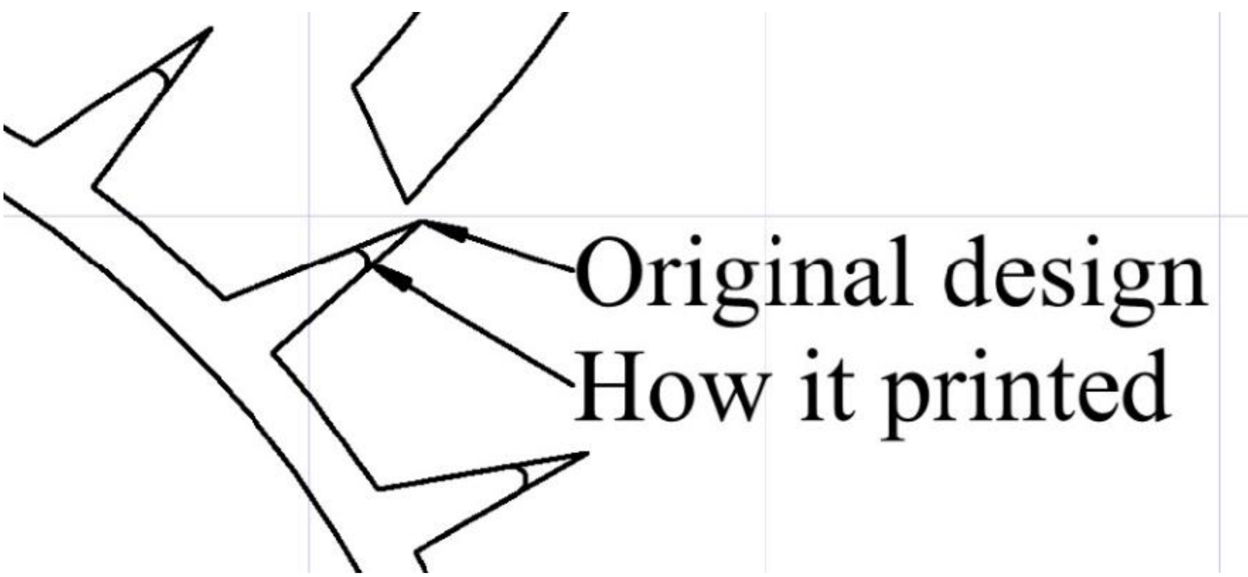

Figure 2 Traditional Deadbeat Escapement

The escapement teeth could be lengthened to compensate, but different printers would need different optimizations. The solution used in this clock is to widen the tips of the escapement 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 traditional 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 cleanly like the fancy gear tooth profile.

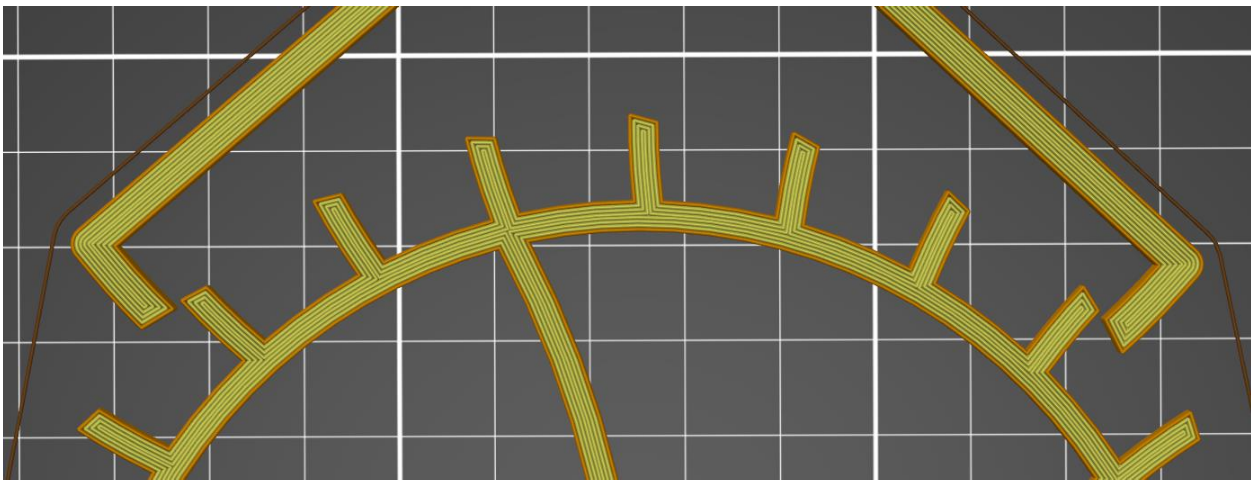

Figure 3 Escapement and pallet slicer output

Gear Ratios

Many traditional clock designs use small pinions with 6 or 8 teeth, but involute gears usually have less friction using pinions with 12 or more teeth. Low tooth count pinions have more rubbing during engagement. The large version of this clock uses 14 tooth pinions, but this clock functions very well with 10 tooth pinions. I suspect that the reduced gear size contributes to the 50% longer runtime even with the lower pinion tooth count.

A traditional grandfather clock would use 60 and 64 tooth gears with 8 tooth pinions. A 30 tooth escapement rotates once per minute with a 39” long pendulum. I am not a fan of 39” long pendulums in anything smaller than a grandfather clock, so an extra gear set was added to provide some flexibility in selecting gear ratios.

This clock uses a 26 tooth escapement with a 14.84” pendulum at 5850 beats per hour. The pendulum length of around 15” looks proportional to the rest of the clock so this helped determine gear ratios used in this clock. Gear ratios were selected to allow 5850 beats per hour to support the 15” pendulum.

Here are the gear ratios and the labels used in the assembly documentation. Some of the STL file names will make sense after looking at the diagram. For example, gear 3 is has 50 teeth on the large gear and 10 teeth on the integrated pinion. It may be called gear 3 or gear3_50_10. The longer name is more descriptive and you can count teeth to help determine if you have the correct gear.

Some of the gears have multiple components associated with a primary gear. The minute hand arbor includes a large gear (gear4_54_24_10day) along with a smaller secondary gear (gear4b_18) and some small spacers (spacer_4a and spacer_4b). The part names help to identify the arbor that they are associated with. The names might get shortened to gear4 and gear4b throughout this document.

There are a few different configurations for this clock. Gears can be swapped to increase the runtime from 10.1 days to 15.3 days. Gears can also be swapped to support a 7.8 day runtime for better reliability. 10.1 days is the initial recommendation, although it is perfectly fine to start with the 7.8 day runtime and wind your clock once per week. Most of the documentation assumes the 10.1 day runtime option. Assembly is the same for the 7.8 or 15.3 day options other than swapping a pair of gears. The longer runtime option may require a slight increase in drive weight.

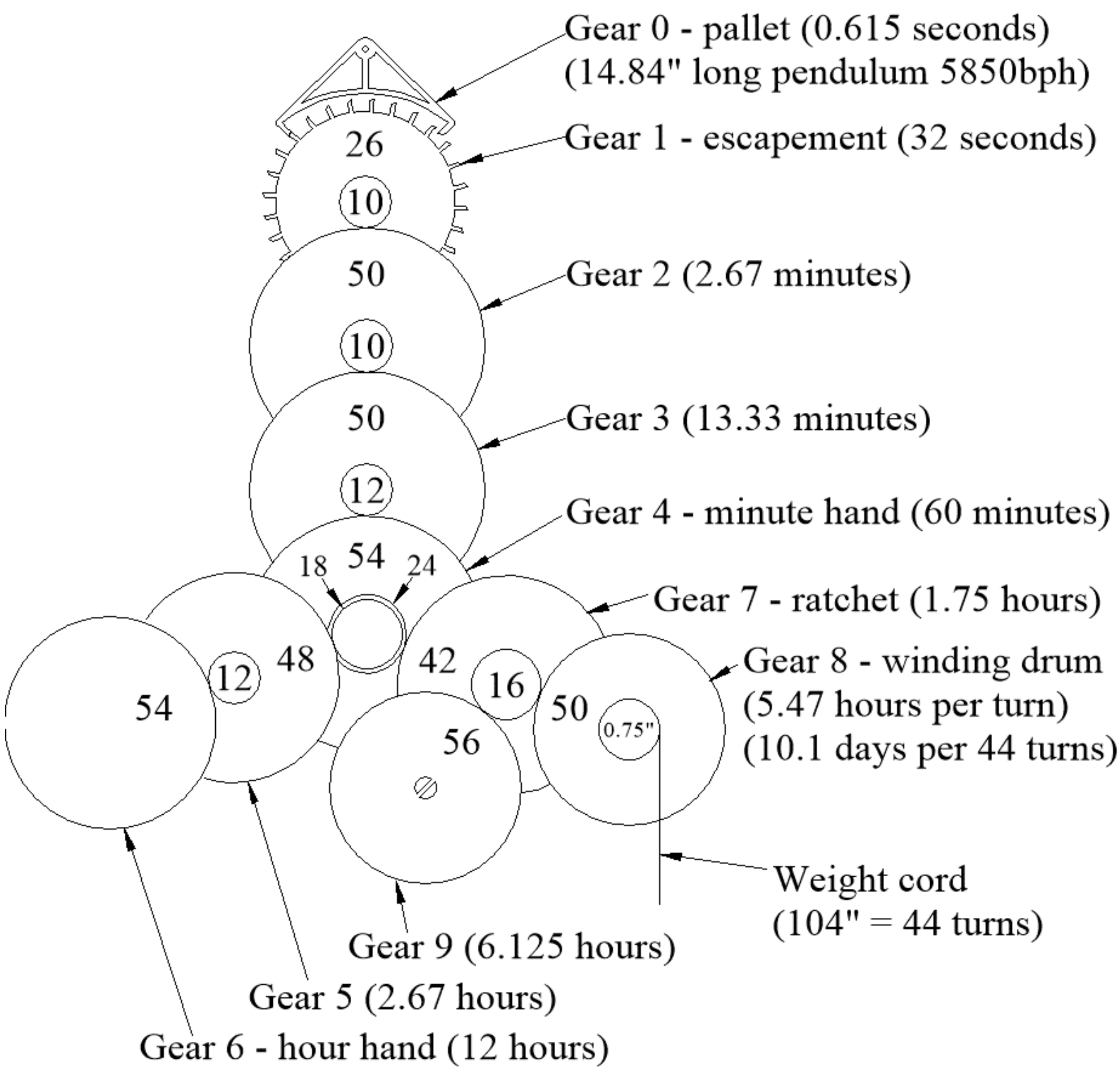

Figure 4 Clock gear ratios for the 10.4 day runtime option

The gear train in this clock has been modified relative to the large version of this clock. Different tooth counts are used even though the overall gear ratios are relatively similar. This clock uses 10 tooth pinions and the large clock uses 14 tooth pinions.

Gear 9 is a new addition to allow winding the clock without adding extra friction of a large diameter loaded shaft passing through the frame. Gear 9 is unloaded during normal operation, so the large diameter shaft has minimal impact to runtime.

Another significant change in this clock is a shift to a horizontal orientation. This allows the pendulum to attach directly onto the pallet shaft. Friction is reduced by spreading the load equally between the bearings and the connection to the pallet is very solid. Runtime is improved compared to my other clocks using similar weights.

The following diagrams show multiple orientations of the clock with the gears labeled as much as possible. Many of the diagrams are reused from the large clock documentation. The topology is very similar, but the gears may have a different number of teeth. Another note is that the component thicknesses are the same, so the arbor lengths are the same in both versions of the clock.

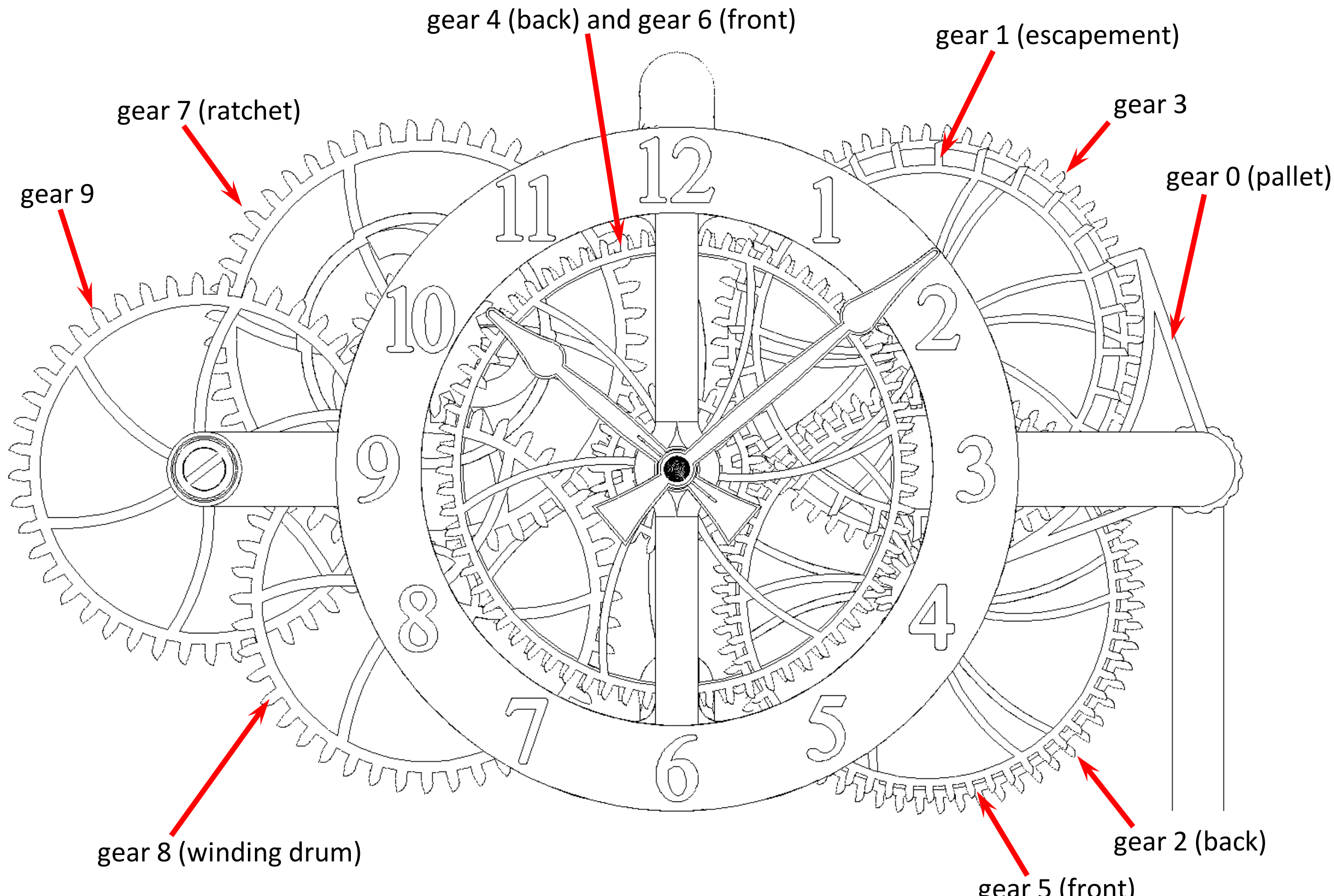

Figure 5 Clock layout front view

Another view from the lower left side

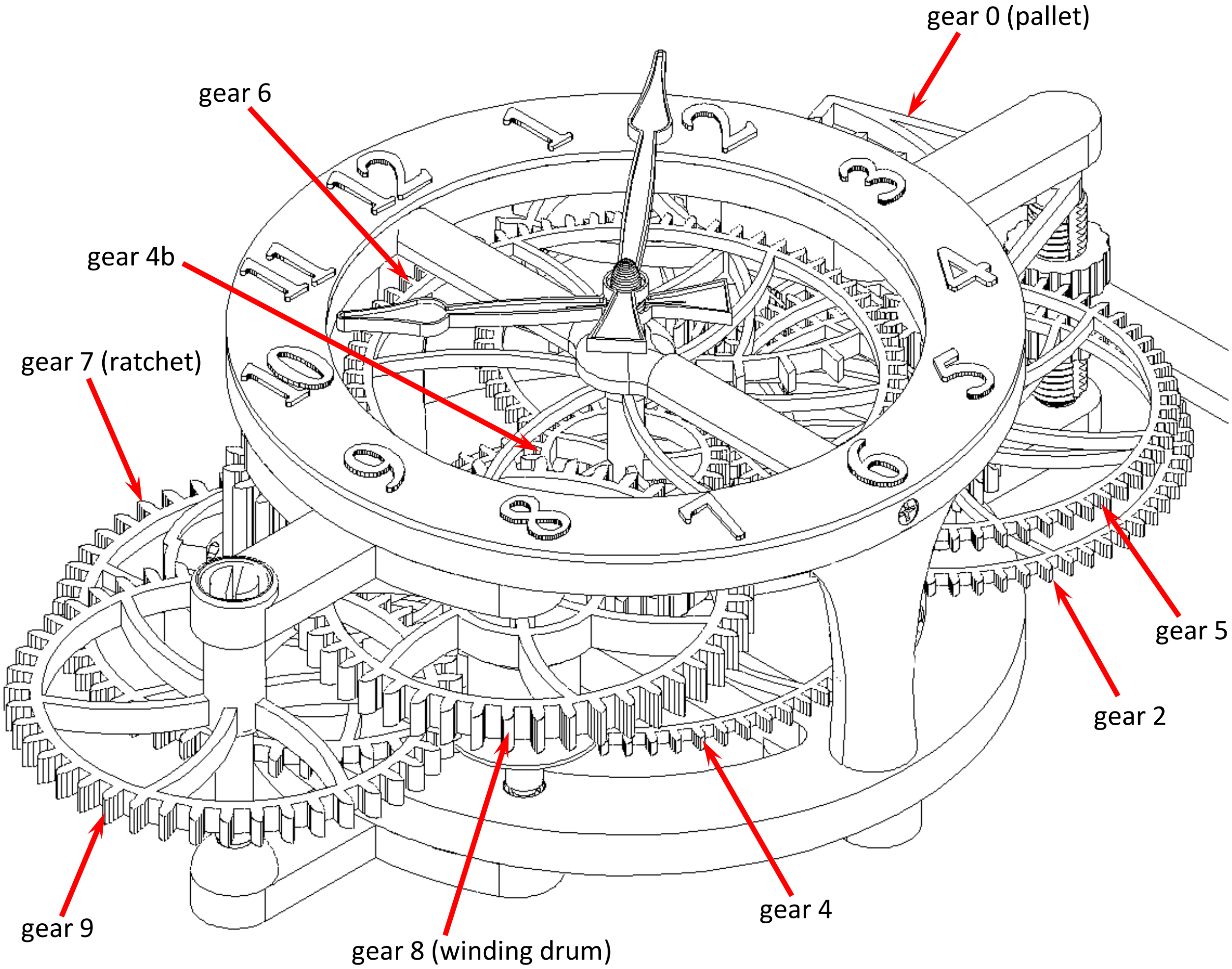

Figure 6 Clock layout lower left view

And the view from the lower right side

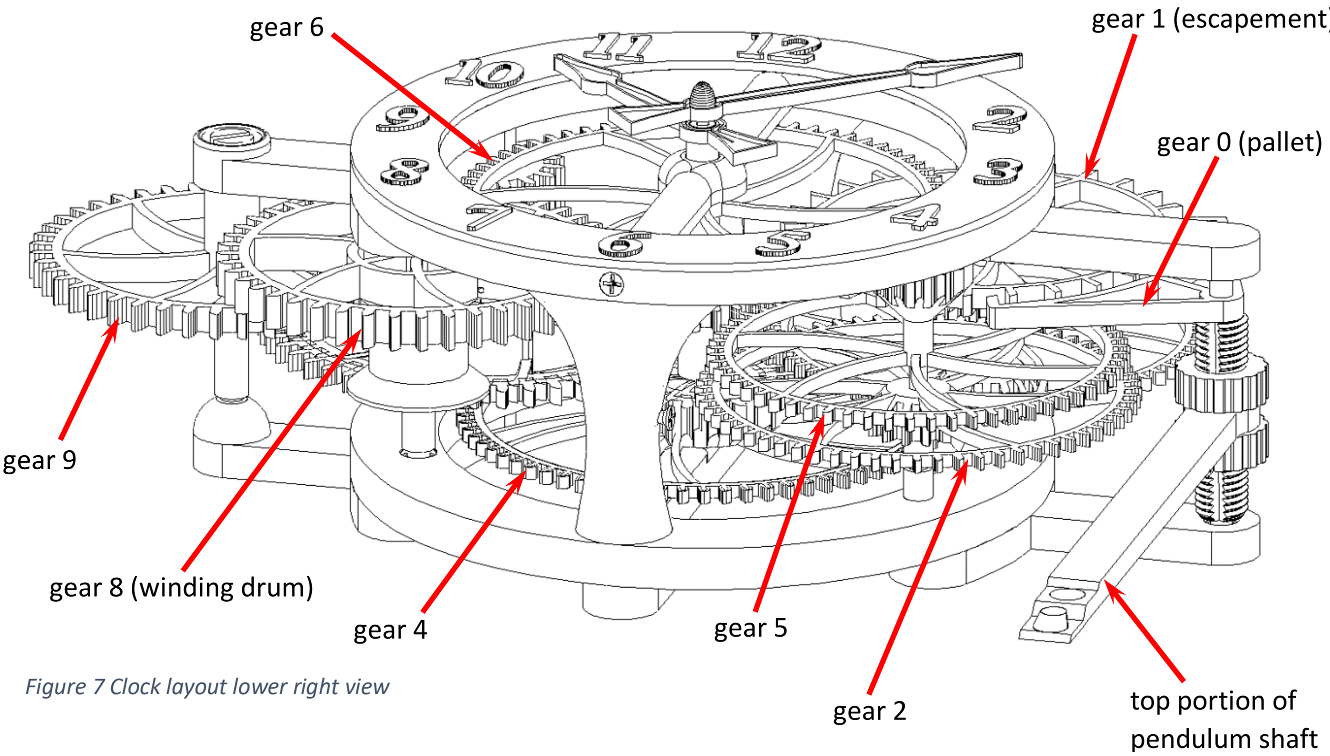

Figure 7 Clock layout lower right view

Printing the Parts

Print all parts using 4 perimeters. As described previously, the gears print very cleanly with the teeth, rim, and spokes formed as solid objects with 3 perimeters, although the hubs are designed for 4 perimeters. The frame becomes stronger when printed with 4 perimeters compared to the default of 2 perimeters, so just set perimeters to 4 and keep it there.

The gears seem to print best using 0.15mm layer heights with 4 perimeters. Make sure to set some elephant foot compensation if your printer needs it.

Most of the remaining parts have looser tolerances and can be printed using 0.2mm layer heights. Keep perimeters set to 4 so the frame has good strength. 30% cubic infill is my default with 6 bottom layers and 7 top layers to provide extra strength for the frame parts. This may be overkill, but it only adds a slight amount of extra print time so I keep using these values.

Other settings include random seam positions to minimize stripes on parts like the weight shell. 0.12mm elephant foot compensation helps keep the gears meshing properly. Prusa Slicer 2.3 added monotonic top and bottom layers that creates nice looking surfaces. I tried ironing, but didn't see enough improvement to justify the additional time. I accidentally ironed the gears once and ended up with elephant foot on the top of the gears. I normally just leave ironing turned off.

The total print time is around 83 hours using 0.15mm and 0.2mm layer heights. This may seem like a lot of time, but you will be creating a work of art that will last for many years. Most parts print flat on the build plate in the default orientation. A few parts might need to be rotated to fit your specific print bed shape.

Supports are never required in any of my clock designs. The large dome at the top of the weight shell forms its own supports as needed. Pinions are formed on the hubs of larger gears using 45 degree angled edges to print without needing supports.

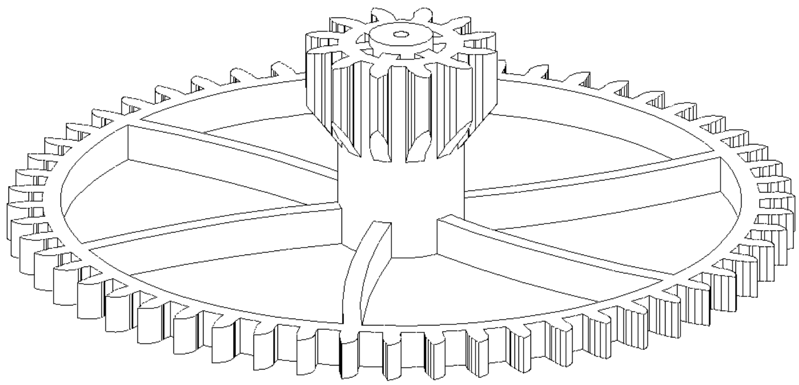

Figure 8 Gear profile example

The center portion of the frame is the largest component of the clock. It sets the minimum printer bed size of around 160x160mm. Side extensions create a larger clock frame than most print beds can handle. There is minimal force on the frame side extensions so they can attach using just a few screws. An added benefit of the split frame is the ability to remove the pallet while testing the clock without tearing the entire clock apart.

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. I usually print the frame using a neutral color with a white dial and dark highlights for the numbers, although you are free to use any colors you like.

The following diagrams will be useful for identifying names and shapes of the gears. There are a few variations depending on options, but the gears should still be distinguishable based on the diagram. For example, the gear sets include options for a 7.8 day, 10.1 day, or 15.3 day runtime. The ratchet still looks like a ratchet if the name changes from gear7_42_ratchet_10day to gear7_48_ratchet_15day.

Print the parts and inspect them to make sure they look good. You may need to remove a few small burrs from the gears. The gears have fairly loose tolerances and can mesh properly with some elephant's foot, but if there is too much then you may need to clean up the teeth with a small file. Check that the arbors fit loosely inside the frame and gear center holes. Drill them out slightly if needed.

Gear4b_18 and spacer_4a are supposed to be a tight fit on the arbor, so do not upsize their center holes.

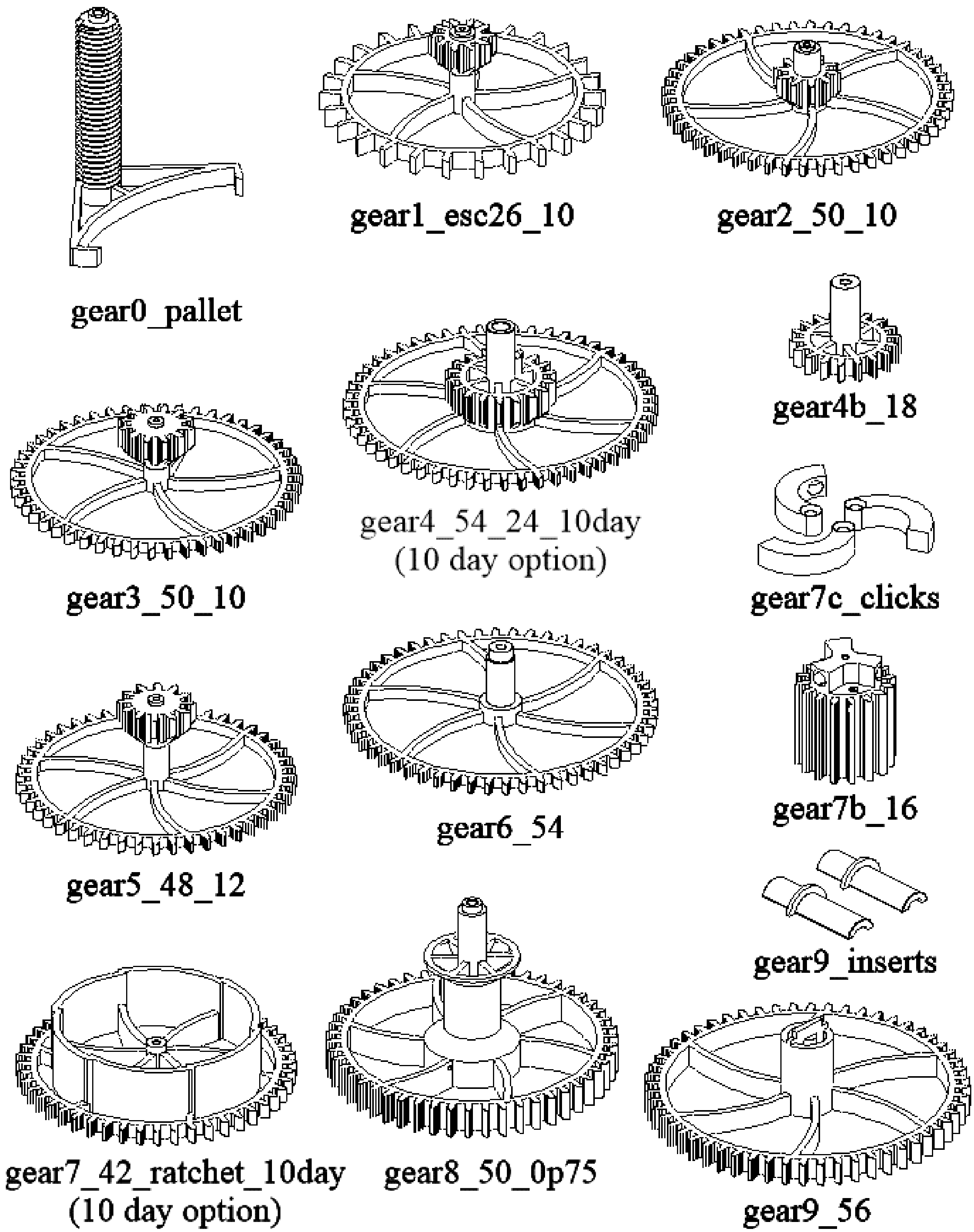

Figure 9 Gear reference chart

File Name	Color Suggestion	Print	Time	Filament	Notes
frame_back_bottom	Tan	1	0h 42m	2.59	
frame_back_center	Tan	1	11h 5m	50.69	
frame_back_left	Tan	1	1h 30m	6.73	
frame_back_right	Tan	1	1h 42m	6.53	
frame_back_top	Tan	1	0h 49m	2.50	
frame_dial_numbers	Tan, Ivory, Black	1	6h 16m	30.27	See note 1
frame_dial_roman	Tan, Ivory, Black	0	6h 17m	30.41	Optional roman numeral dial
frame_front_left	Tan	1	1h 33m	6.46	
frame_front_right	Tan	1	1h 12m	5.25	
gear0_pallet	Gold	1	3h 38m	4.60	0.15mm layer height
gear1_esc26_10	Gold	1	2h 6m	5.21	0.15mm layer height
gear2_50_10	Gold	1	1h 33m	3.72	0.15mm layer height
gear3_50_12	Gold	1	1h 43m	4.20	0.15mm layer height
gear4_54_24_10day	Gold	1	3h 1m	7.24	0.15mm layer height, see note 2
gear4b_18	Gold	1	1h 7m	2.00	0.15mm layer height
gear4b_18_tight	Gold	0	1h 9m	2.00	0.15mm layer height, see note 3
gear5_48_12	Gold	1	1h 51m	4.37	0.15mm layer height
gear6_54	Gold	1	1h 40m	3.81	0.15mm layer height
gear7_42_ratchet_10day	Gold	1	2h 54m	8.16	0.15mm layer height, see note 2
gear7b_16	Gold	1	2h 34m	6.36	0.15mm layer height
gear7c_clicks	Gold	1	0h 52m	2.20	0.15mm layer height
gear8_50_0p75	Gold	1	5h 33m	12.46	0.15mm layer height
gear9_56	Gold	1	3h 4m	7.88	0.15mm layer height
gear9_inserts	Gold	1	0h 29m	1.36	0.15mm layer height
hands_serpentine	Black	0	0h 39m	1.26	Optional hand style, see note 4
hands_spade	Multi-color	1	0h 28m	1.30	
pendulum_bob	Bronze	1	4h 47m	21.41	
pendulum_shaft	Black	1	3h 44m	15.85	
nut_0p25	Black	2	0h 16m	0.92	Used below pendulum bob
nut_0p40	Gold	2	0h 25m	1.41	Used at top of pendulum shaft
weight_shell_bottom_2p6	Bronze	1	0h 58m	4.69	See note 5
weight_shell_top_2p6	Bronze	1	10h 29m	36.56	See note 5
weight_shell_short_2p6	Bronze	0	8h 51m	30.65	See note 5
weight_shell_quarter_2p6	Bronze	0	5h 48m	17.72	See note 5
weight_shell_pulley	Bronze	1	0h 27m	1.59	See note 5
crank_handle	Tan	1	1h 22m	3.23	
crank_knob	Gold	1	0h 55m	3.01	
swing_gauge	Ivory, Black	1	0h 23m	1.63	
spacers	Gold	1	1h 3m	2.27	See note 6
Total		**36**	**82h 52m**	**280.8m**	

Table 1 Printed Components

Note 1: Two different dials are provided with this clock. Use either one that you like. The picture on the front cover uses simple numbers. The roman numeral dial can be seen in the pictures of my second clock at the end of this document.

Note 2: Gear 4 and 7 can be configured for runtimes of 7.8 days, 10.1 days, 15.3 days, 21.3 days, or 32.2 days. The runtime option is encoded into the file name. It is recommended to start with the default 10.1 day runtime option that has a good chance of working properly. You can try the 15.3 day option later if your clock is running well and you want a bit more runtime. It might require a slight increase in drive weight. The 7.8 day option is a backup if you have trouble getting the 10.1 day version running reliably. Try the 21.3 day or 32.2 day options only after your clock has been running nicely using one of the safer (shorter) runtimes.

Note 3: Gear4b_18 is designed to be a press fit onto the minute hand arbor. Different printer tolerances might make the part loose, so gear4b_18_tight with a smaller center hole has been provided. You may need to experiment with partially drilling out the hole until the arbor fits properly. Another option is to rough up the arbor and glue gear4b_18 in place.

Note 4: Two different hand styles are provided with this clock. I think the spade hands look best with the simple number dial and serpentine hands look best with roman numerals.

Note 5: Multiple weight shell sizes are provided. Your clock might need more or less weight to function reliably. Determine the minimum amount of weight needed for your clock to run and add at least 50% more weight. If the clock runs for a few hours on 5 pounds, then it should run great on 8 pounds. There are several options to achieve the desired weight for your clock. Files are included with 2.4”, 2.6”, 2.8”, 3.0”, and 3.2” diameter weight shells. Also, 1/4 height extensions can be added to the bottom of the weight shell to add extra weight. There is a section later in this document describing the weight shell options in more detail.

Note 6: Small spacers for the arbors are grouped into a file called spacers. The following diagram shows what they look like along with the corresponding arbor number. Spacer_0 goes on the pallet arbor (gear0). Spacer_2 goes on the gear2 arbor. Etc. All the spacers are grouped into a single file for easy printing. They also exist as separate files if you want to print them individually. Spacer_4a may need to be scaled to make it to fit tight on the minute hand arbor.

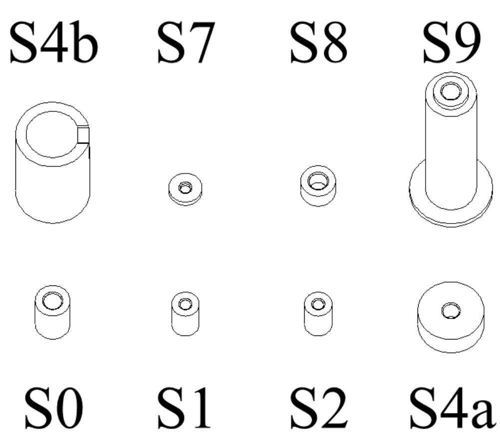

Figure 10 Misc spacers

Print File Options

Several parts have multiple print file options. Here is a description.

Component	Option	File Name	Description
Dial	simple numbers	frame_dial_numbers	Front dial with numbers (shown on the cover photo)
	roman numerals	frame_dial_roman	Front dial with roman numerals (shown in photos near the end)
Hands	spade	hands_spade	Simple spade hands
	serpentine	hands_serpentine	Ornate hand style
Weight Shell Diameter	2.4" diameter	weight_shell_*_2p4	Smallest diameter weight shell
	2.6” diameter	weight_shell_*_2p6	Small diameter weight shell
	2.8" diameter	weight_shell_*_2p8	Medium diameter weight shell
	3.0” diameter	weight_shell_*_3p0	Large diameter weight
	3.2” diameter	weight_shell_*_3p2	Largest diameter weight shell
Weight Shell Height	full height	weight_shell_2p6 (or other dia.)	Full height weight shell in one piece
	3/4 height top section	weight_shell_short_*	Partial height weight shell for limited height printers, about 75% height
	quarter height bottom section	weight_shell_quarter_*	Quarter height weight shell used as an extension to add a small amount of additional weight
Runtime Options	7.8 day runtime	gear4_54_28_7day, gear7_38_ratchet_7day	Safest gear set option with a 7.8 day runtime
	10.1 day runtime	gear4_54_24_10day, gear7_42_ratchet_10day	Recommended gear set with a 10.1 day runtime
	15.3 day runtime	gear4_54_18_15day, gear7_48_ratchet_15day	Alternate gear set option with a 15.3 day runtime
	21.3 day runtime	gear4_54_14_21day, gear7_52_ratchet_21day	Alternate gear set option with a 21.3 day runtime
	32.2 day runtime	gear4_54_10_32day, gear7_56_ratchet_32day	Most aggressive gear set option with a 32.2 day runtime
Spacers	one file	spacers	All the arbor spacers in one file
	individual files	spacer_0 (or _1, _4a, etc.)	Individual spacers. Spacer_4a may need to be scaled to fit the arbor

Table 2 Print Options

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 3 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. Different clocks might require more or less weight depending on the friction throughout the clock. There are options to extend the height of the weight shell to increase the drive weight if needed. The frame on this clock is robust enough to support more than 10 pounds (4.5kg) without sagging if your clock needs this much weight. You can use any combination of weight shell components to achieve the desired weight.

Color Changes

The front frame has an integrated dial that needs a color change at 13.00mm to highlight the numbers. Another color change can be added at 10.40mm to add light color dial. My clock starts with a tan base, ivory at 10.40mm, and blue at 13.00mm for the numbers. Both dial styles have similar thicknesses, so the layer changes occur at the same heights.

PrusaSlicer has a really easy method for adding layer changes.

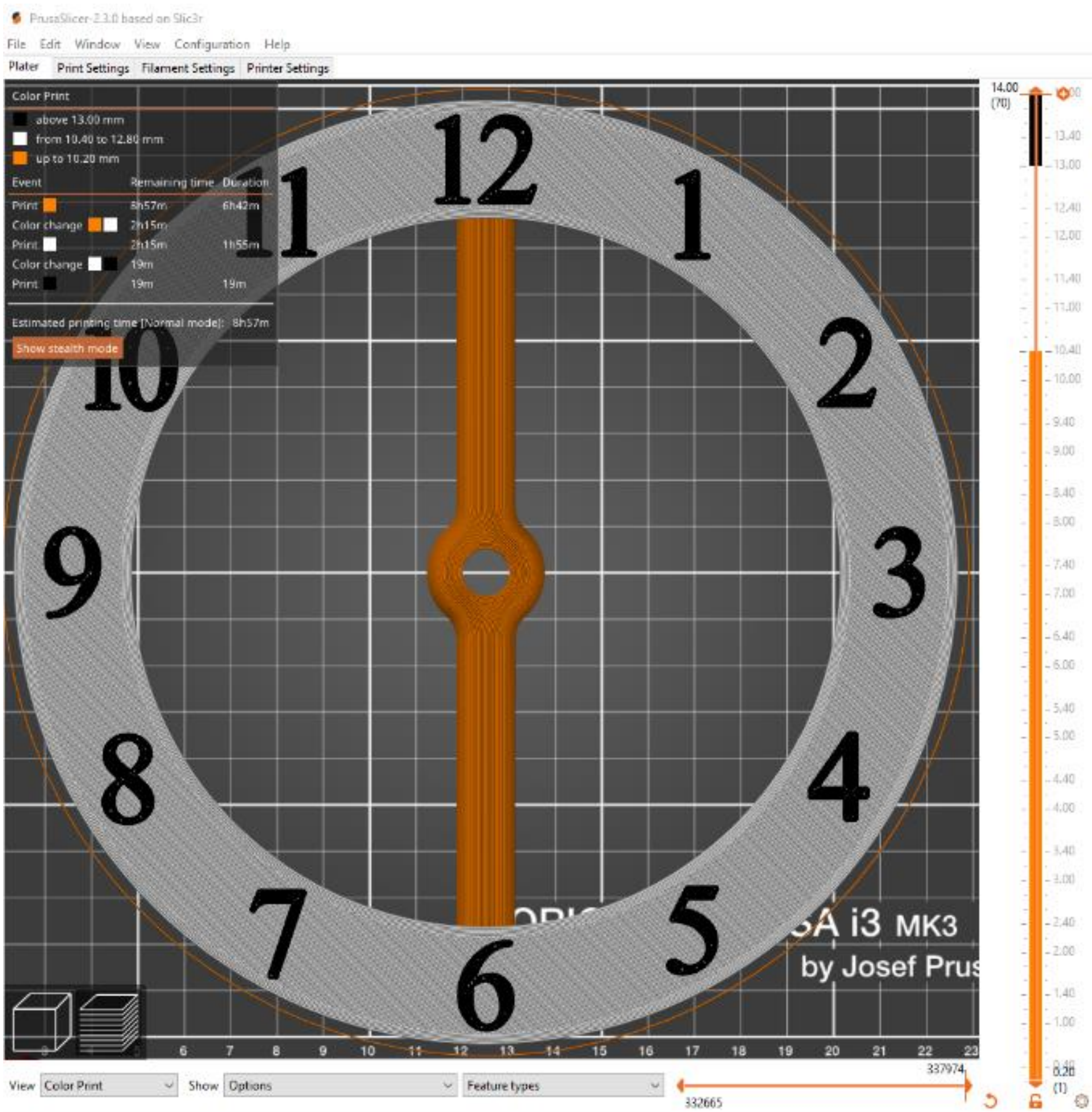

Figure 11 Layer changes for front frame

There are two options for the clock hands. The serpentine hands are intended to print as a solid color, but the spade hands look best with a layer change at 2.8mm to highlight the perimeter. Experiment with different colors. Sometimes dark colors look good, but lighter colors are more visible if you have dark colored gears.

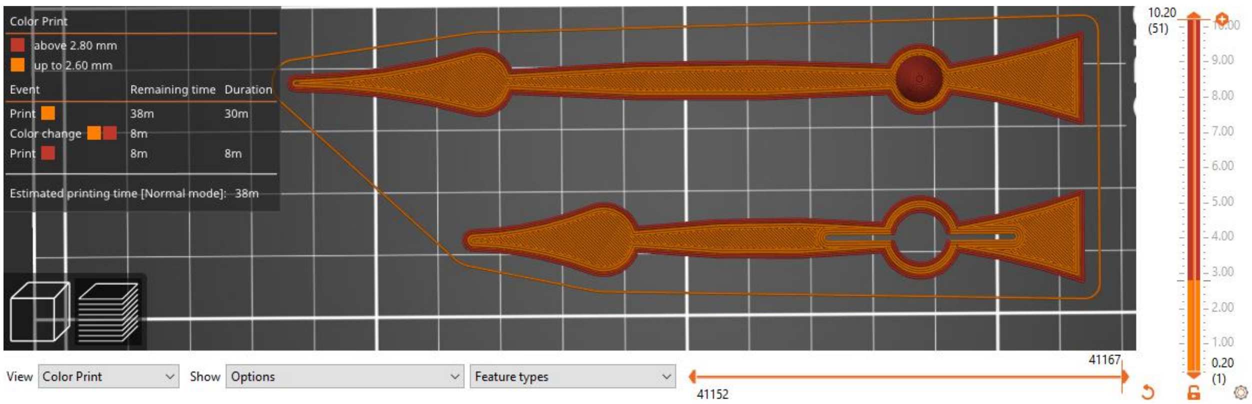

Figure 12 Clock spade hands layer change

The swing gauge is useful for determining the pendulum amplitude and also for balancing the escapement trip positions. It should have a color change to a darker color when the lines appear.

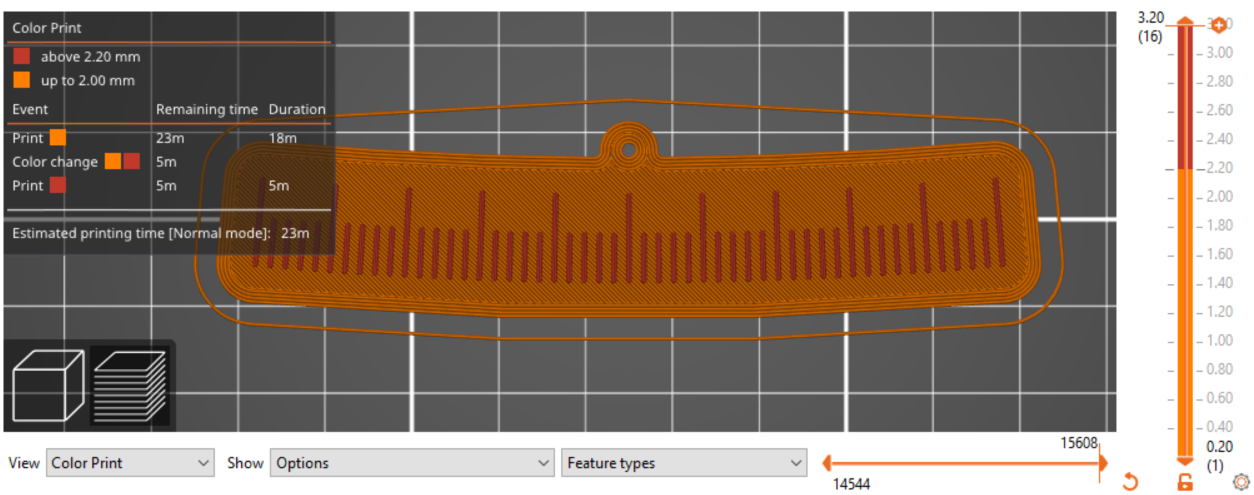

Figure 13 Swing gauge color highlights

Additional Components

There are a few fully 3D printed clocks posted on the internet, but most of them have extremely short runtimes. I certainly do not want to wind a clock several times per day. All of my clocks last for several days between winding so they are actually useful time pieces. It takes a few metal components to reduce friction for this to happen. Ball bearings are used to support the pendulum and small diameter steel rods are used as arbors. And using real screws to hold components is much more reliable than printed screws.

One of the goals in designing this clock was to reduce the bill of materials compared to my earlier clocks. This clock uses about half as many non-printed components as my other clocks without any sacrifice to runtime.

Here is a complete list of non-printed parts needed to build this clock.

Qty	Component Imperial or (metric) sizes	Notes
~25	6x3/4” flat head wood screw	Metric equivalent is ~19mm long
1 or 2	8x1-1/2” pan head wood screw or nail	For hanging clock on wall
18" (0.5m)	3mm stainless or brass rod	Cut to 2”, 3”, 3”, 3.5”, and 4.5” (51mm, 76mm, 76mm, 89mm, and 114mm)
9" (0.25m)	1/16” or 1.5mm music wire	Cut to 3”, 3”, and 3” (76mm, 76mm, and 76mm)
12' (3.5m)	microfilament fishing line	I use PowerPro Spectra Fiber braided fishing line 65 lb. test, Eq Dia 16
~8 lb. (3.6kg)	lead shot or BBs	~11000 BBs are a great option. Lead shot allows a smaller weight shell, but more difficult to find
5	623RS bearing (3x10x4mm)	Open bearings are best, but rubber seals (623RS) can easily be removed. Metal shields (623ZZ) are difficult
4	click pen springs	Use springs from ball point pens

Table 3 Non-printed Parts

6x3/4” wood screws are used throughout this clock. A single size was selected that is strong where needed without being too large in other places. A longer pan head wood screw or nail is used to hang the clock on the wall. Any size that fits into the hanging hook is good.

Music wire is great for the arbors because it is typically hardened, although almost any metal rods should work in this clock. The 3mm diameter rod needs to fit inside the ball bearings. The small rod can be either 1/16” or 1.5mm in diameter. 1.6mm may also work.

Microfilament fishing line has been working great in my clocks for several years. It has an amazing strength in a very small diameter. Other cord is 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 25-30 times around the winding drum.

I have switched my weight shell preference from lead shot to copper plated BBs since they are less toxic and easier to find. The density of copper plated steel BBs is only around 20% lower than lead shot, so the size increase for the same weight is minor. You may also be able to use random pieces of steel for the weights, but you may need to experiment to find the proper size. The weight shell extensions help if you need a bit more weight.

The 623RS ball bearings are the most critical component required to get the clock functioning properly. I have tried other options and cannot find any better method to support the pendulum. Clock suspension springs have been used for centuries, but are not readily available. 3D printed knife edges might work with a 1-2 day clock, but have way too much friction for an 8-10 day runtime. String suspensions might be an option, but they would be difficult to set up properly. I will stick with small ball bearings until I can find something better.

I purchase generic ball bearings from the typical places (Amazon, eBay, AliExpress, etc.) for around US$5-10 in lots of 10. Open bearings without seals or shields would be best, but they are difficult to find. Rubber sealed bearings (623RS) are an acceptable solution because the seals are easy to remove using a small pin. The thick factory grease needs to be removed for the pendulum support bearings. This requires removing the seals and soaking the bearings in solvent. Brush out or use an air gun to remove the remaining gunk. Select the best ones for the pendulum support and any of the others for the weight shell. The weight shell bearings can keep the seals intact if desired.

The final items are a few springs from ball point pens. One spring is used for the minute hand adjustment and three springs are used in the ratchet.

Figure 14 Non-printed components

Component Pre-Assembly

Metal Parts

Most of the gears in this clock use music wire for the arbors. The motion work arbors use small diameter rods to keep friction low. There is enough tolerance in the design that either 1/16”, 1.5mm, or 1.6mm diameter music wire should work. Cut the lengths to size or slightly shorter. Round over the ends to remove any slight burr from the cutting process. Keep in mind that hardened music wire needs an appropriate cutter. Cheap diagonal cutters might not work well. A Dremel cutoff disk is a better choice.

The larger arbors use 3mm stainless steel or brass rods. They are better for supporting the weight shell load. The bearings have a 3mm center hole so 3mm rods are used here as well.

Below is a diagram showing the cut metal parts used in this clock. It is much a much simpler list than any of my other clocks. The diagram is approximately to scale when printed.

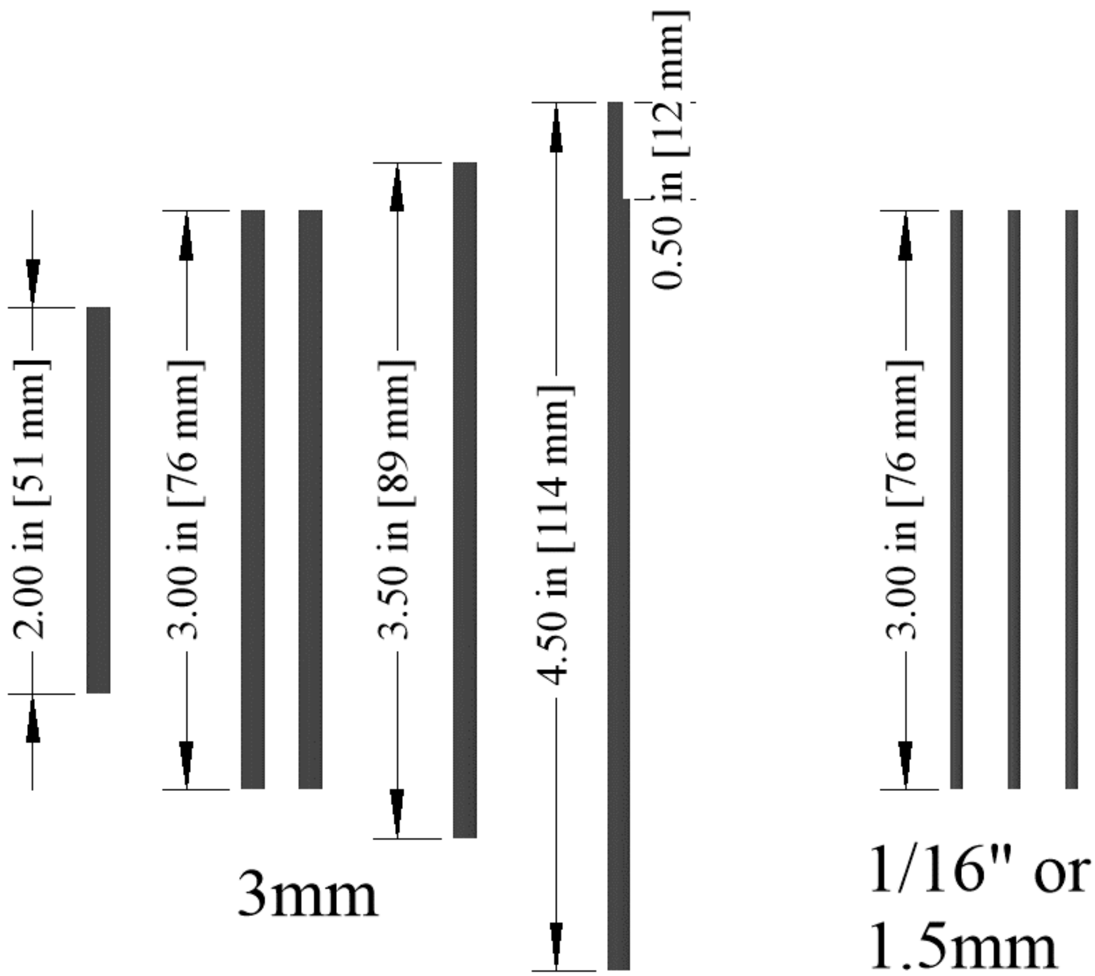

Figure 15 Cut metal parts

The minute hand arbor needs a flat on one end to fit the minute hand. Print the hands and file down the notch until the arbor can be pushed into the minute hand.

Back Frame

The back frame consists of five pieces held together using 6x3/4" wood screws. The screws are common wood screws from the local hardware store with around 18 threads per inch. They should screw into built-in threads relatively easily. Follow the diagram below.

The clock will be supported by a printed hanging hook near the top of the frame. The three screws holding frame_back_top support most of the weight. The other screws are simply holding parts in position without much force.

The lower support column has a screw on the side that will be used to hang one end of the weight shell cord. A screw with a small shoulder as shown in the diagram is preferrable to keep the threads from cutting into the weight cord.

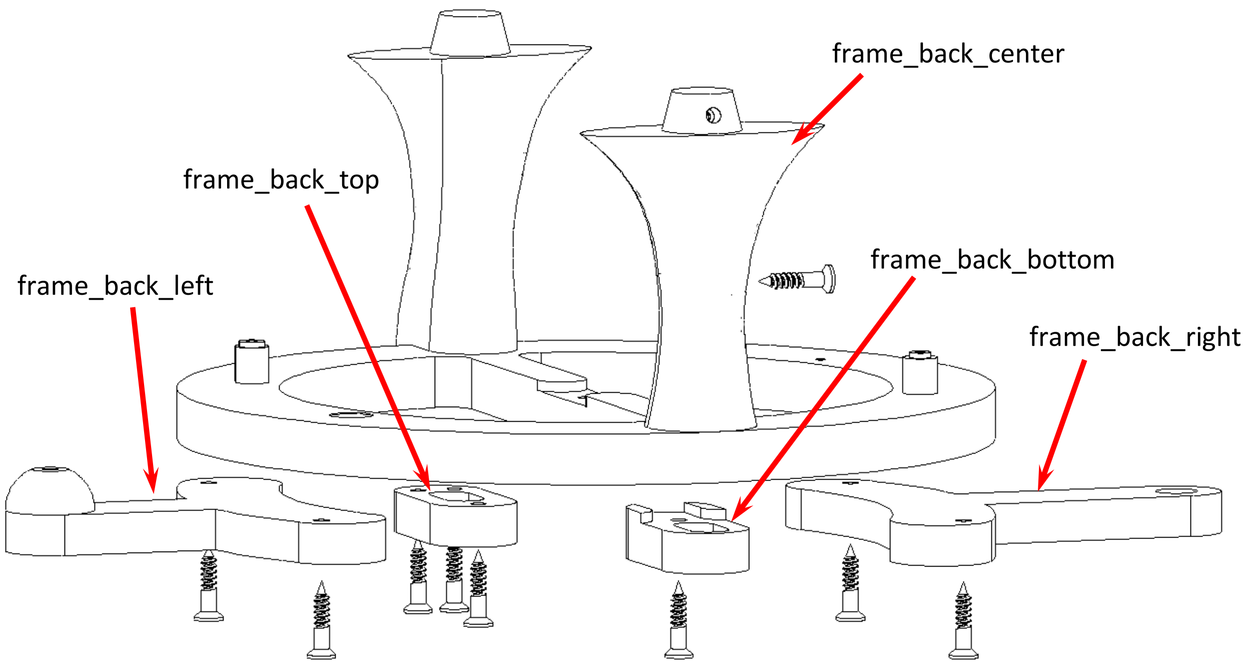

Figure 16 Back frame assembly

Front Frame

The front frame consists of only three components assembled as shown below. The dial can either be the version with simple numbers (frame_dial_numbers) or roman numerals (frame_dial_roman).

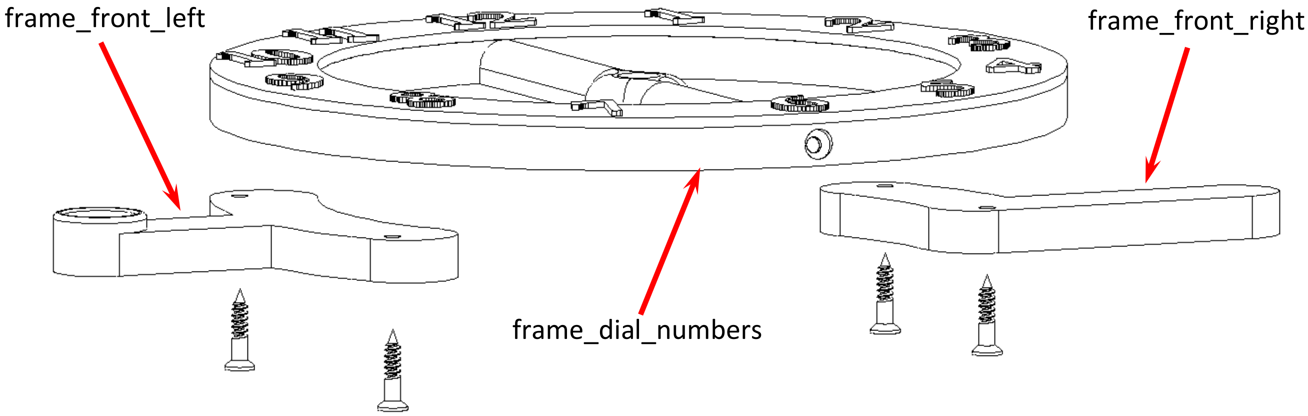

Figure 17 Front frame assembly

Test that the two halves of the frame go together easily and can be attached with two 6x3/4" wood screws. 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.

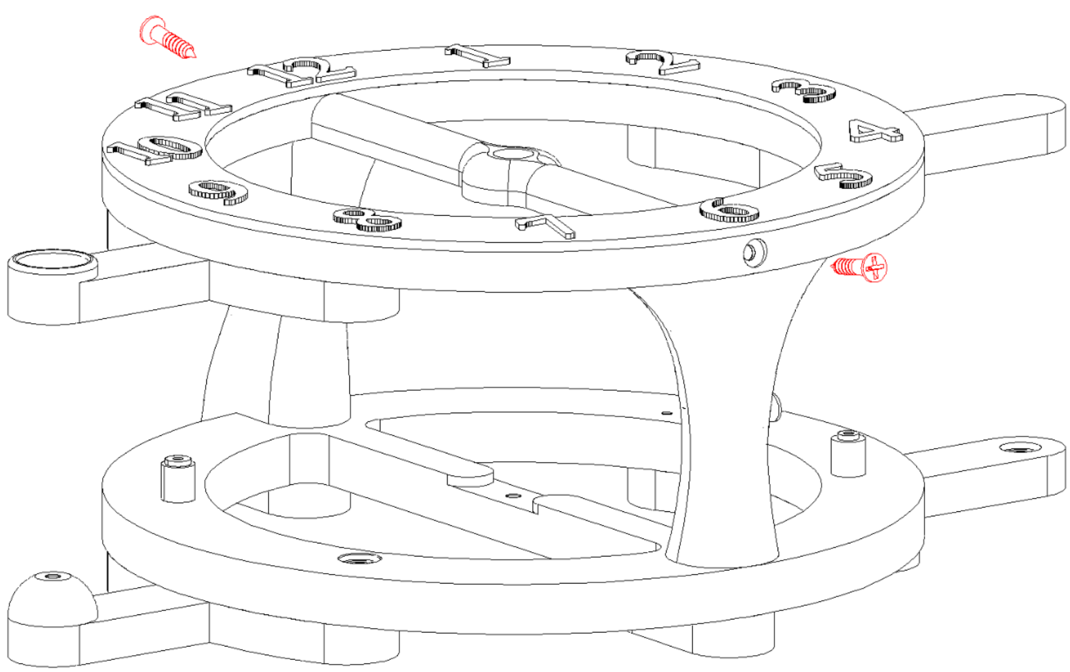

Figure 18 Completed Frame

Winding Drum and Ratchet

The winding cord should be added to the winding drum before assembling the clock.

Insert one end of the microfilament fishing line through the hole on the winding drum spokes and tie a knot. Trim the end short and wrap most of the line around the drum in the direction shown. 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 two years 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.

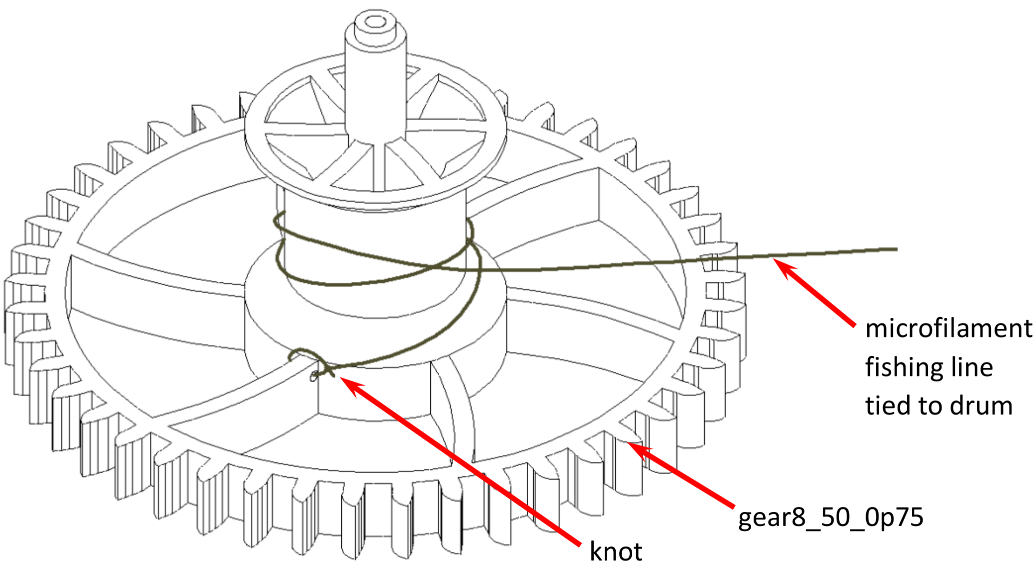

Figure 19 Winding drum assembly

The ratchet allows you to wind the clock. Attach the three clicks (gear7_clicks) to the ratchet center hub (gear7b_16) with 6x3/4" wood screws. The clicks have a beveled hole for the screw head. Tighten the screws 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 to the ratchet outer hub (gear7_42_ratchet_10day) and 3"x1.5mm rod. The ratchet should rotate easily in one direction.

The springs only need to be strong enough to push the clicks to the outer ratchet. It will be noisy when winding if the springs are too strong. Cut or compress the spring length until the ratchet feels good. It is OK for the ratchet to be loose, as long as the clicks just barely engage with the ratchet.

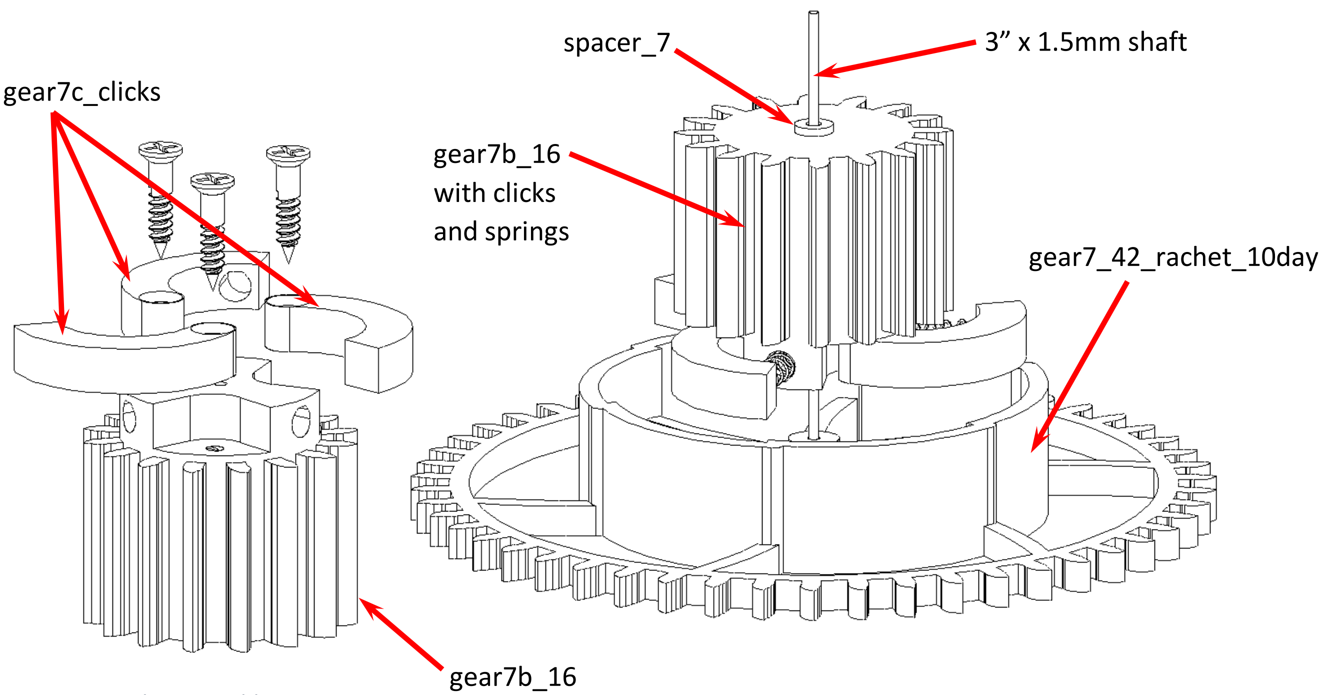

Figure 20 Ratchet assembly

The ratchet assembly process is identical if you are building the 7.5 day or 15.2 day options. The only change is a different number of teeth on the large gear. Some of the ratchets have gear teeth that attach directly to the ratchet hub. Other ratchets have a separate outer hub for the gear teeth, as seen in the picture above. The function is the same, but don't be surprised if the ratchet looks slightly different than in the picture.

Minute Hand

The minute hand arbor contains a friction clutch that slips to allow setting the time without stopping the clock. A spring from a ball point pen provides the holding force. Power continues to be provided to the escapement though the large gear when setting the time.

The first step is to add gear4b_18 to the minute hand arbor. This is designed to be a snug fit that gets pounded or pressed into place. If gear4b_18 from your printer is too loose, then try gear4b_18_tight that has a smaller hole. You may need to experiment with drilling partially though using a 3mm (or 2.9mm) drill bit until you get a good fit. Another option is to rough up the shaft slightly and epoxy gear4b_18 in place. The bottom end should stick out 1.9” below gear4b_18.

The second step is to add spacer_4b, a pen spring, gear4_54_24_10day, and spacer_4a to the bottom end of the shaft. The pen spring can be stretched to around 1.2” to provide extra pressure. The slot in spacer_4b should slide over the tab on gear4_54_24_10day. It is designed to be a close fit, but make sure it is not too tight. Enlarge the slot slightly if needed.

Spacer_4a is a press fit. It can be scaled in X and Y to make it fit tightly. Alternatively, a 1/8” shaft collar with a set screw can be used to allow the assembly to be taken apart if you need to adjust the spring pressure. The arbor should stick out the lower end about 0.25” when it is fully assembled.

Hold the large gear in one hand and rotate the small gear. It should rotate on the arbor with a small amount of resistance. It should also have enough holding force to keep the minute hand rotating when the large gear is rotated.

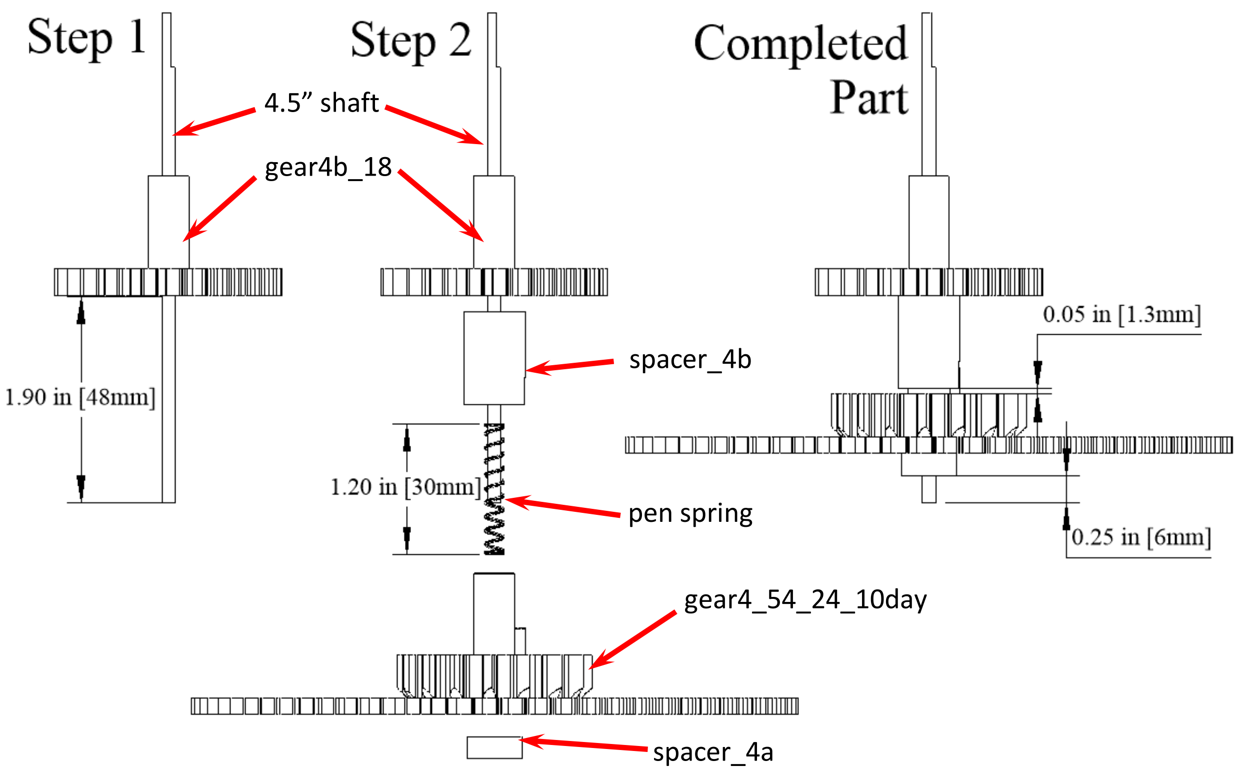

Figure 21 Minute hand assembly

Pendulum

The pendulum and pallet have been simplified considerably on this clock. All the critical components are printed except for two ball bearings to support the pallet. The pendulum shaft is three segments that drop into position using tapered pegs to hold the position accurately. All three shaft components are in one file called pendulum_shaft, or separately as pendulum_shaft_upper, pendulum_shaft_mid, and pendulum_shaft_lower. Slightly shorter or longer versions of the middle portion are available as pendulum_shaft_mid_short and pendulum_shaft_mid_long, but you may not need to use these.

The upper portion of the pendulum shaft is placed on the pallet as shown with 0.4” nuts on each side to hold it in position. Orient the shaft as shown so the finial below the bob will be positioned properly. The pallet shaft is keyed so the beat can be changed by moving the pendulum shaft forward or backward. Start with the shaft centered along the threads. Tighten the nuts securely.

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 bob could be filled with washers, small rocks, or anything that fits. Pennies are cheaper than washers and they fit nicely. Secure the back of the pendulum bob with two 6x3/4” wood screws. The assembled pendulum bob on this clock weighs between 6 and 8 ounces. The bob slides over the lower portion of the pendulum shaft when assembling the clock. Two 0.25” nuts are used to set the length of the pendulum to set the rate. Start with the nuts positioned near the center of the threads.

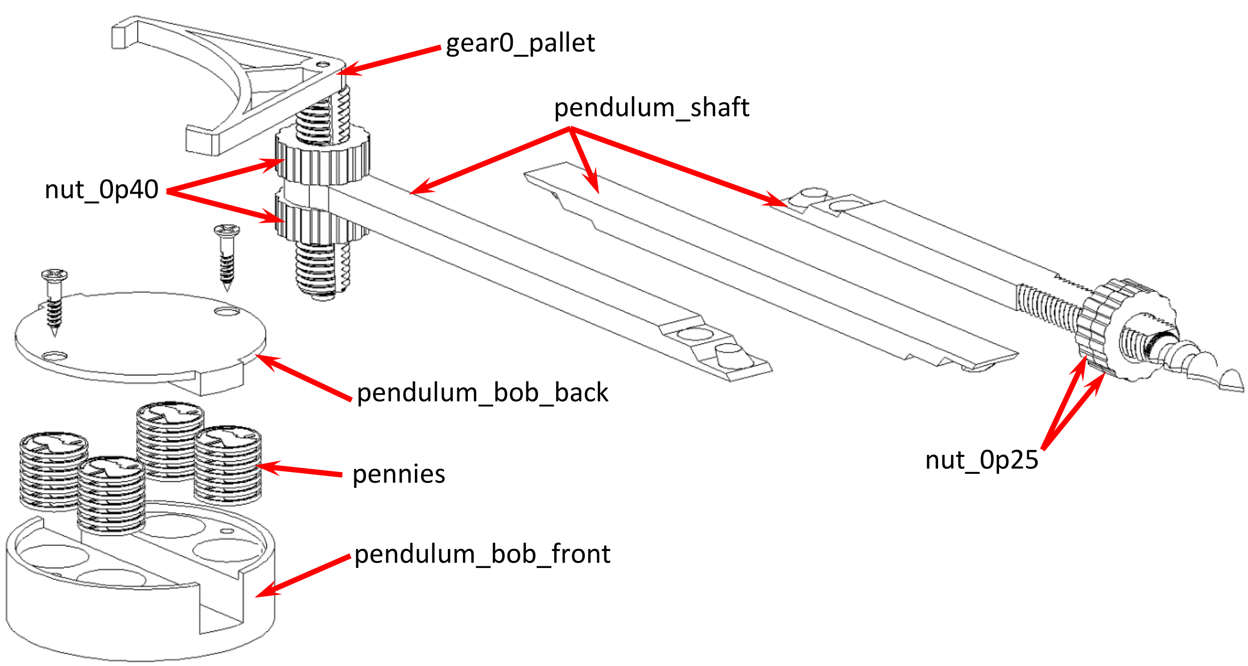

Figure 22 Pallet and pendulum

You could test the pendulum support bearings at this time. The bearings need to have low friction so the pendulum doesn't lose too much energy with each swing. Assemble the clock frame with the pallet, bearings, and pallet arbor. Use the following diagram as a guide. Hang the clock on the wall and attach the pendulum.

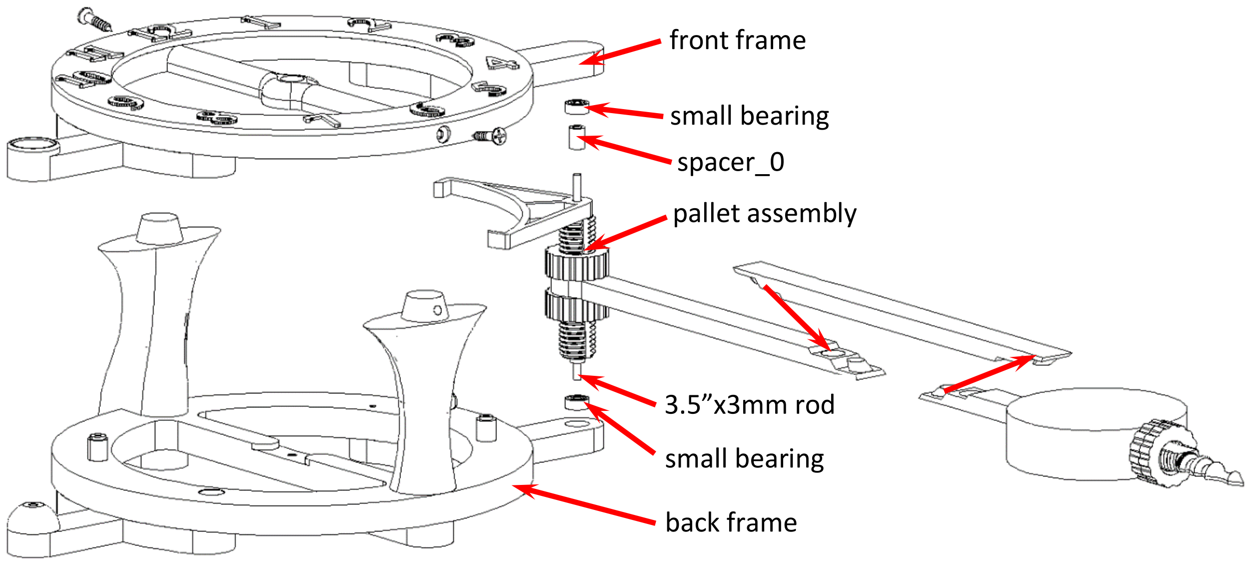

Figure 23 Pallet and pendulum support assembly

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 approximately 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. The average quality bearings are still good enough for the weight shell since the slow speed can easily overcome a slight amount of bearing friction.

Weight Shell

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

The weight shell is filled with lead shot or BBs to provide energy to keep the clock running. Multiple weights were tested before settling on around 8 pounds (3.6kg) as an acceptable drive weight. Your clock might run using a smaller weight, but extra weight makes the clock more reliable. There are multiple options to create different size weight shells.

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

Below is a table showing the approximate weights of various size weight shells. I have built a few of the sizes and extrapolated the rest. The normal height column includes just the weight_shell_top in different diameters. One extension is listed, although you can add multiple extensions if needed.

Weight Shell Diameter	Lead Shot Normal Height	Lead Shot with One Extension	Normal Height Filled with BBs	One Extension Filled with BBs
2.4”	5.3	6.4	4.3	5.2
2.6”	6.5	8.0	5.3	6.4
2.8”	7.9	9.7	6.3	7.8
3.0”	9.4	11.7	7.6	9.4
3.2”	10.9	13.5	8.8	10.9

Table 4 Approximate weight shell capacities in pounds

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

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

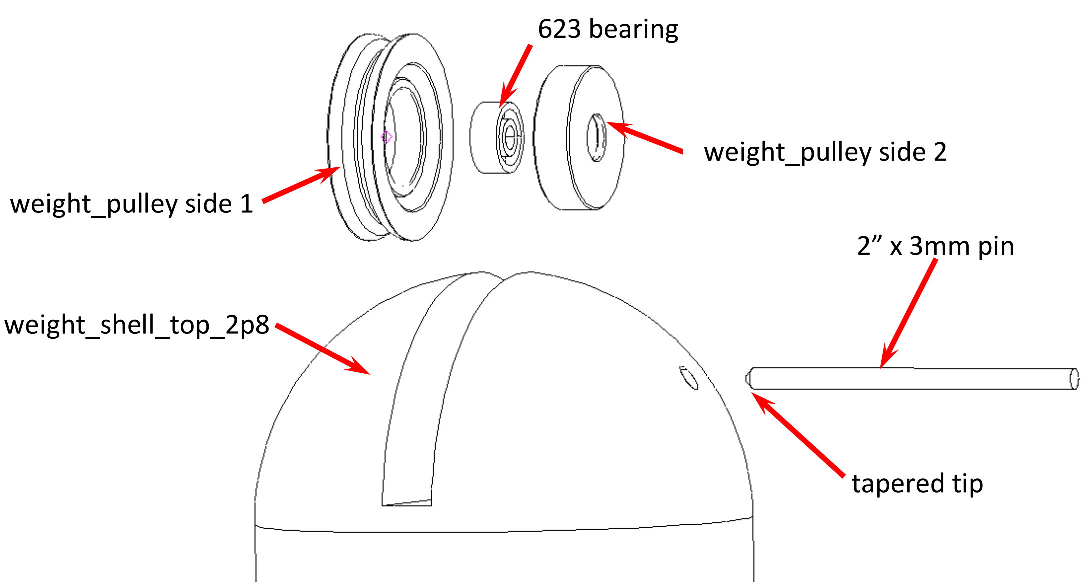

Figure 24 Top portion of weight shell

Turn over the weight shell and fill it with BBs (or lead shot). Take appropriate safety precautions if using lead. Assembly should be obvious when you see the parts. Each weight shell extension uses four 6x3/4” wood screws. Multiple extensions can be used if needed. Fill the weight shell and add the cover using four 6x3/4” wood screws. The completed weight shell should weigh a bit over 8 pounds. Your clock might need slightly more or less weight.

Building the Clock

Reducing friction is very important in a mechanical clock. The clock will tick over a million times in 7.5 days, with the weight shell dropping about 50” over this time. That is only around 0.00005” of weight shell drop per tick. The weight shell falling 1” needs to provide enough energy to keep the pendulum swinging back and forth 20000 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, although the clock seems to run just fine without it. Use the tip of a toothpick to add a small drop to the ends of the arbors and where the arbors enter the gears. I sometimes lubricate 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. It appears to be safe for PLA, but test it before adding it to your completed clock.

Most of the printed parts are designed to fit loosely over their shafts. Different printers and different filament might produce different sized holes. It would be a good idea to test that the gears are loose on their arbors. There are only two hole sizes used throughout this clock. The large holes are 3mm. They can be drilled out by slowly running a 1/8” or 3.2mm drill bit through the holes. Remember that gear4b_18 and spacer_4a are supposed to be tight, so do not drill them out. The small holes are sized for either 1.5mm, 1.6mm, or 1/16” shafts. A drill bit that is just slightly larger than your shafts is good if they need to be enlarged slightly.

The gear profiles used in this clock have fairly loose tolerances and they can accept a bit of printer inaccuracies. I add around 0.12mm of elephant foot compensation before printing and rarely have to worry about any print quality issues other than drilling out a few holes. Do a quick inspection of the gears and clean up any rough surfaces if needed. The fancy gear profiles printed with 4 perimeters usually leave very clean gear teeth.

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 diagrams show the components added at the current step highlighted in red.

Assembly starts with the back frame sitting flat on a table. The gears are added from the bottom working up towards the top. Gear 4 in the minute hand assembly is the lowest gear in the clock so it gets added first.

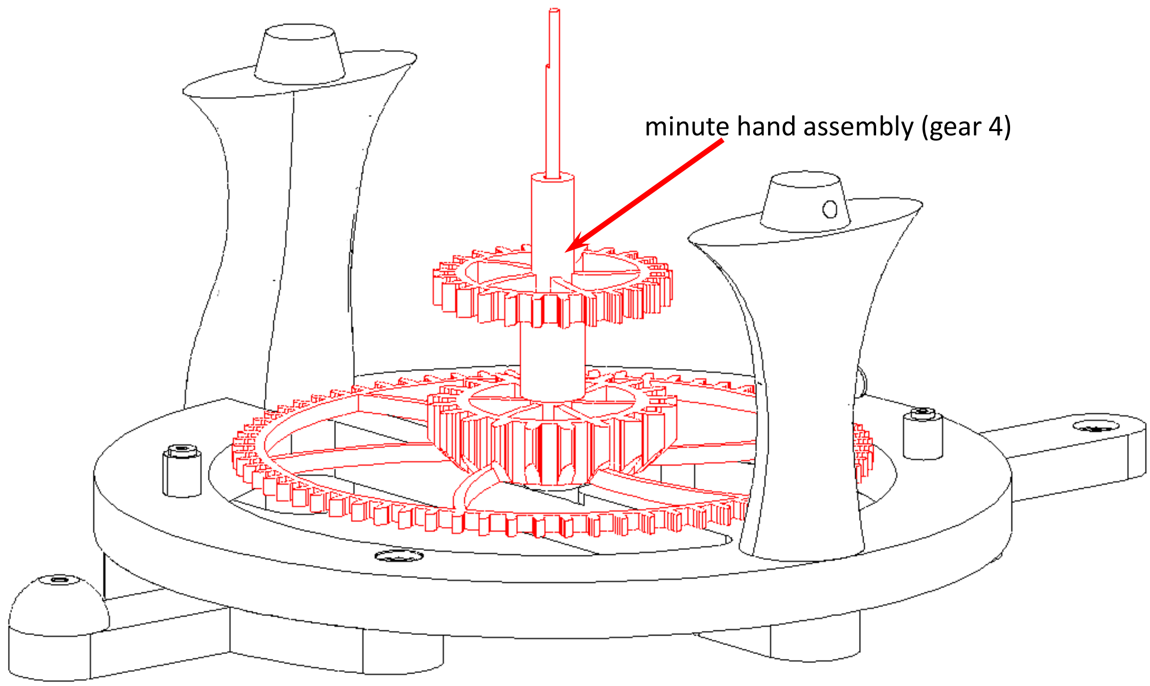

Figure 25 Back frame with gear 4 added

Power Train

The left and right sides of the clock do not interfere with each other so either side can be assembled first. Let's start with the power train on the left side of the clock. Add the gear 7 ratchet assembly using a 3" long small diameter shaft into the upper left mounting hole. The two gears should mesh nicely. Add spacer_7 onto the gear 7 arbor.

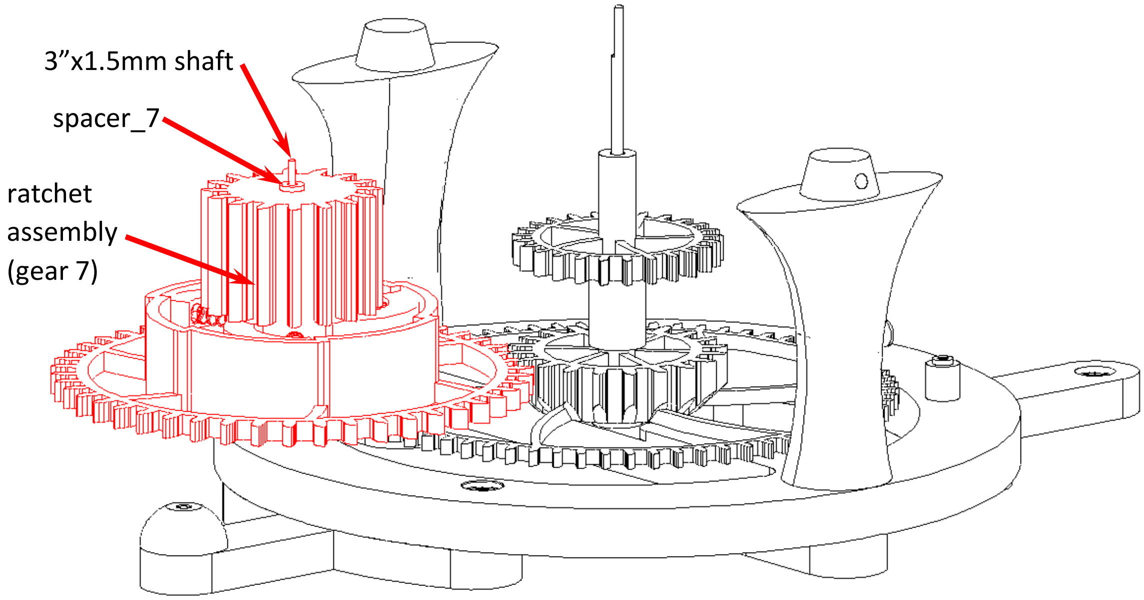

Figure 26 Gear 7 ratchet

Add a 3"x3mm shaft into the left hole. Spacer_9 goes over the shaft.

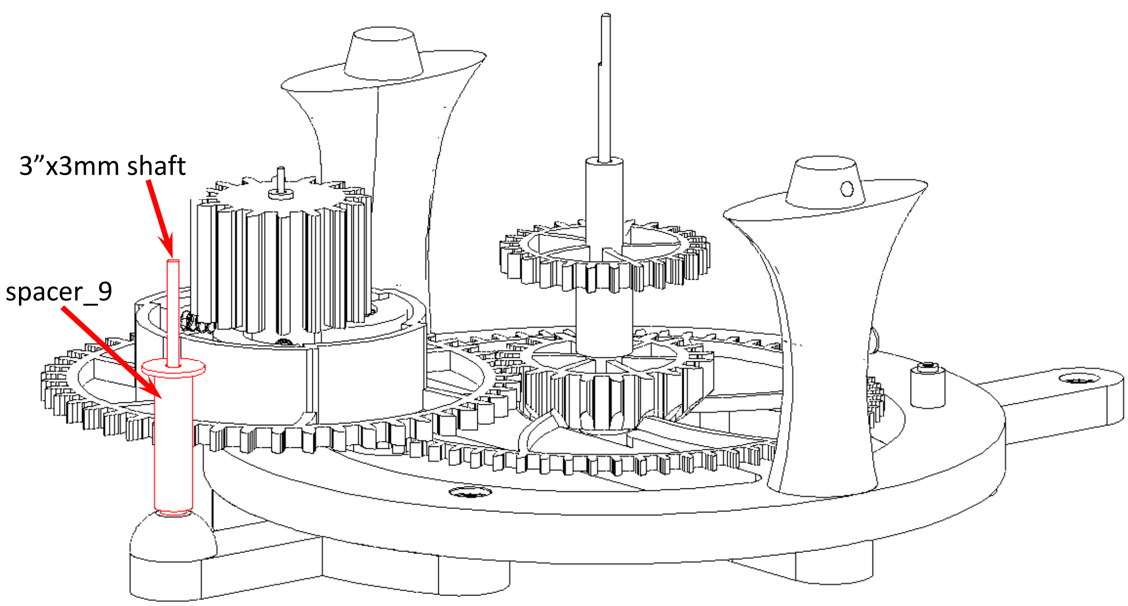

Figure 27 Gear 9 arbor

Add gear 9 onto the gear 9 arbor and place the gear 9 inserts into gear 9. The inserts have enough strength to turn the winding drum when they are printed horizontally. Gear 9 should mesh nicely with the tall pinion on the ratchet.

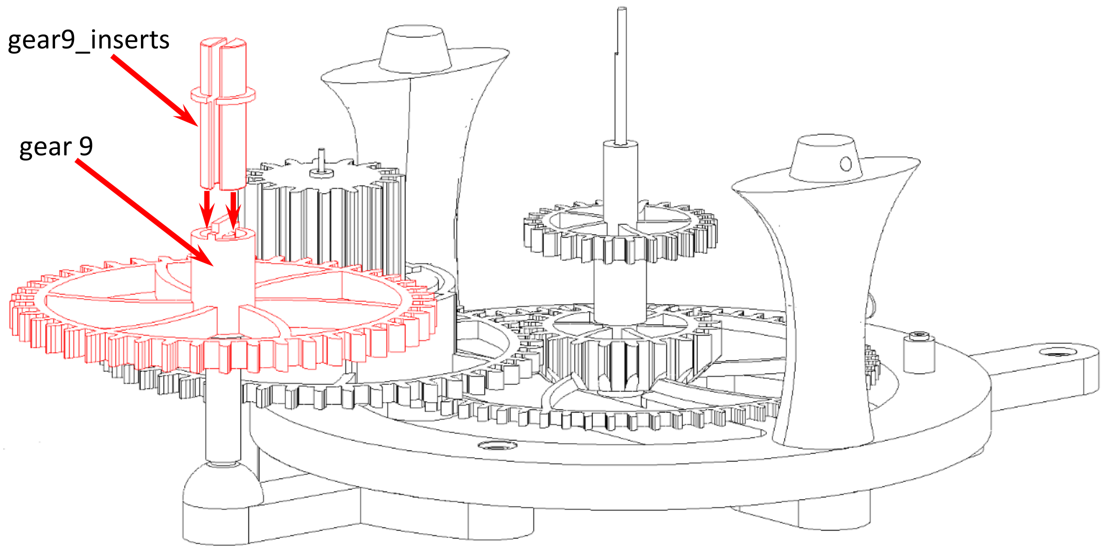

Figure 28 Gear 9

Add a small ball bearing into the mounting hole and place a 3”x3mm shaft into the bearing. Add gear8 onto the shaft followed by spacer_8 and another small ball bearing. Gear 8 should also mesh with the tall pinion on the ratchet.

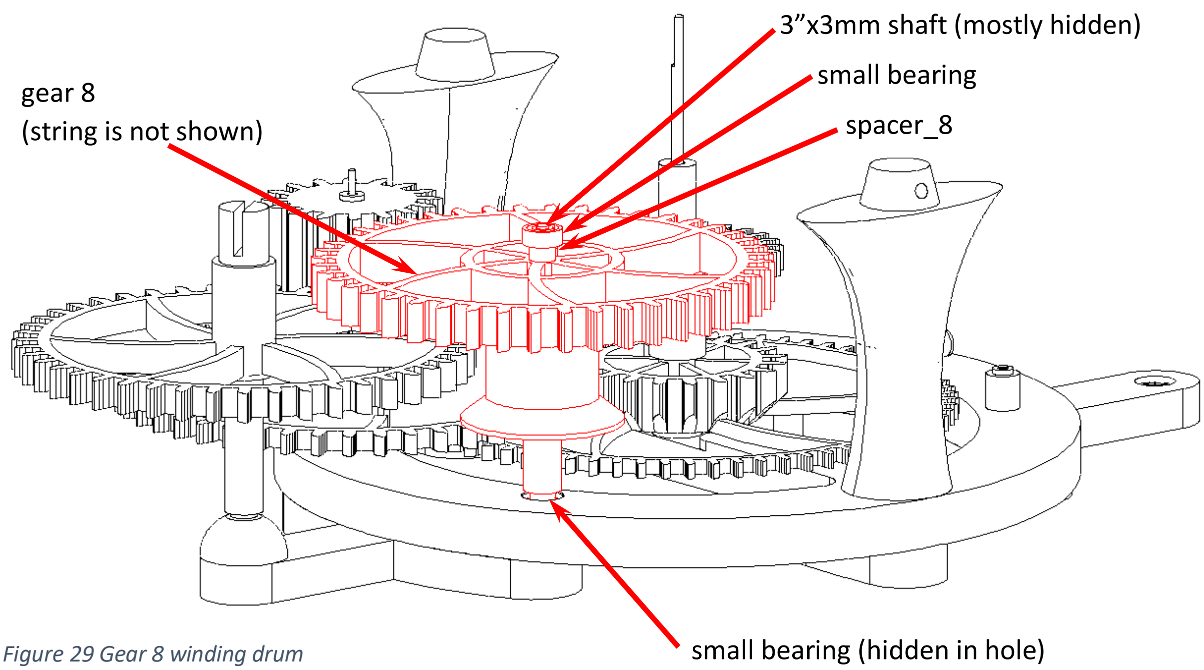

Figure 29 Gear 8 winding drum

Motion Works

We can now add in the gears between the minute hand and the escapement, also known as the motion works. The following diagrams are shown from the perspective of the lower right corner.

Place a 3”x1.5mm shaft into the upper right hole and add gear 3. The pinion should mesh nicely with gear4.

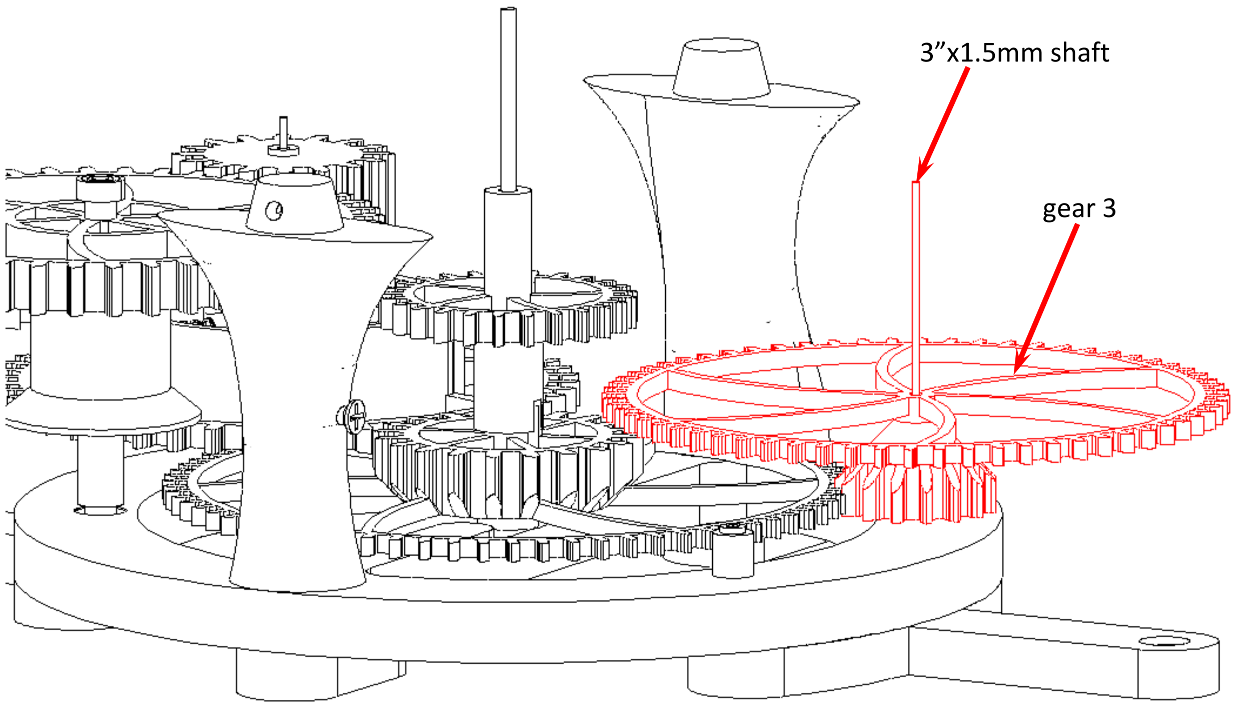

Figure 30 Gear 3

Place a 3”x1.5mm arbor in the lower right hole and add gear 2. Add spacer_2 above gear 2.

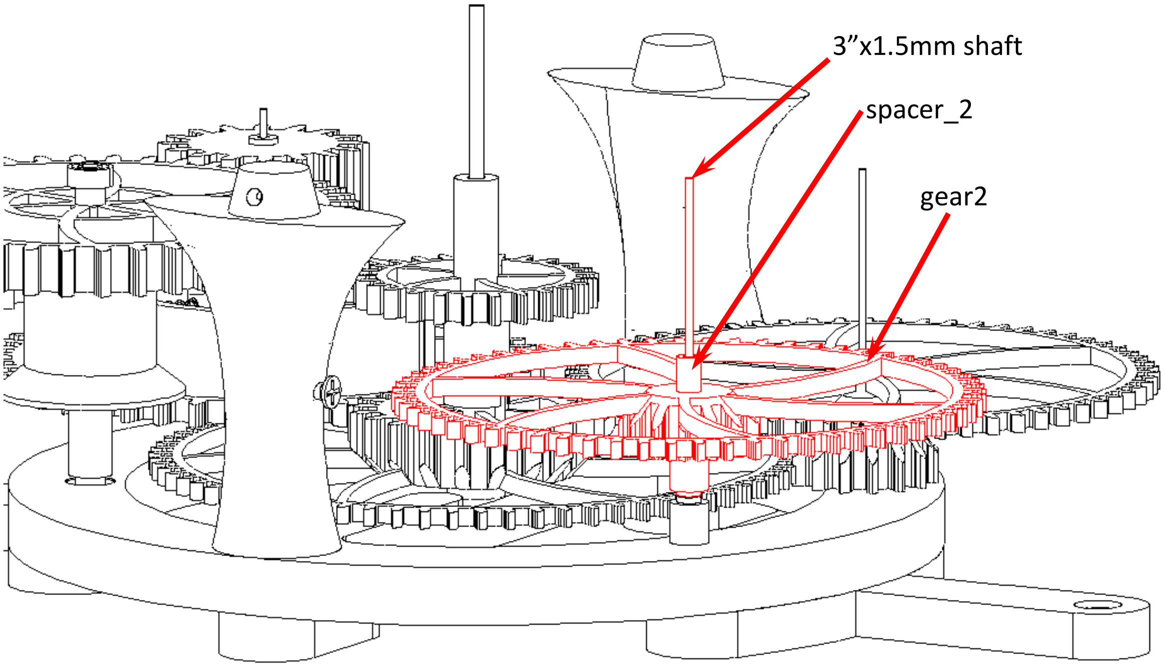

Figure 31 Gear 2

Add gear 5 onto the lower right arbor.

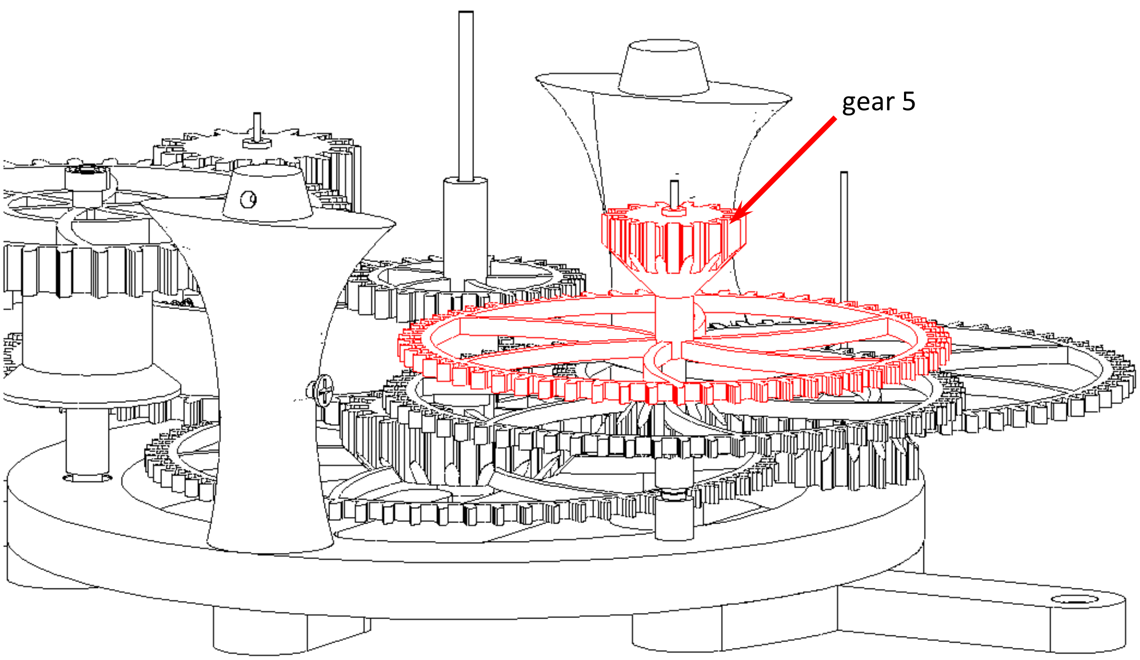

Figure 32 Gear 5

Add gear 1 (escapement) and spacer_1 to the upper right arbor.

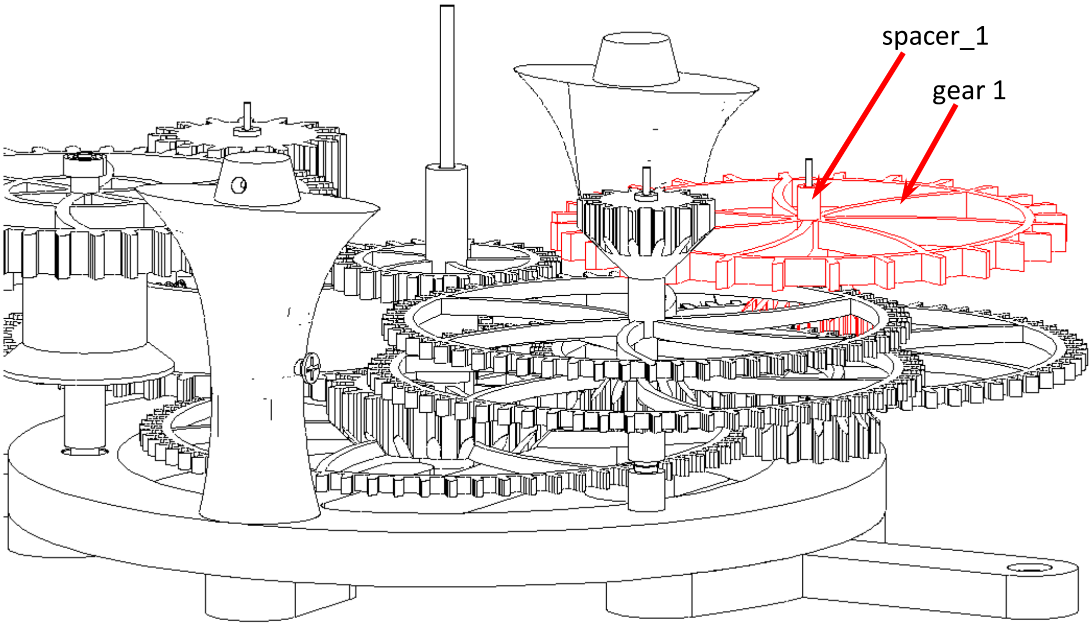

Figure 33 Escapement

Add the pallet assembly back into the clock. Assembly of these components was described earlier in this document. Include spacer_0 and a small bearing in the assembly.

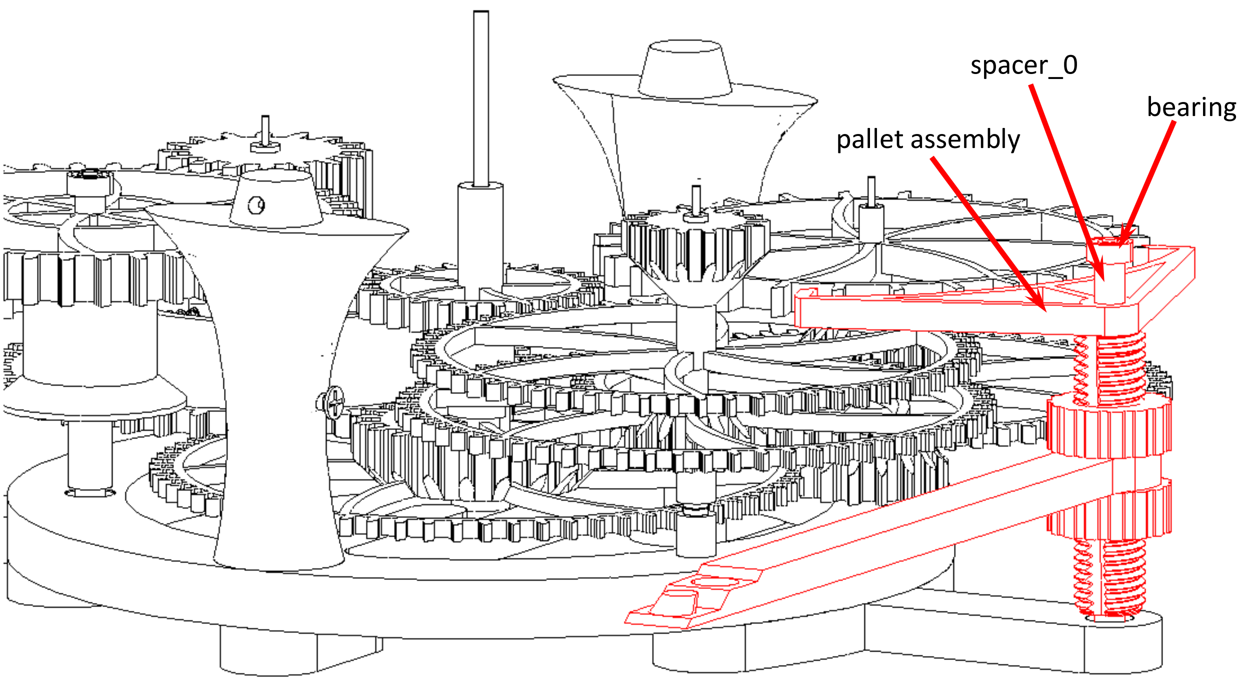

Figure 34 Pallet

The hour hand gear 6 is the final gear to be added to the clock. It is added to the minute hand arbor.

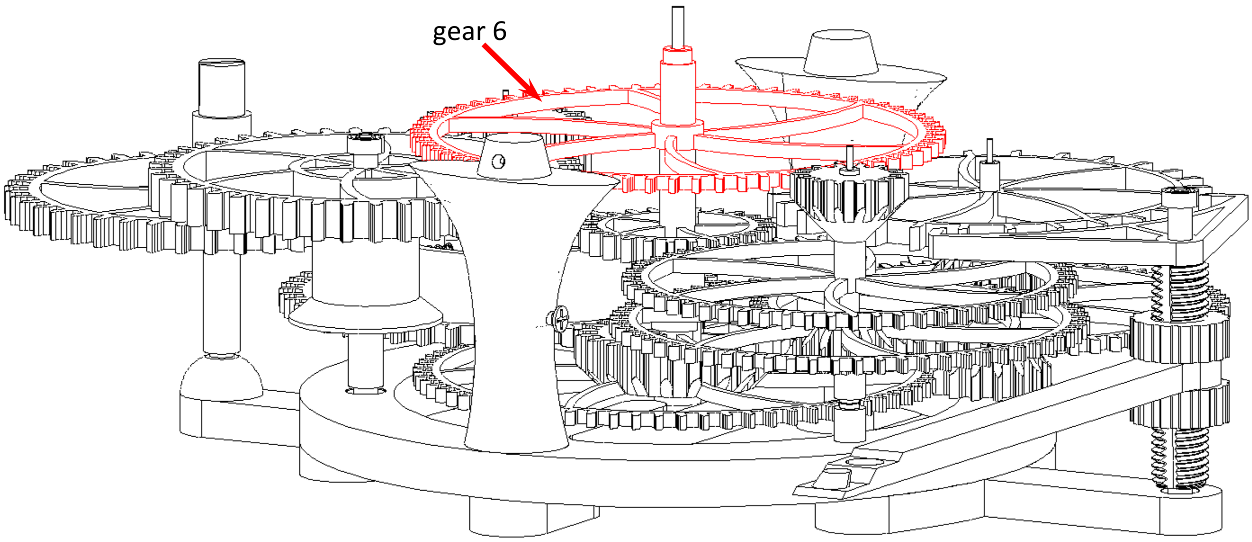

Figure 35 Gear 6

Front Frame

It is time to put the face on the clock. This step is a little tedious because there are 7 arbors and 2 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. This design was optimized to help make final assembly as easy as possible. Tapered support columns are easier to align than straight columns and they hold just as securely. The arbor holes in the front frame are chamfered so the arbors are easier to insert.

Start by placing the front frame over the minute hand arbor and line up the large hole for the winding key on the left. This gets most of the frame lined up, but the arbors are often tilted to the side. The two halves will go together part way and stop if any arbor is not lined up with its hole. 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 two 6x3/4" wood screws, one at the top and one at the bottom.

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.

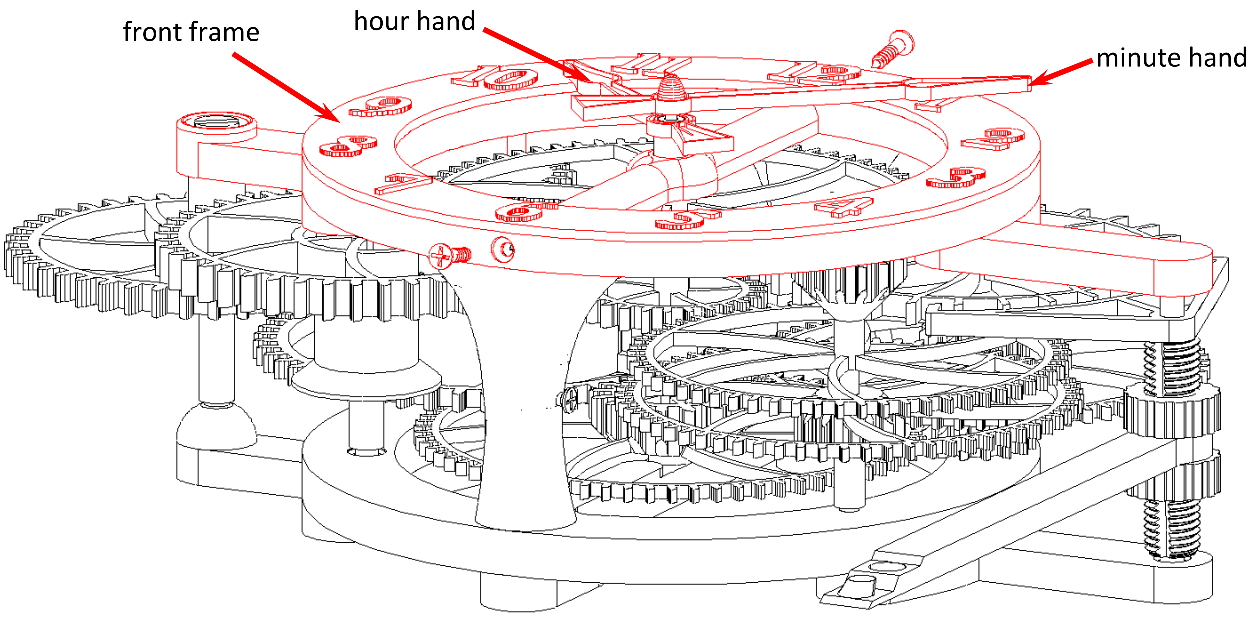

Figure 36 Front Frame

Testing the Clock

The clock mounts on the wall using a single screw or nail driven into a wall stud. A second screw at the bottom of the frame can be added to hold the clock perfectly vertical, although this is optional. The clock stays mostly balanced using only the upper screw. Placing the top screw 70" from the floor will give around 52" of drop on the weights. Hang the clock on the wall and add the pendulum. The pendulum shaft uses tapered pegs that drop into position to hold the pendulum securely with minimal play.

Attach the swing gauge to the wall so it is centered below the tip of the finial.

Tie a loop in the end of the winding cord and hang a small weight on the end. This will be used to determine how much weight the clock needs to run reliably. Start with around 2-3 pounds or 1-1.5kg.

Setting the Beat

Move the pendulum slowly to the left and right until the clock ticks. The position of the pallet relative to the pendulum needs to be adjusted until the clock ticks evenly on each side. This clock can be adjusted by tilting the clock frame or moving the pendulum along the angled notch on the pallet shaft. 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 the clock is in beat. Each tall line on the swing gauge corresponds to 1 degree of pendulum motion and 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. Tilt the clock frame slightly to one side or adjust the pendulum position along the pallet arbor. Tighten the pendulum nuts securely to lock the pendulum solidly to the pallet. Push the pendulum about 3 degrees to one side and release. The clock should continue ticking. Add extra weight to the cord if needed.

Once the clock is running reliably, start removing weight until the clock stops working. Find the minimum weight required for the clock to run for an hour or two. Increase this weight by 1.5X or 2X to provide a safety margin and double it again to account for the pulley. This should be the target weight for your clock. My test clock would just barely run using 1.0 pounds directly on the cord in the 7.8 day configuration. It should run very well with 3.0 to 4.0 pounds of drive weight on the pulley. Scaling proportionately, the 10.1 day option should run with 3.9 to 5.2 pounds and the 15.3 day option should run with to 5.9 to 7.8 pounds. Your clock might need slightly different amount of weight.

Print a weight shell large enough to handle your target weight. Pass the cord under the weight shell pulley and hang the end on the screw at the side of the lower support column.

The pendulum needs at least 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 at least 2 degrees of swing in each direction. Adding extra weight would increase the swing and the clock should be a bit more reliable, although it 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. The lower adjustment nuts are relatively coarse at around 12 threads per inch. One complete rotation of the adjustment nut will add or subtract around 3 minutes per day. Partial turns of the nut allow the time to be accurate within a few 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. My clock is usually accurate to about two or three minutes per week. I consider this to be pretty amazing.

Winding

Attach the winding_key_handle to the winding_key_knob using a 6x3/4" screw. Keep the screw slightly loose so the knob spins on the handle.

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 steady the frame when winding the clock to prevent it from shifting and changing the beat. I quickly check the beat after each winding.

Debugging

Debugging the clock often involves isolating the pallet from the escapement so each portion can be debugged independently. A great feature of this design is that the pallet can be removed without taking the entire clock apart. Remove two screws holding frame_back_right to remove the pallet. The pallet can be rotated 180 degrees on the pendulum shaft so the pallet arms do not touch the escapement.

Start the debug process with the pendulum free swing test described previously when building the frame. Rotate the pallet 180 degrees so it is isolated from the escapement. If the pendulum does not swing for at least 10 minutes, then the bearings likely have too much friction for the clock to work properly.

The next test is to check the overall gear train friction. Keep the pallet isolated from the escapement. Add a small weight directly to the cord. The escapement should rotate freely with 12-16 ounces of weight. Stop the escapement and check that it starts spinning again. Let the weight fall to the floor. It might take an hour or two because the weight is so small. If the escapement does not spin easily, then debug each pair of gears individually to see if you can identify where the extra friction is coming from.

Put the pallet back into position and keep the small weight on the cord. Manually move the pendulum back and forth. The escapement should move one step each time the pendulum moves. Continue testing through a full rotation of the escapement. The small weight won't have enough energy to keep the clock running, but the escapement should keep rotating.

Add the full weight shell back into the clock.

If the clock runs for a few minutes and stops, it is important to observe how it stops. Move the pendulum back and forth manually. Does the escapement continue rotating? If it is not rotating, then check for friction in the power train. If it is rotating, is the beat set properly? Does the clock tick equally at each side of the pendulum movement? If all of these things are working properly, does the pendulum amplitude slow down over time until the clock stops? If so, maybe it needs a bit more weight or the pendulum bearings need cleaning. Try adding a 1/4 height extension to the weight shell. You can temporarily test the clock with twice the drive power by hanging the weight shell directly on the cord without using the pulley. The weight balance may shift causing the frame to tilt, so you may need to hold the frame or use the lower wall hanging screw.

Observe the pendulum amplitude when the clock is running properly. The pallet needs a minimum of 1.5 degrees of swing to each side plus a bit more for safety. It is great to see a total of 3 degree to each side, although 2 degrees should be enough for the clock to continue running.

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.

Final Comments

This clock design is the result of several years of development. My early clocks were often designed using components from my reasonably well stocked workshop. After hearing feedback from other builders, it became obvious that not everyone has access to the same materials that I have. Acquiring parts to build one of my older clock designs may be frustrating to makers around the globe. I designed this clock with the goal of making it as easy to build as possible. It was a fair amount of effort and I have a box or two of scrap parts left over.

This is my third 3D printed pendulum clock design. Each design becomes my new favorite. This clock is no exception. I hope you enjoy building the clock as much as I enjoyed designing it.

Future plans include a smaller version of this clock that should be printable on a Prusa Mini or other machines with a small print bed. I also hope to build a few wooden gear clocks.

Please feel free to support me by purchasing some of my other clocks at MyMiniFactory. I have a Patreon page at https://www.patreon.com/user?u=30981480 (Steve's Clocks) with a small amount of clock design information. I hope to add more content regarding clock design in the near future. For now, it is mostly a repository for sharing files before a user commits to buying a design at MyMiniFactory.

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 my second clock design. It needs a bit of fine tuning before it can be released. The second image is a rendering of one of my designs as it may look after porting to use wooden gears.

Figure 37 Grasshopper clock modification and a wood clock rendering

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

Figure 38 Wooden gear experiments

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 39 Desk clocks

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

Figure 40 Original Thingiverse design

This is my second clock design posted to https://www.myminifactory.com/object/3d-print-137009

Figure 41 My Second Clock

It is a similar size as the existing clock with a vertical orientation.