CRAZY GEAR WALL CLOCK

SP12 Assembly Notes

Instructions for building a large 3D printed skeleton clock
This design has been optimized for easy construction
Run time up to 15 days

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05-Jul-2023

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05-Jul-23 Original version

Description

This is my newest and possibly best clock design so far. It merges the best features from all of my previous clocks and adds few new ones. This is the clock I wished I could have created when I started designing clocks several years ago.

The exaggerated gears have the new profile from the "Crazy Gear Desk Clocks". The frame uses simple assembly like the "Easy Build" clocks with a more natural looking vertical orientation. The pendulum efficiency allows runtimes up to 15 days. Several minor improvements include a more reliable winding key and adjustable support feet to keep the frame flat against any wall. Accuracy is about a minute or two per week.

This is my largest clock at 9.5" (240mm) wide, 23" (580mm) tall, and 7" (175mm) deep. The dial is the largest part requiring a bed size of at least 205x205mm. A Prusa MK3S (250x210) or Creality Ender3 (220x220) or larger printer will work great. Total print time is approximately 140 hours on a Prusa MK3S. Many of the newer machines can reduce this considerably. Total filament is around 1.5kg.

The following criteria were used while designing the clock:

1) The clock must look good. I wanted a nice symmetrical layout from side to side and top to bottom. This design has a classic look with a large escapement right up front.
2) The clock must be accurate. The deadbeat escapement provides great stability with an accuracy of around a minute or two per week.
3) The clock must be reliable. Another win for the deadbeat escapement. The large size and loose tolerances make this clock easy to set up and get working. Once the clock is finished and fitted with the proper drive weight, it should continue running reliably for many years.
4) The clock must be easy to build. Every feature in this clock was designed with the intent of being easy to build. All parts print flat on the build plate without supports. The frame uses simple assembly using only a few screws. The non-printed parts have been reduced as much as possible. The only machining steps required are cutting the metal arbors to the proper lengths. A few holes may need to be drilled to the proper size depending on your printer tolerances. Everything else just goes together and the clock runs.
5) The clock must have a long runtime. A design target is to have runtimes of at least a week to match a traditional grandfather clock. The improved pendulum efficiency in this clock has a minimum configuration of 7.6 days. Additional modes extend this up to 15.2 days. My clock runs reliably in the 10.7 day mode using 9.2 pounds (4.2kg) of drive weight.

This document describes the assembly process.

Quick Start

If you have printed any of my other clocks, then you may already have most of the materials on hand. This clock uses many of the same parts. The bill of materials has been consolidated to a very small list.

Here is a quick summary of the steps if you are in a hurry to build the clock:

1) Print out the manual pages 6, 7, 9, 10, 12, and 18 as a quick reference.
2) Start gathering the non-printed components listed in table 5 on page 15.
3) Print the frame components listed in table 1 on page 6 using at 3 perimeters and 30% infill. You have a choice of dial styles and hands.
4) Print the gears listed in table 2 on page 7 using 5 perimeters. The 8 day runtime option is a good first choice for a very reliable clock.
5) Cut the metal arbors to match figure 8 on page 18.
6) Assemble the clock using the diagrams on pages 19 through 34.
7) Print a weight shell that will be large enough to run the clock using table 6 on page 27. A good starting point is about 0.8-0.9 pounds (0.36-0.40kg) per day of runtime.

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 two sizes of ball bearings that are readily available worldwide. Two sizes of metal shafts and two screw sizes 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. All parts simply fit together or attach using screws.

The gears in this clock are around 6.25 diametral pitch (6.25DP or MOD 4.064) which gives the largest 36 tooth gear a pitch diameter of 5.76” (146mm) and an overall size of 6.00” (152mm). The gear profile has a 14.5 degree pressure angle and optimizations for printing by merging the rim into the teeth. This gear profile looks great and prints with the minimum amount of material.

This clock was designed to be easy to build. Print the parts, cut the metal shafts to length, and assemble the clock. There are only a few non-printed parts to collect.

Printing the Parts

The parts to print are split into three categories. The frame is the largest group with just over half of the total print time. The gears need special considerations for optimal printing. Finally, the weight shell can be printed after most of the clock has been finished and you have determined how much weight is actually required.

The frame parts in the following table can be printed using 3 perimeters and 30% infill with 0.2mm layer heights. The print times shown were for a Prusa MK3S and can be used as a rough estimate for each part. Many newer printers are faster. The colors listed would create a clock similar to the one on the front cover. Obviously, you are free to be creative and use any colors you like.

Part Name	Color	Print	Time	Filament	Notes
frame_back_center	tan	1	11h 41m	162.50g	
frame_back_hanger	tan	1	4h 35m	52.93g	
frame_back_lower_a	tan	1	3h 34m	51.79g	
frame_back_lower_b	tan	1	0h 57m	1.36g	
frame_back_standoff_upper	tan	1	0h 37m	6.02g	
frame_back_standoff_lower	tan	2	0h 58m	9.76g	
frame_back_standoff_cover	tan	3	0h 39m	6.83g	
frame_back_upper_a	tan	1	4h 21m	62.09g	
frame_back_upper_b	tan	1	7h 13m	98.83g	
frame_dial_numbers	tan, white, purple	1	9h 51m	144.26g	Add color changes at 12.80mm and 14.60mm
frame_dial_roman	tan, white, black		9h 58m	145.09g	Add color changes at 12.80mm and 14.60mm
frame_front_lower_a	tan	1	2h 59m	40.09g	
frame_front_lower_b	tan	1	1h 33m	18.14g	
frame_front_upper_a	tan	1	4h 47m	67.91g	
frame_front_upper_b	tan	1	3h 47m	46.25g	
hand_gothic_hour_normal	gold	1	0h 25m	3.76g	
hand_spade_hour_normal	black, gold		0h 19m	3.33g	Add color change at 2.80mm
hand_gothic_minute_normal	gold	1	0h 28m	3.67g	
hand_spade_minute_normal	black, gold		0h 28m	4.46g	Add a color change at 2.80mm
pendulum_arm_a	tan	1	1h 53m	22.36g	5 perimeters
pendulum_arm_bc_short	tan	0	1h 16m	16.83g	Optional short pendulum arm
pendulum_arm_bc_normal	tan	2	1h 23m	18.60g	Normal length pendulum arm
pendulum_arm_bc_long	tan	0	1h 30m	20.37g	Optional long pendulum arm
pendulum_arm_d	tan	1	1h 20m	15.77g	
pendulum_bob_back	gold	1	0h 58m	15.47g	
pendulum_bob_front	gold	1	3h 42m	44.88g	
pendulum_nut	tan	5	0h 17m	2.63g	Used for pendulum bob and back frame standoffs
winding_arm	tan	1	1h 18m	11.90g	
winding_knob	gold	1	0h 58m	10.09g	
	Total	**32**	**75h 8m**	**971.26g**	

Table 1: Printed frame parts

The gears have been optimized to print best using 5 perimeters. Arachne is best for the gears in this clock.

Part Name	Color	Print	Time	Filament	Notes
gear_spacers	purple	1	2h 35m	18.07g	All spacers in one file
gear0_pallet	purple	1	4h 5m	41.08g	
gear1_25_8_esc	purple	1	5h 2m	26.88g	0.12mm layer height
gear2_36_8	purple	1	3h 3m	28.05g	
gear3_36_8	purple	1	3h 44m	35.20g	
gear4_8	purple	1	0h 37m	5.56g	
gear4_36_8	purple	1	3h 6m	29.34g	
gear5_36_12	purple	1	3h 13m	34.29g	
gear6_32	purple	1	1h 39m	17.10g	
gear7_15	purple	1	3h 27m	30.60g	
gear7_36_ratchet	purple	1	4h 21m	47.48g	
gear7_clicks	purple	1	1h 21m	14.97g	
gear8_36_8days	purple	1	7h 58m	82.96g	Print one of these gears for your desired runtime. The 8 day option is the easiest to get running reliably.
gear8_36_11days	purple		7h 3m	70.31g	
gear8_36_15days	purple		6h 2m	60.00g	
	Total	**13**	**43h 15m**	**398.93g**	

Table 2: Printed gears

The weight shell works best with 4 perimeters for extra strength. The numbers in the file names indicate the diameter in inches. See the section near the end to determine which version to print.

File Name	Color	Print	Time	Filament	Notes
weight_shell_bottom_2p4	Gold	0	0h 47m	10.88g	Parts used to build the 2.4" diameter weight shell
weight_shell_top_2p4	Gold	0	9h 57m	96.05g	
weight_shell_short_2p4	Gold	0	8h 29m	81.17g	
weight_shell_quarter_2p4	Gold	0	5h 20m	47.32g	
weight_shell_bottom_2p6	Gold	0	1h 0m	14.05g	Parts used to build the 2.6" diameter weight shell
weight_shell_top_2p6	Gold	0	11h 0m	107.32g	
weight_shell_short_2p6	Gold	0	9h 19m	90.12g	
weight_shell_quarter_2p6	Gold	0	5h 47m	51.98g	
weight_shell_bottom_2p8	Gold	1	1h 12m	17.49g	Parts used to build the 2.8" diameter weight shell
weight_shell_top_2p8	Gold	1	12h 5m	119.19g	
weight_shell_short_2p8	Gold	0	10h 10m	99.56g	
weight_shell_quarter_2p8	Gold	1	6h 14m	56.81g	
weight_shell_bottom_3p0	Gold	0	1h 26m	21.34g	Parts used to build the 3.0" diameter weight shell
weight_shell_top_3p0	Gold	0	13h 13m	132.04g	
weight_shell_short_3p0	Gold	0	11h 3m	109.72g	
weight_shell_quarter_3p0	Gold	0	6h 40m	61.62g	
weight_shell_bottom_3p2	Gold	0	1h 41m	25.62g	Parts used to build the 3.2" diameter weight shell
weight_shell_top_3p2	Gold	0	14h 28m	145.49g	
weight_shell_short_3p2	Gold	0	12h 5m	120.36g	
weight_shell_quarter_3p2	Gold	0	7h 10m	66.52g	
weight_shell_pulley	Gold	1	0h 29m	4.76g	Used for all sizes of weight shells
	Total	**4**	**20h 0m**	**198.25g**	

Table 3: Printed weight shell parts

Notes: Most parts can be printed using somewhat generic settings with at least 3 perimeters, 30% infill, and 0.2mm layer heights. Exceptions are listed in the tables above. I typically use 7 top layers, 6 bottom layers, random seam positions, and 0.08mm elephant foot compensation. Supports are never needed.

All of my previous clocks have gear profiles that were optimized with the classic slicing algorithm. The new Arachne slicing engine leaves tiny bits of filament at every gear tooth, so I usually recommended to use the classic slicer. The gear profiles in this clock were optimized to work best with the Arachne slicer. The gears can be printed using the classic slicer, but they are slightly better with Arachne. I used Arachne for this entire clock, only changing the number of perimeters for some parts.

Total print time for this clock is close to 140 hours on a Prusa MK3S using about 1.5kg of PLA filament. The dial is the largest component at 8" in diameter needing a printer with at least a 205x205mm print area. A smaller version of this clock may not be possible without drastically changing the gear profiles.

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. My new favorite gear color is MatterHackers dual color Blue Raspberry Quantum PLA. It is a bit pricey, but looks incredible.

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

Several parts have options to make different looking clocks. For example, the dial is available with a classic roman numeral dial or a simple number dial. Look at both in the slicer and select the one you prefer. There are also two different styles of hands with a loose, normal, or tight fit on the shaft. Start with the normal options and print one of the others if needed.

The weight shell should be printed last after you have determined how much weight your clock needs to be stable. There are five diameter options and an optional 1/4 height extension to add additional weight if needed. More details are near the end of this document.

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 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. Also, check that the hour hand gear spins easily where it passes through the front dial.

The following diagrams show the various gears used in the clock. The numbers in the file names help indicate where the gears get placed and the number of teeth. There are three 36 tooth gears with 8 tooth pinions. They can be distinguished by pictures hare and the side profiles in a few pages.

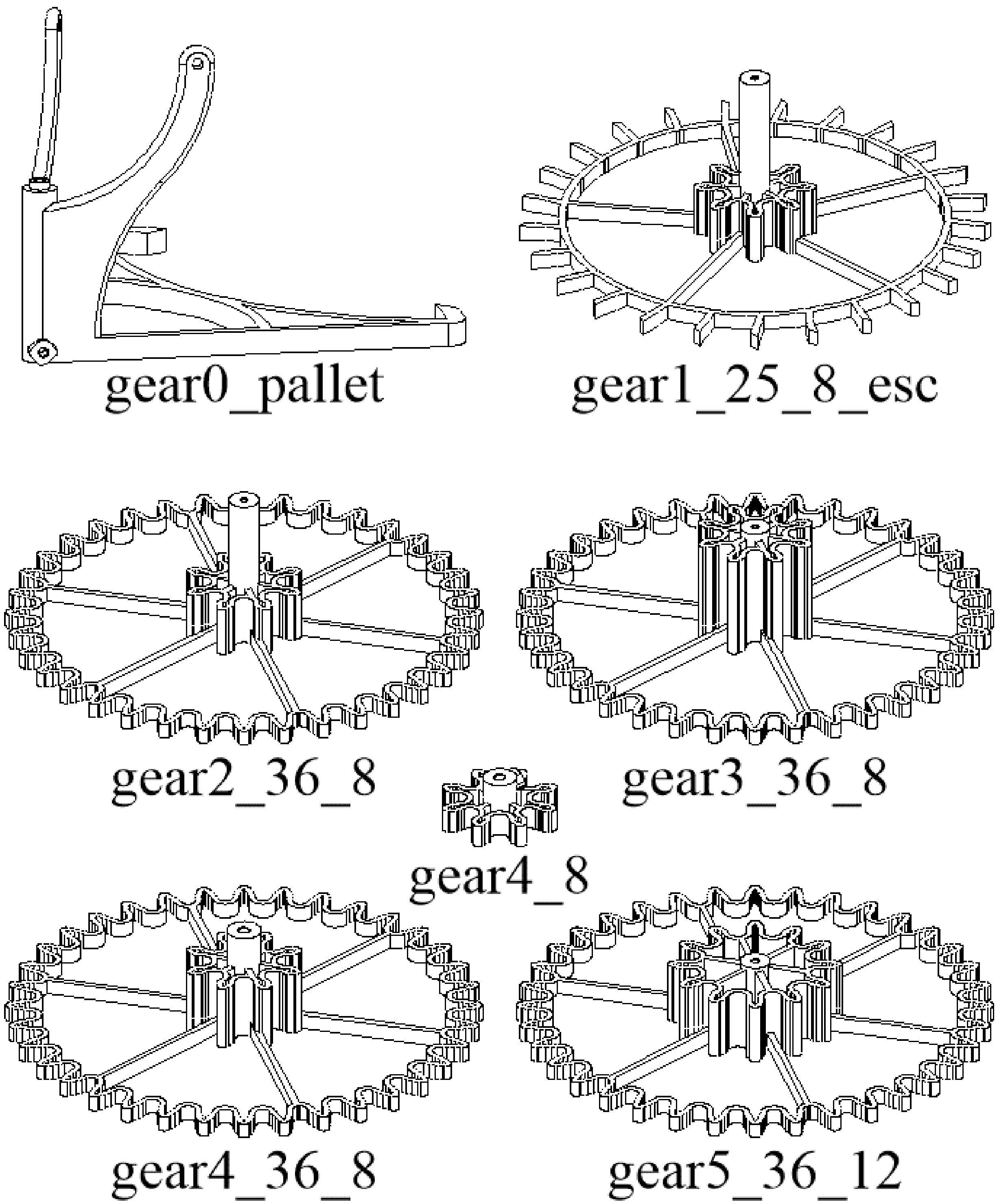

Figure 1: Gear diagrams (page 1)

These are the remaining gears used in the clock. Gear 8 has three versions to support different runtimes. The 8 day option is a good starting point. It can be changed later by only re-printing one new gear. The longer runtime options are often less reliable and may require additional drive weight.

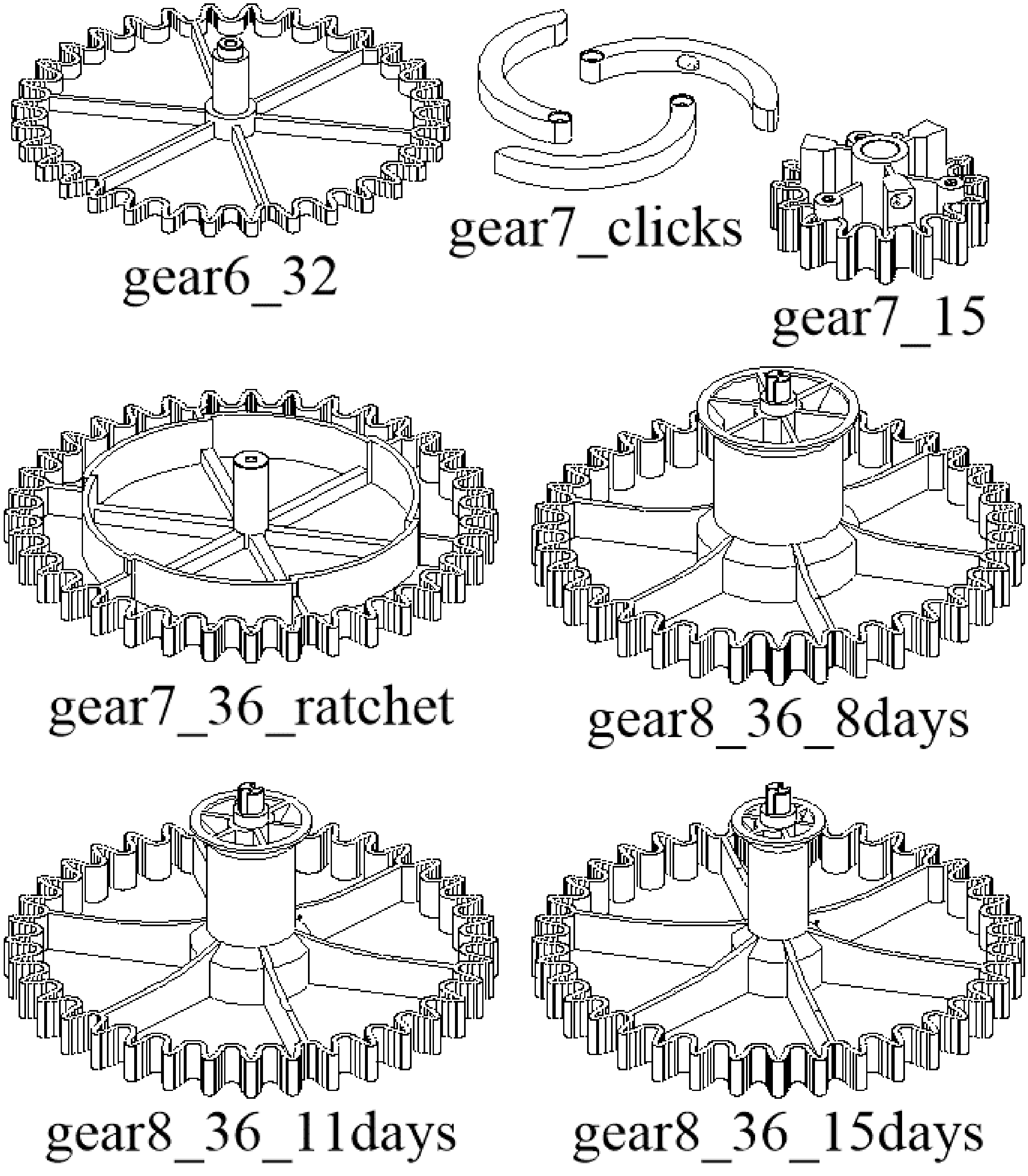

Figure 2: Gear diagrams (page 2)

These are the side profile of the three gears with 36 teeth and 8 tooth pinions.

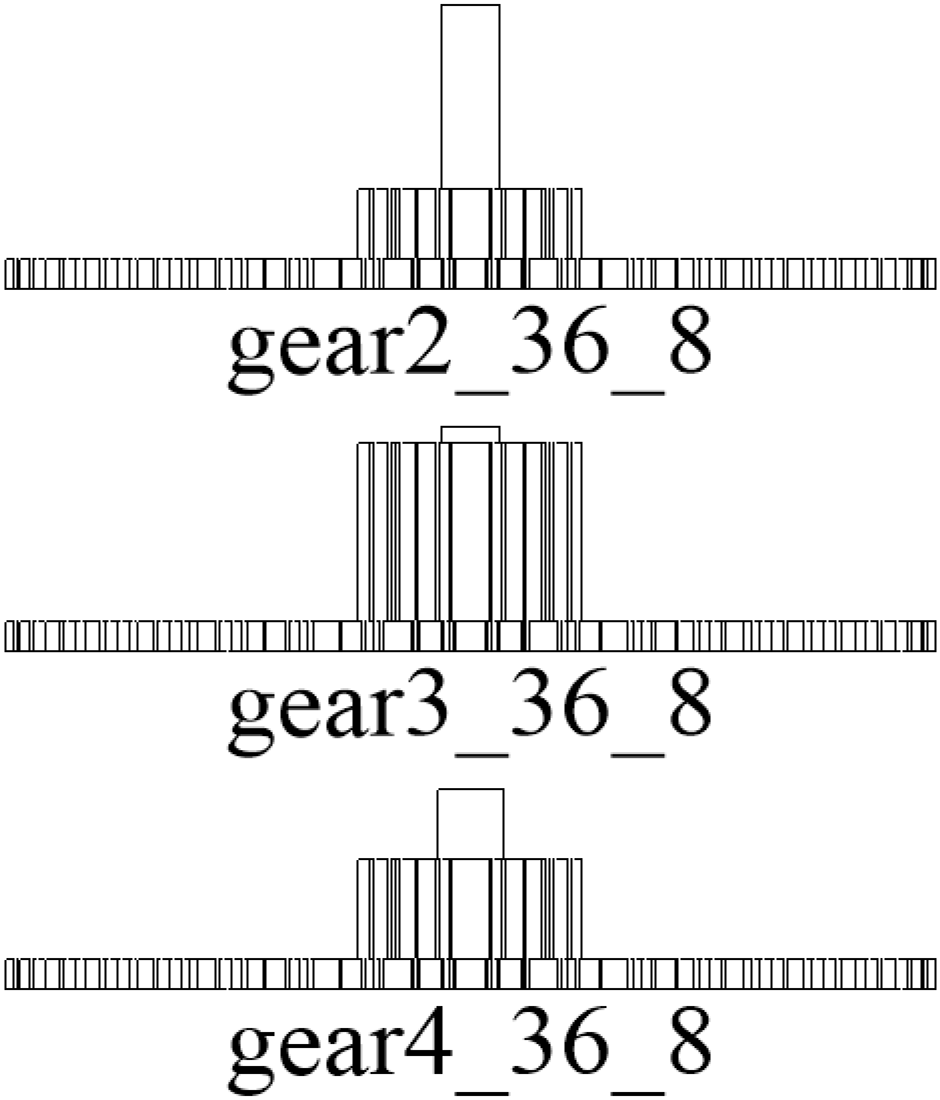

Figure 3: 36 tooth gear details

Many gears use spacers to hold their position between the back and front frame. The documentation will list them as spacer 0, spacer 1, etc. according to the gear they are associated with. All spacers are combined into a single file to be printed one time. The following diagram shows the side, top, and 3D profiles of the spacers to help distinguish them. Gear 7 uses two identical spacers that are slightly shorter than spacer 0.

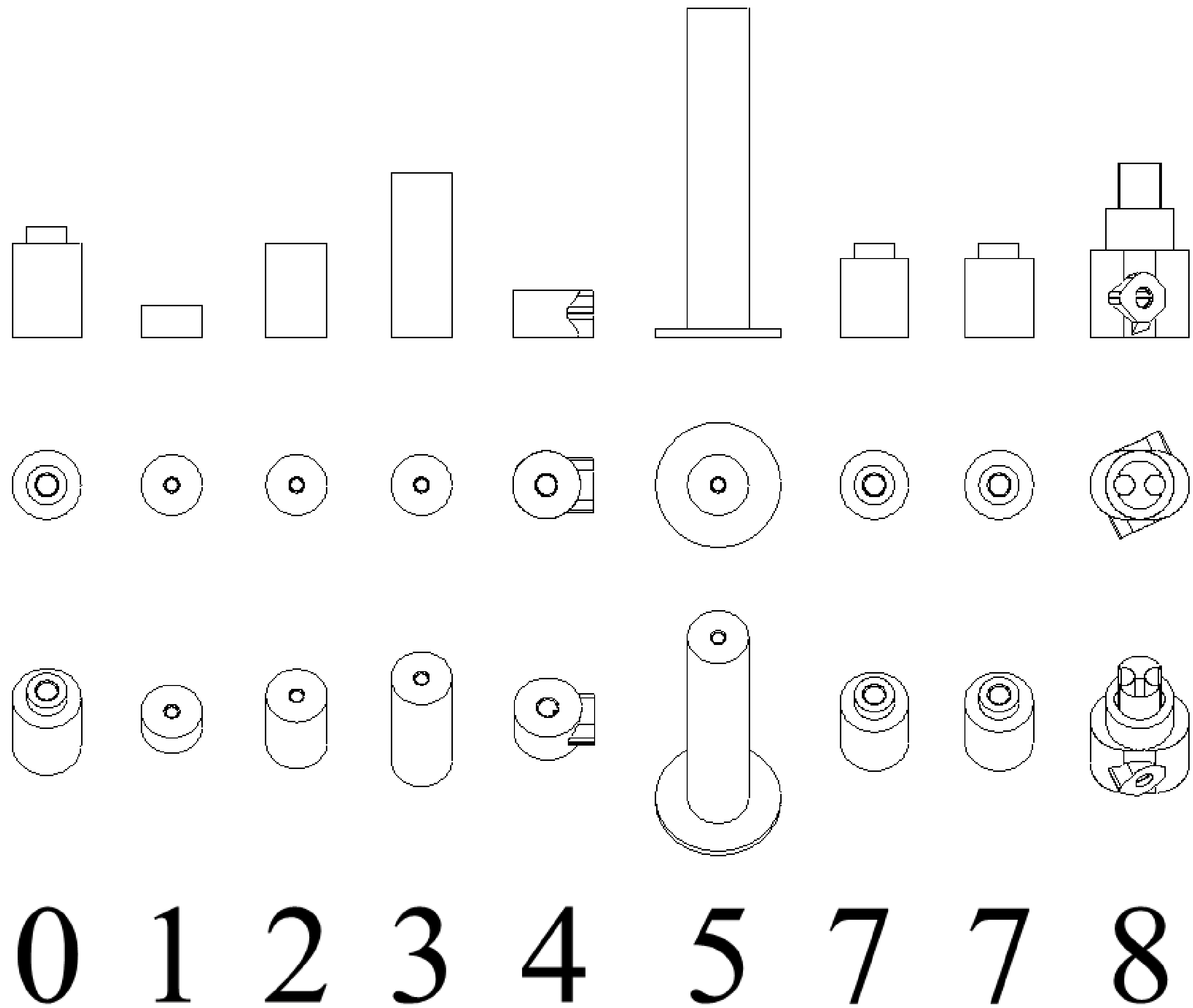

Figure 4: Spacer summary

Print File Options

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

Component	Option	File Name Example	Description
Dial	simple numbers	frame_dial_numbers	Front dial with numbers
	Roman numerals	frame_dial_roman	Front dial with Roman numerals (shown on the front cover)
Hand Style	spade	hand_hour_spade_normal	Simple spade hands
	gothic	hand_hour_gothic_normal	Ornate hand style
Hand Fit	loose	hand_hour_spade_loose	Hands that fit loosely on the shaft
	normal	hand_hour_spade_normal	Hands with a default fit on the shaft
	tight	hand_hour_spade_tight	Hands with a tight fit on the shaft
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	7.6 day runtime	gear8_36_8days	Safest option with a 7.6 day runtime
	10.7 day runtime	gear8_36_11 days	Option with a 10.7 day runtime
	15.2 day runtime	gear8_36_15 days	Option with a 15.2 day runtime

Table 4: 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. 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. 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 14.60mm to highlight the numbers. Another color change can be added at 12.80mm to add lighter color dial. My clock starts with a tan base, ivory at 12.80mm, and black at 14.60mm for the numbers. Both the roman numeral and simple number dial styles have similar thicknesses, so the layer changes occur at the same heights.

PrusaSlicer has a really easy method for adding layer changes.

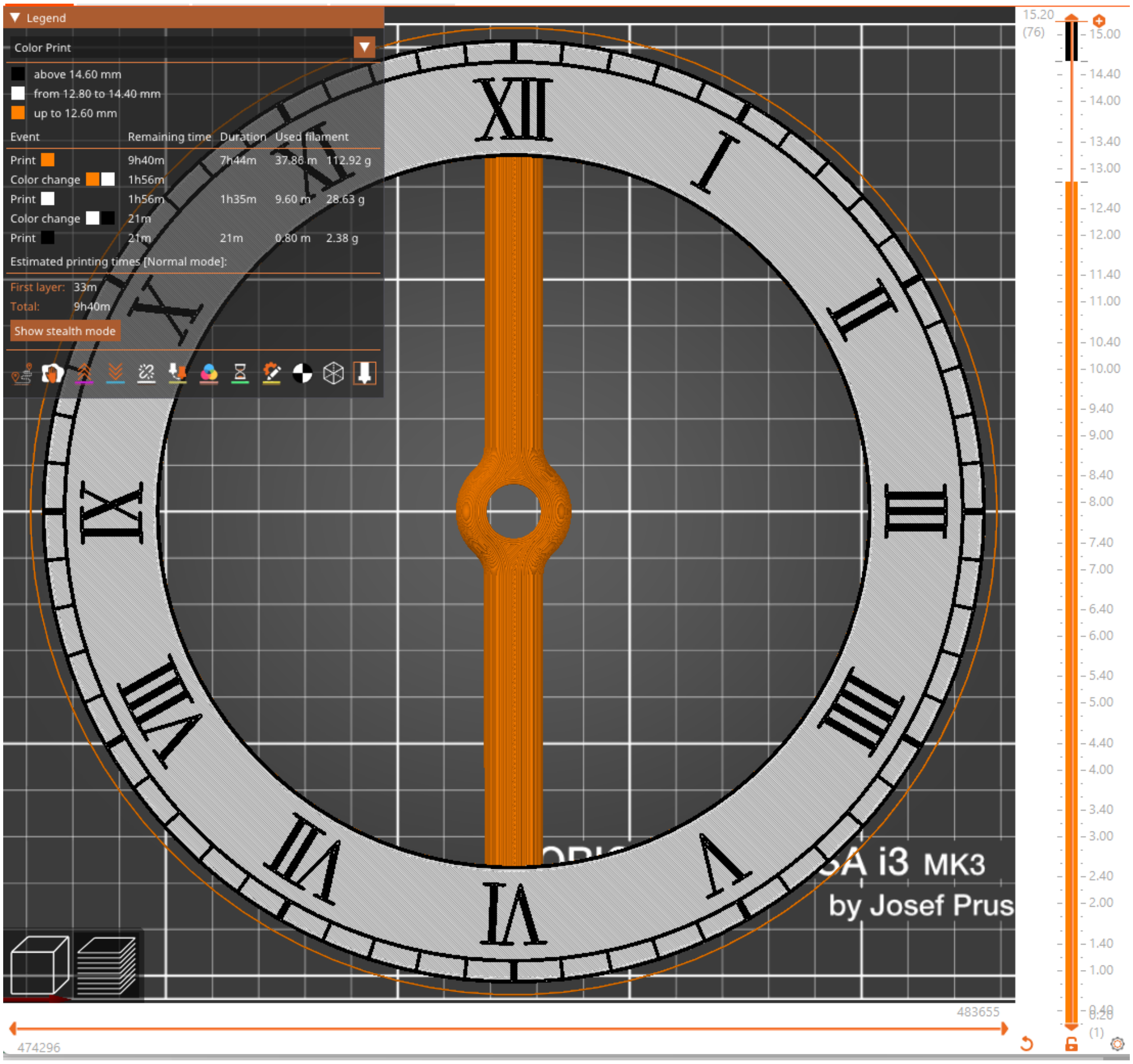

Figure 5: Layer changes for dial

There are two options for the clock hands. The gothic style hands are intended to print as a solid color, but the spade hands look best with a layer change at 2.80mm to highlight the perimeter. Experiment with different colors. Sometimes dark colors look good, but lighter colors may be more visible if you have dark colored gears or a dark colored wall.

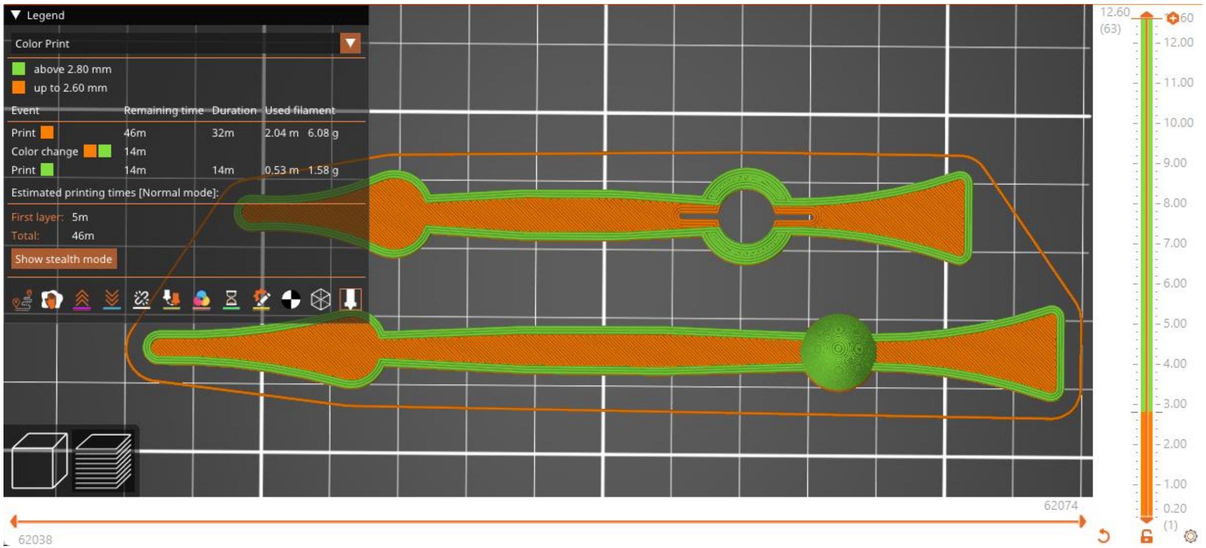

Figure 6: Clock spade hands layer change

Additional Components

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

Qty	Component Imperial or (metric) sizes	Notes
~34	#6x3/4" flat head wood screw	Metric equivalent has a 3.5mm diameter and a length of 18-20mm. M3.5x20mm is the closest size.
~8	M3x8mm socket head screw	6-10mm lengths may also work in most locations
1	8x1-1/2" pan head wood screw or nail	For hanging clock on wall. Metric size is around 4mm in diameter and 40mm long.
24" (0.61m)	3mm stainless steel or brass rod	See cut list a few pages ahead.
13" (0.32m)	1/16" or 1.5mm music wire	1/16" or 1.5mm both work equally well. See cut list a few pages ahead.
10-12' (3-4m)	microfilament fishing line	I use PowerPro Spectra Fiber braided fishing line 65 lb. test, Eq Dia 16
~6-9 lb. (3-4kg)	BBs (preferred) or lead shot	BBs are a great option. Lead shot allows a smaller weight shell, but is slightly toxic.
5	623RS bearings (3x10x4mm)	Open bearings are best, but rubber seals (623RS) can easily be removed. Metal shields (623ZZ) are difficult
2	608 bearings	Larger size bearings often used in skate boards.
4	click pen springs	Use springs from ball point pens

Table 5: Non-printed parts

Notes:

There are a few fully 3D printed clocks on the internet by other designers. It is a great challenge and shows off a 3D printer's capabilities, but they are often poor timekeepers. Most have extremely short runtimes due to the high friction from large diameter printed shafts. I certainly do not want to wind a clock several times per day. My clocks use a few hidden metal parts to reduce friction and provide useable runtimes. Ball bearings are used to support the pendulum and small diameter steel rods are used as arbors.

#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. M3x8mm socket head screws are used as set screws that thread directly into the PLA. One long 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.

The 3mm diameter rod needs to fit inside the 623 ball bearings. It sometimes comes slightly oversized and will need to be reduced to fit the bearings. I place one end in a power drill and pinch it with sandpaper to reduce the diameter. A metal file can also work.

Music wire is great for the small diameter arbors because it is very strong, although almost any metal rods should work in this clock. The small arbors 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 or copper for the weights. 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 tried other options and cannot find any better method to support the pendulum. Clock suspension springs have been used for centuries, but only available at specialty clock supply stores. 3D printed knife edges could work with a 1-2 day clock, but have 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 623 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 larger size 608 bearings to support the winding drum are commonly used in skateboards and rollerblades. They are relatively cheap. Any quality can be used since they only rotate once every 10.8 hours. This clock uses a new winding key design that is simple to make and also super reliable. Two pieces of 3mm rods pass through the center of the large bearings for the winding key. My previous clocks used a brass rod with a tricky to machine slot on one end. The new design only needs the rods cut to the proper length.

The final items are springs from ball point pens. You may have some laying around already. One spring will be used for the minute hand adjustment and three springs are used in the ratchet. The minute hand adjustment spring must be large enough to slide over the 3mm rod. The remaining three springs can be any size.

Here is a picture showing the non-printed parts (not including the 3mm and 1.5mm rods).

Figure 7: Non-printed components

Below is a diagram showing the cut metal parts used in this clock. Most lengths are not very critical. Any length within 1-2mm of the target is usually fine. The music wire rod is usually hardened and very stiff. The cutters need to be designed for cutting hardened steel. A metal cutting disk in a Dremel tool is another option. The 3mm rod can be softer brass or stainless steel. It is easy to cut with a hacksaw. Clean up any burrs on the ends using a grinding wheel or metal file.

The 4.75" minute hand arbor needs a flat on one end to fit the minute hand. Print the hands and grind a notch until the arbor can be pushed into the minute hand.

The diagram below is approximately to scale when printed.

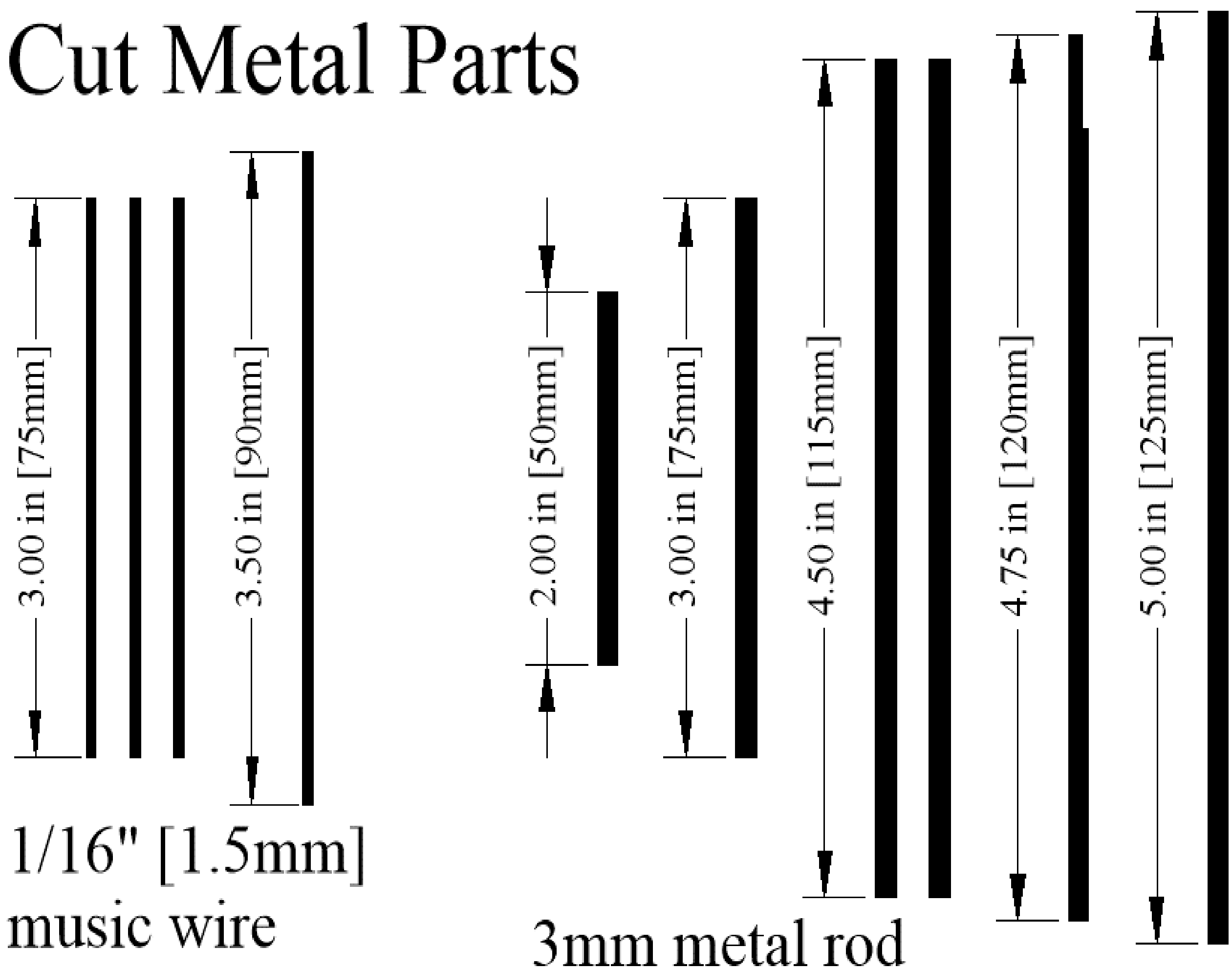

Figure 8: Cut metal parts

Component Pre-Assembly

A few components can be pre-assembled before adding the gears into the clock. The frame is built up using several printed components to make the larger back and front frame modules. Several gears have multiple components that are easier to build ahead of time.

Back Frame

The back frame has five printed parts held together using #6x3/4" flat head wood screws. The screws are common wood screws from the local hardware store in the US with around 18 threads per inch. The closest metric equivalent size is M3.5x19mm, although anything between M3.5x18mm and M3.5x20mm is acceptable. The printed alignment pegs provide most of the holding strength.

Follow the diagram below to assemble the main portion of the back frame. A 608 skateboard bearing gets enclosed in a pocket and covered by frame_back_lower_b.

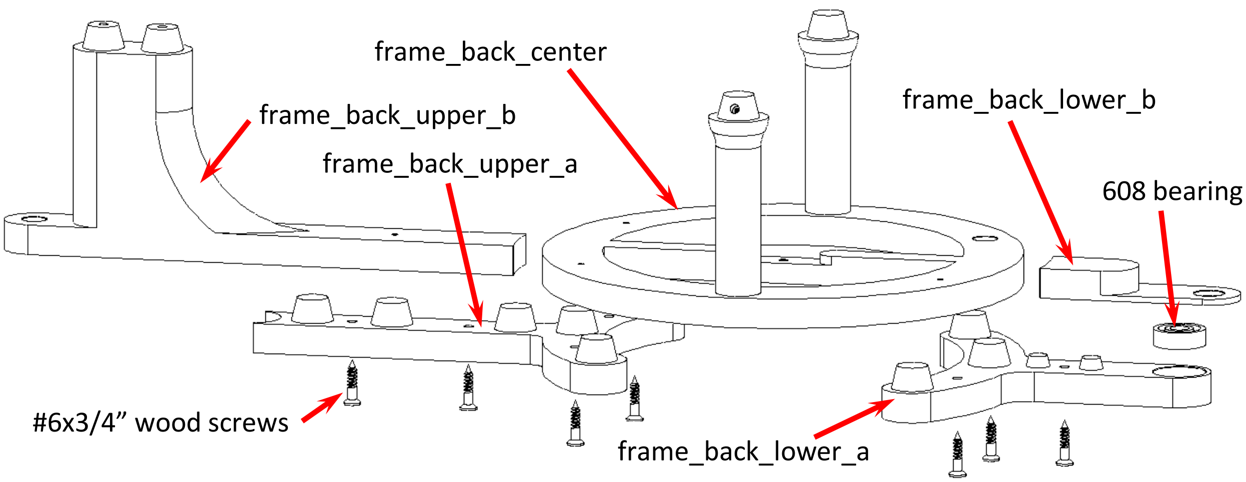

Figure 9: Back frame assembly

The frame_back_hanger and back standoffs are added as shown in the diagram below. The frame back_hanger needs to be oriented so the keyhole hanger is facing the proper direction.

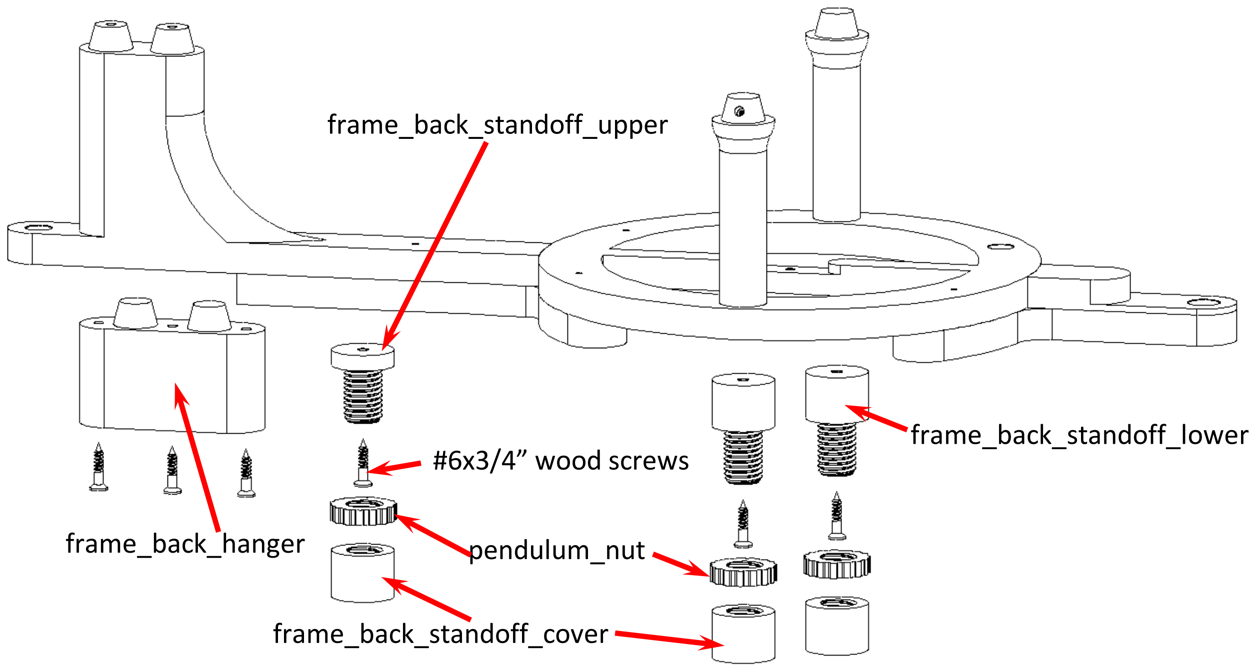

Figure 10: Back frame standoffs

The standoffs have adjustable lengths to allow the frame to be perfectly leveled against an uneven wall. The final depth will be determined by your wall. Start with a gap size of around 1/4” (6mm).

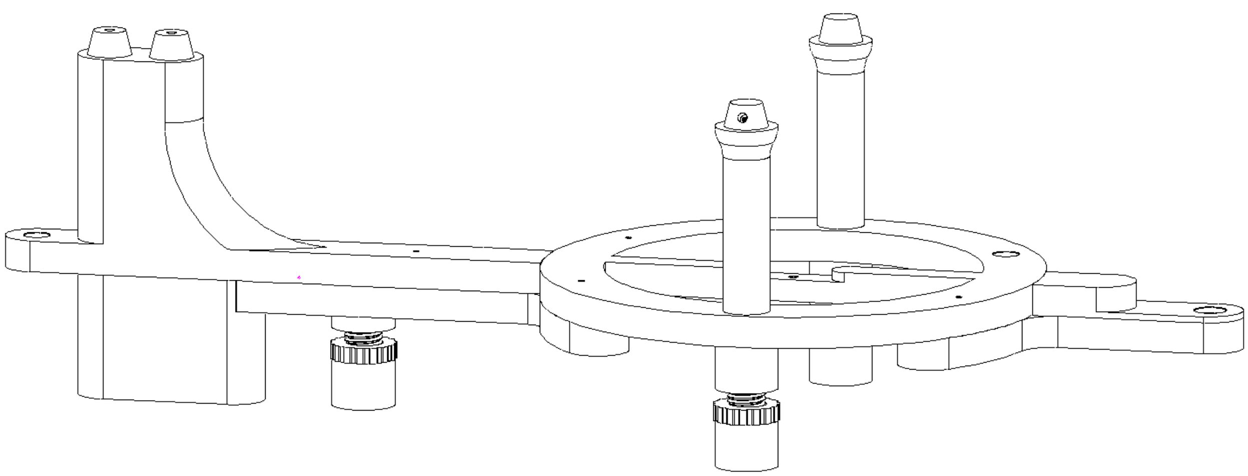

Figure 11: Completed back frame

Front Frame

The front frame assembly is shown below. The dial can be either roman numerals or simple numbers. A 608 bearing is enclosed in a pocket and covered by front_frame_lower_b.

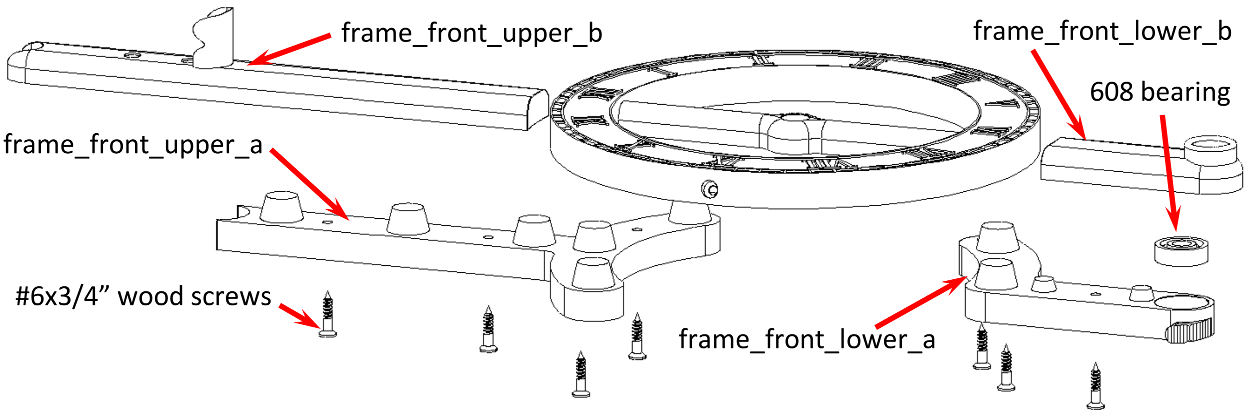

Figure 12: Front frame assembly

Test that the front and back frame pieces fit together easily. The top two screws have a single support layer that the screw should easily push through. The two lower screws go in at an angle pointing downwards.

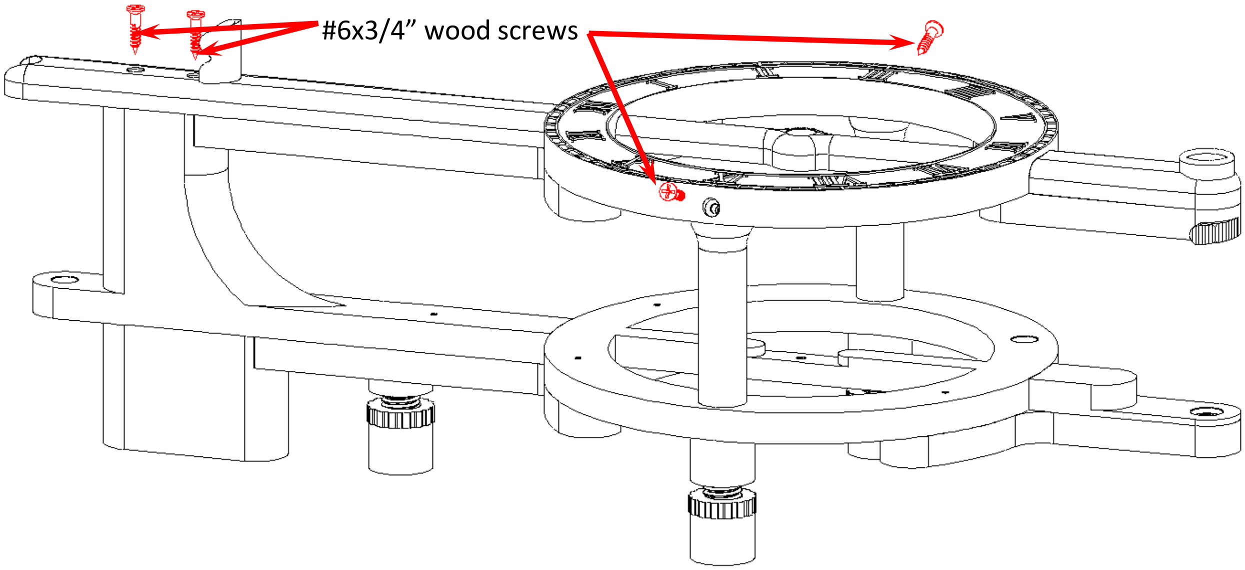

Figure 13: Fully assembled frame

If desired, you can hang the frame on the wall and adjust the depth of the levelling standoffs without any gears in the way. You should be able to pull down on the front of the frame without any visible sagging.

Gear Sub-Assemblies

Several components can be pre-assembled now before adding gears into the clock. This includes the pallet, gear 4, ratchet, and the winding drum.

The pallet bearings support the pallet and pendulum. Low friction bearings are important for a reliable clock that runs using the minimum amount of drive weight. Luckily, the cheapest 623 bearings available in sets of 10 on eBay or Amazon can be used in the clock. The 623 bearings have a 3mm inner diameter, 10mm outer diameter, and 4mm thickness. The factory grease should be removed and replaced with or dry Teflon lube (or very light oil). Select the two bearings that appear to have the lowest friction for the pallet assembly. Any of the remaining bearings can be used in the ratchet and weight shell.

Start the pallet assembly by checking that the arbor fits into the bearings. Place the arbor in a power drill and sand or file it slightly until the bearings fit. Slide the arbor into the pallet with spacer 0 and a bearing at the top end. Another bearing goes on the lower end. Position the arbor so it extends just past the top bearing and secure the position with an M3x8mm set screw.

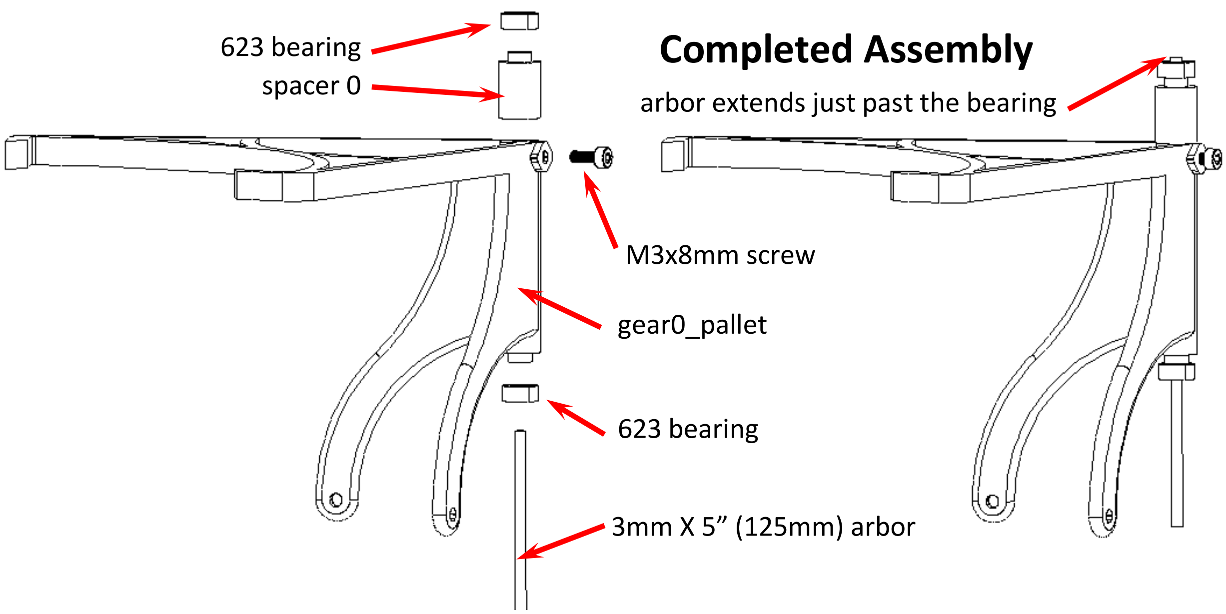

Figure 14: Pallet assembly

The gear 4 sub-assembly creates a friction clutch to allow setting the time while the clock is running. M3x8mm set screws hold gear4_8 and spacer 4 tight to the shaft. The pen spring applies pressure against gear4_36_8 allowing it to slip when setting the time. A notch needs to be ground or filed on one end so gear4_8 will always rotate when the minute hand is moved. Adjust the positions to match the diagram on the right.

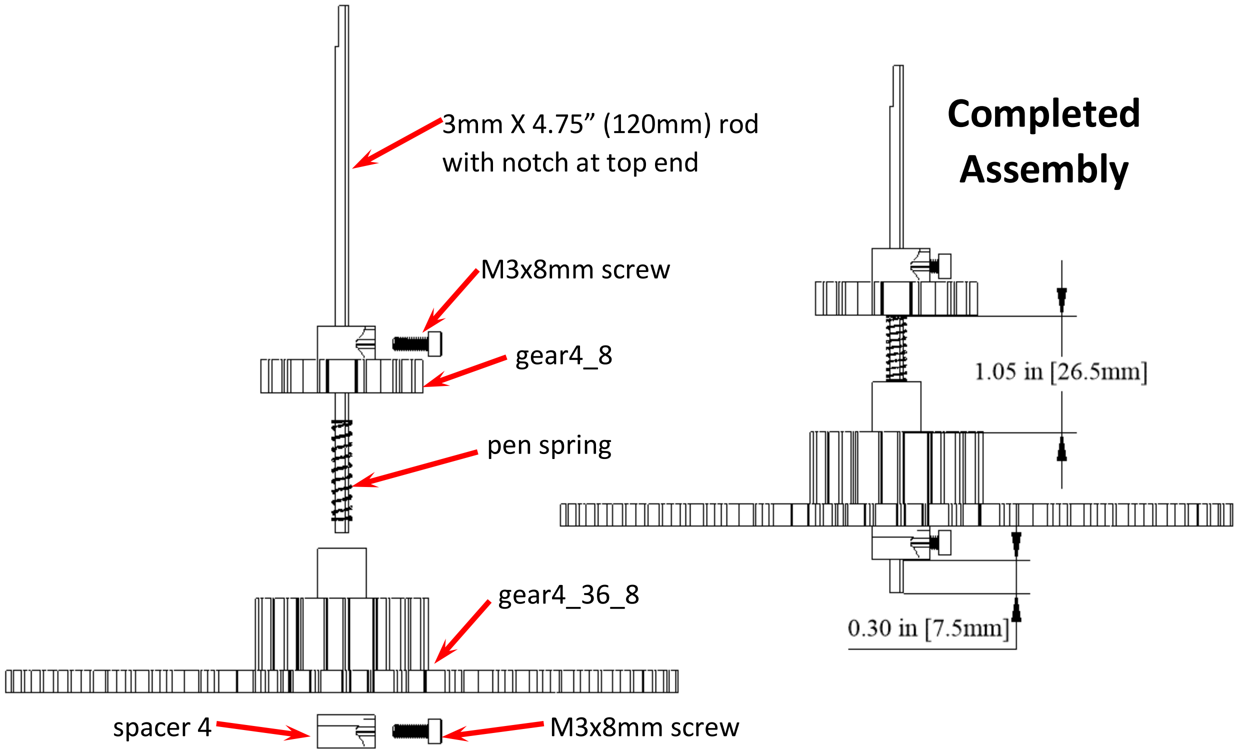

Figure 15: Gear 4 assembly

The ratchet sub-assembly attaches gear7_clicks to gear7_15 using three #6x3/4” wood screws. Tighten the screws most of the way and loosen them so the clicks can swing freely. Add three pen springs into the pockets and place the module on top of gear7_36_ratchet. You may need to sand or file down the hub on gear7_36_ratchet for it to rotate freely. Add a tiny bit of grease to the tips of the clicks to help them slide easily.

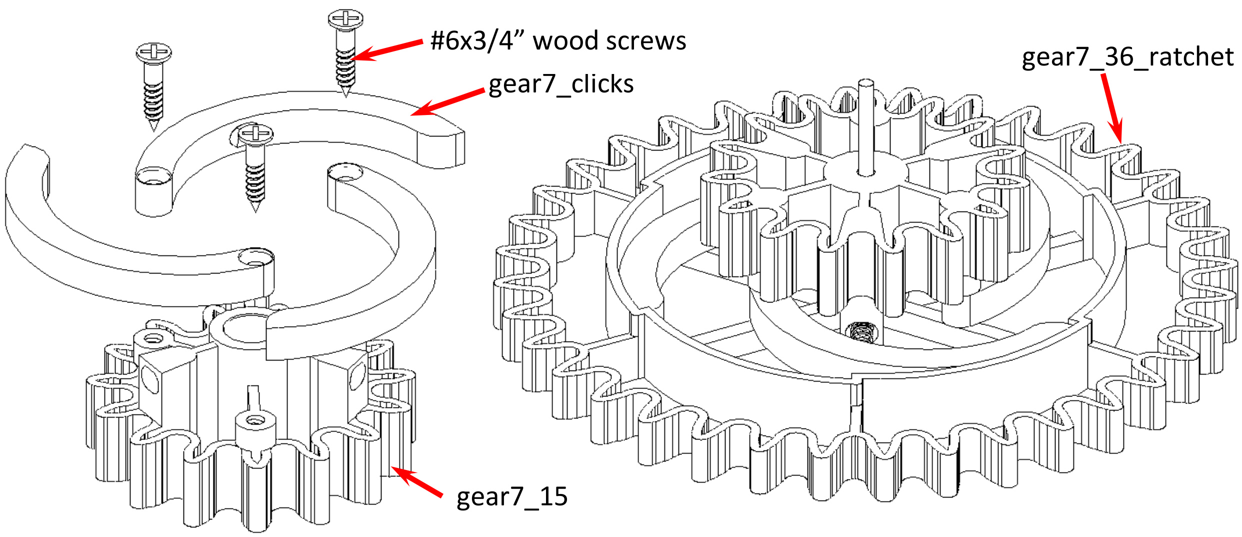

Figure 16: Ratchet assembly

The ratchet 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 have enough pressure engage with the ratchet.

Add a spacer 7 and a 623 bearing on both ends of the arbor. Both spacer 7s are the same size. The ratchet bearings run at really low speed, so select the best bearings for the pendulum and use any of the rest for the ratchet. The arbor ends might need to be sanded down so the bearings fit. The completed ratchet assembly looks like this.

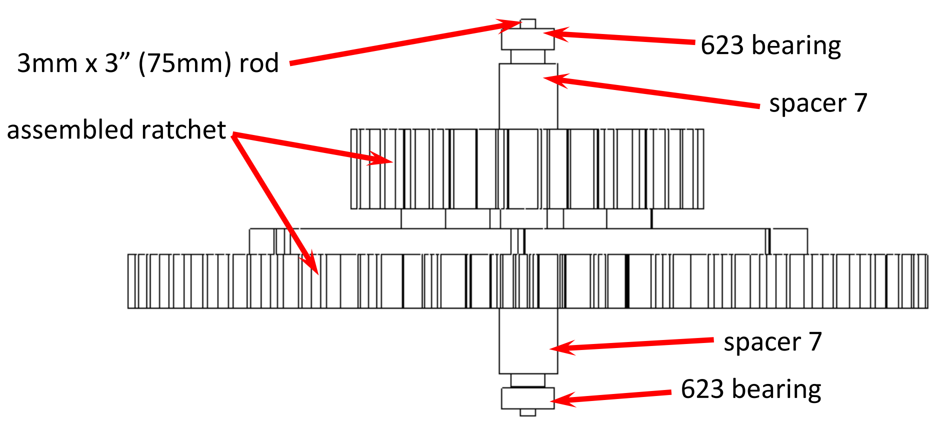

Figure 17: Completed ratchet

The winding cord should be added to the winding drum before assembling the clock. Multiple versions of the winding drum are available with different runtime options. The largest diameter drum is the easiest for building a functional clock and it still provides a respectable 8 day runtime. Longer runtimes are possible, with the risk of less stability or needing additional drive weight. I run my clock with the 11 day option using 9.2 pounds (4.2kg) of drive weight. It will just barely run in 11 day mode with 6.6 pounds (3.0kg) of drive weight, but is extremely reliable with the larger 9.2 pound weight. Other clocks may require different ratios of drive weight depending on friction in your gear train.

The winding drum assembly needs the cord tied off and wrapped around the barrel. 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 (3.0-3.6m) 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. Many other cord styles can also be used. Some are specifically designed for clocks.

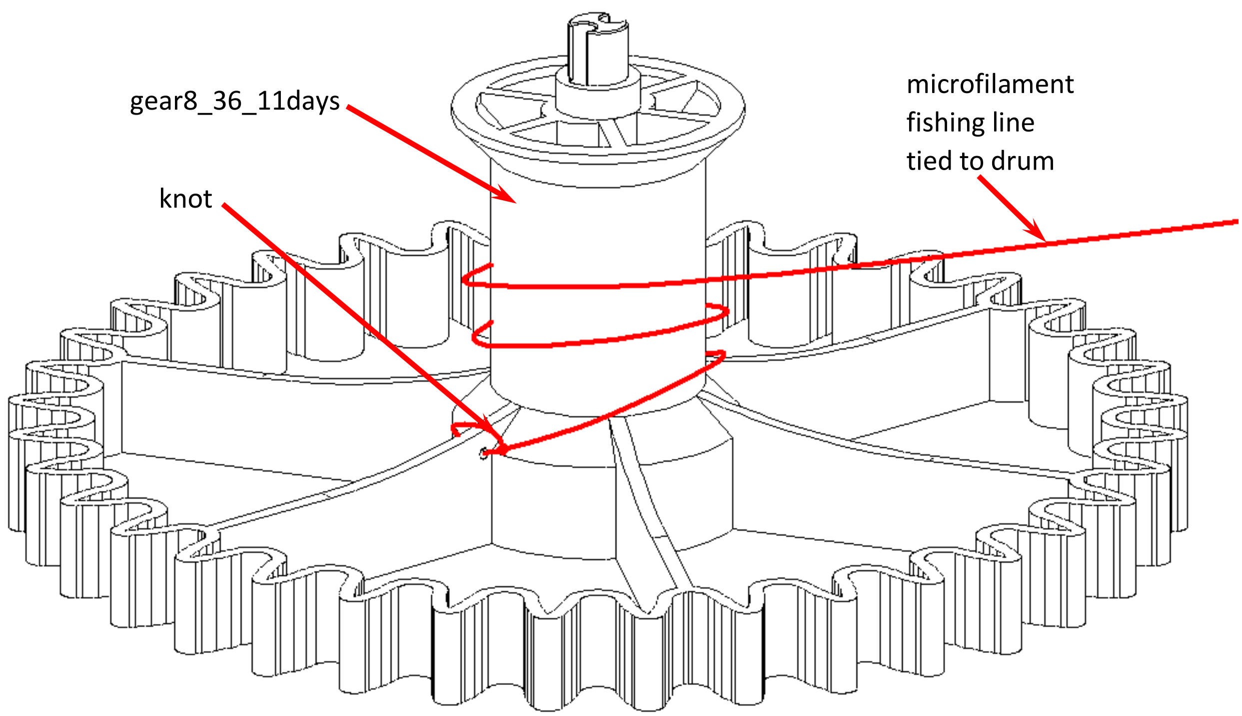

Figure 18: Gear 8 assembly

Check that the two pieces of 3mm rod will fit through the holes in gear 8 and spacer 8. Drill out the holes using a 1/8” or 3.2mm bit if needed. Add the rods into gear 8, add spacer 8, and secure the rod position using two M3x8mm set screws. The completed gear 8 assembly looks like the following picture.

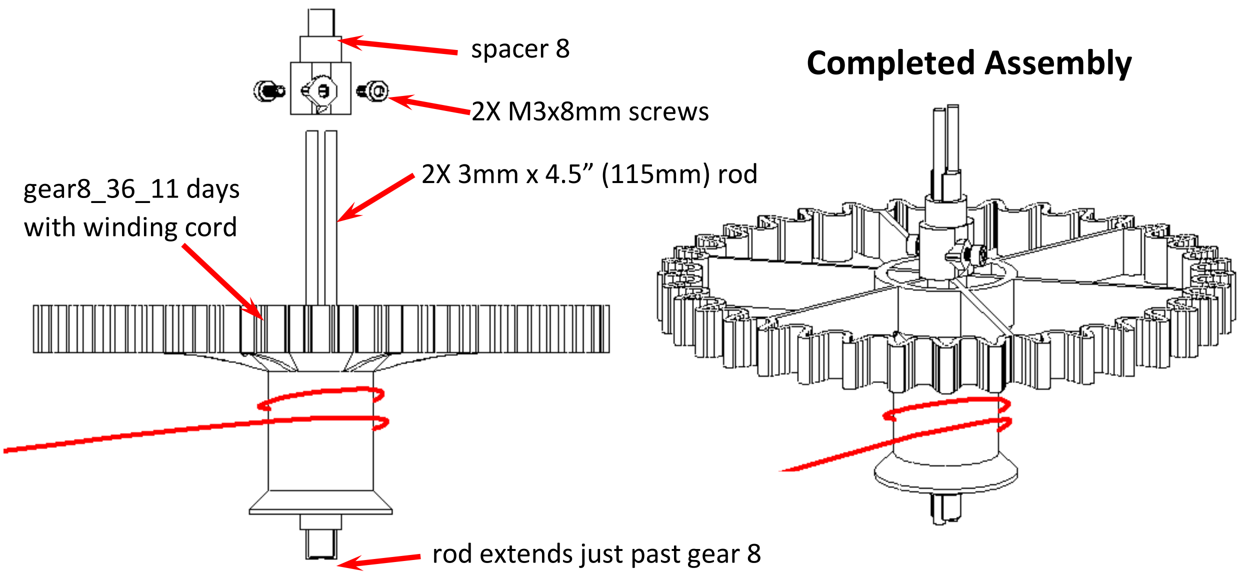

Figure 19: Completed gear 8

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

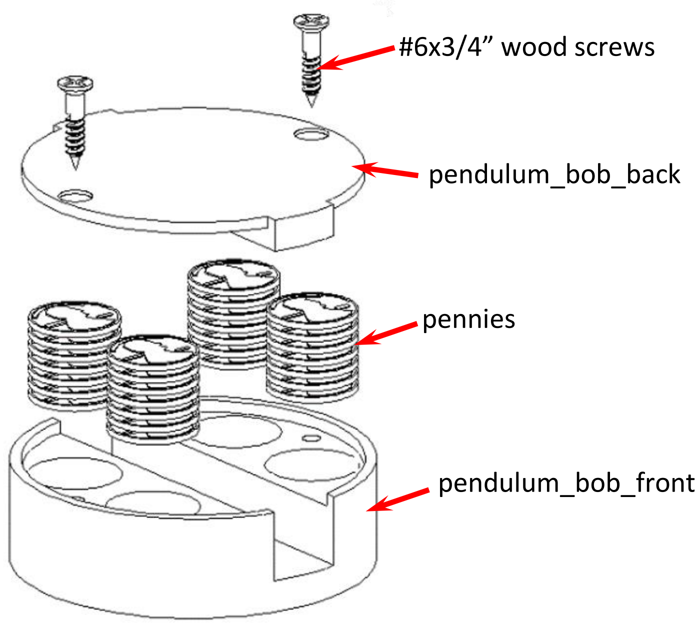

Figure 20: Pendulum bob

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

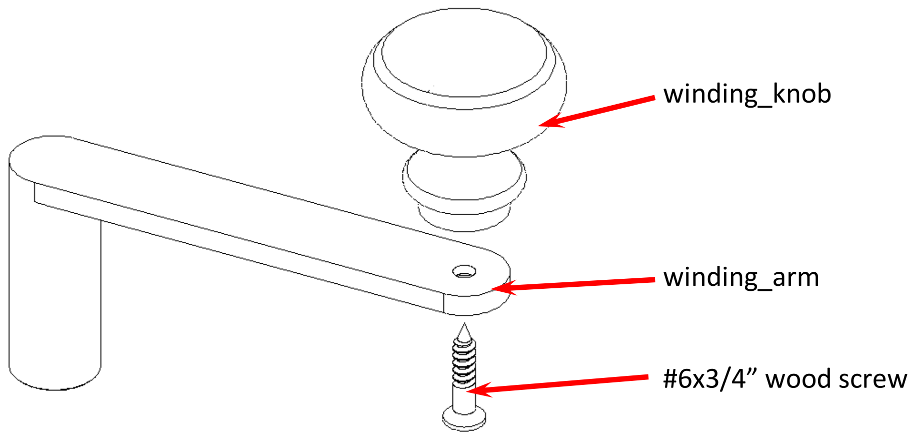

Figure 21: Winding key

Weight Shell

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

The weight shell is filled with BBs or lead shot to provide energy to keep the clock running. Longer runtime options will require additional drive weight. 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 25% larger than one filled with lead shot to achieve with the same weight. BBs are less toxic and easier to find than lead shot, so it makes sense to use BBs to fill the weight shells.

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

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

Table 6: Approximate weight shell capacities

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

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

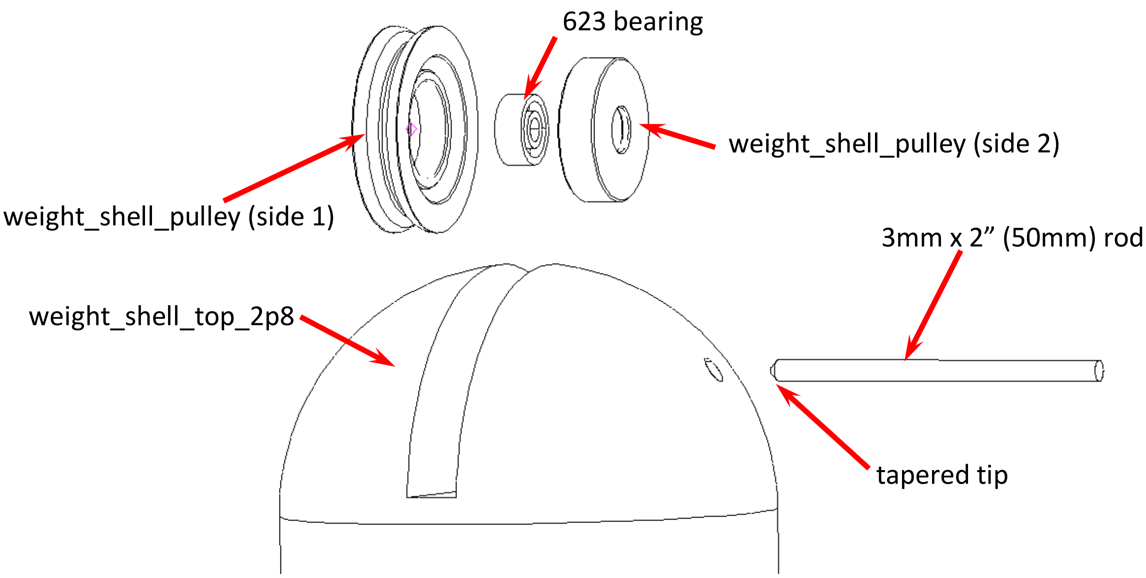

Figure 22: Top portion of weight shell

Turn over the weight shell and fill it with BBs (or lead shot). Take appropriate safety precautions if using lead shot. Assembly should be obvious when you see the parts. 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.

Building the Clock

Reducing friction is very important in a mechanical clock. The clock will tick over a 100,000 times per day, with the weight shell dropping only a few inches. 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. I have also used lightweight oil and thick lithium grease on PLA without any detected side effects.

Most of the printed parts are designed to fit loosely over their shafts. Different printers and different filament might produce different sized holes. It is 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. 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 works well. A 1/16” bit works great for 1.5mm shafts.

The gear profiles used in this clock have fairly loose tolerances and can accept some printer inaccuracies. I use around 0.08mm of elephant foot compensation while printing and rarely have to worry about any print quality issues other than drilling out a few holes. I have heard reports that the faster coreXY machines create small inner hole sizes, especially with silk PLA. They will need to be drilled to fit the arbors. Do a quick inspection of the gears and clean up any rough surfaces if needed.

Final Assembly

These steps show the gears as they are inserted into the clock. An assembly video will be posted to go along with these printed instructions. Each step shows the gear being added with red highlights.

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

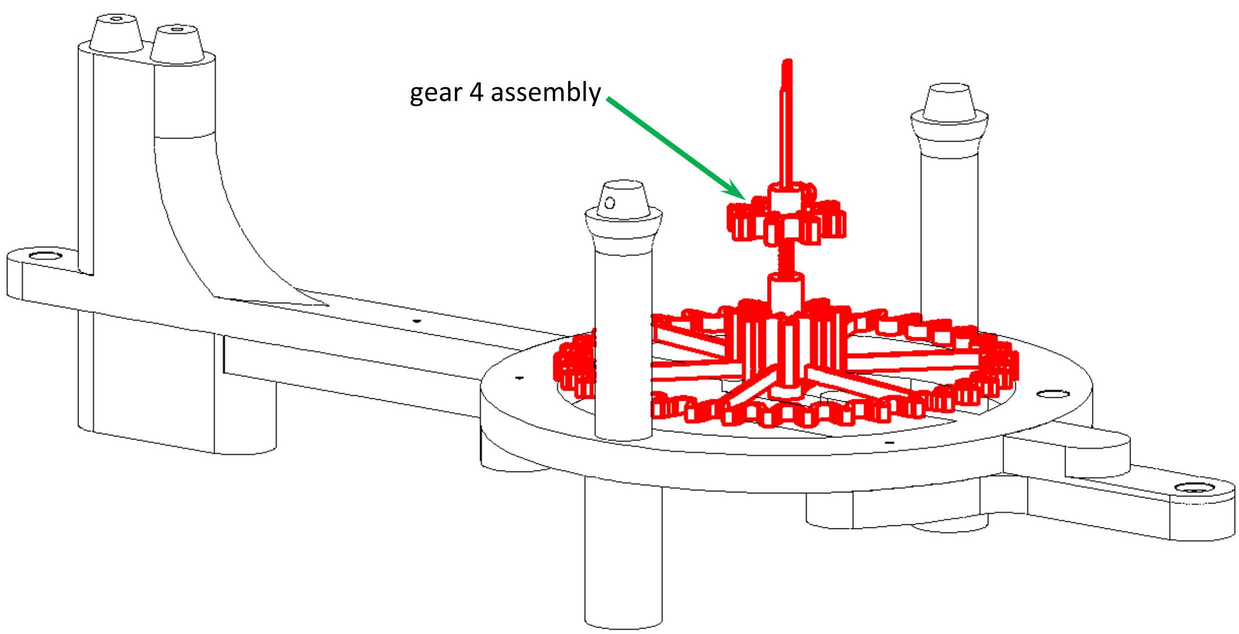

Figure 23: Gear 4 assembly

Gear3_36_8 gets added to the upper left position using a 1.5 x 3” (75mm) arbor. The pinion meshes with gear 4. Spacer 3 is added above the gear. Check that the gears spin easily.

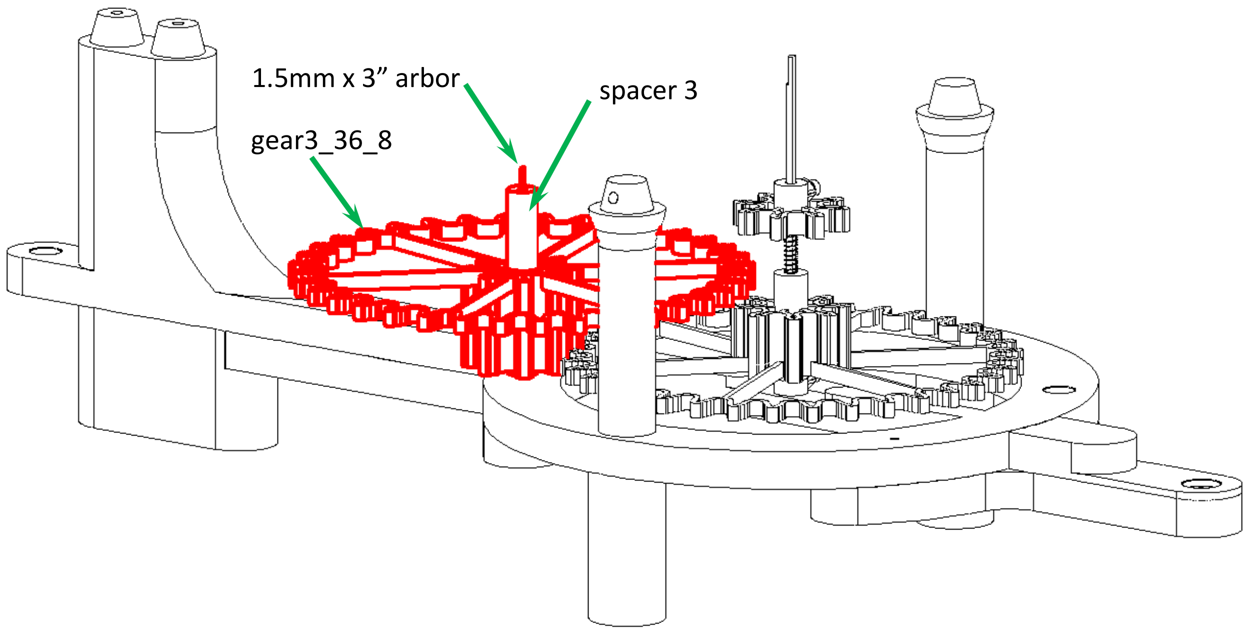

Figure 24: Gear 3

Gear2_36_8 is added to the upper right position using a 3” (75mm) arbor. Spacer 2 is added on top.

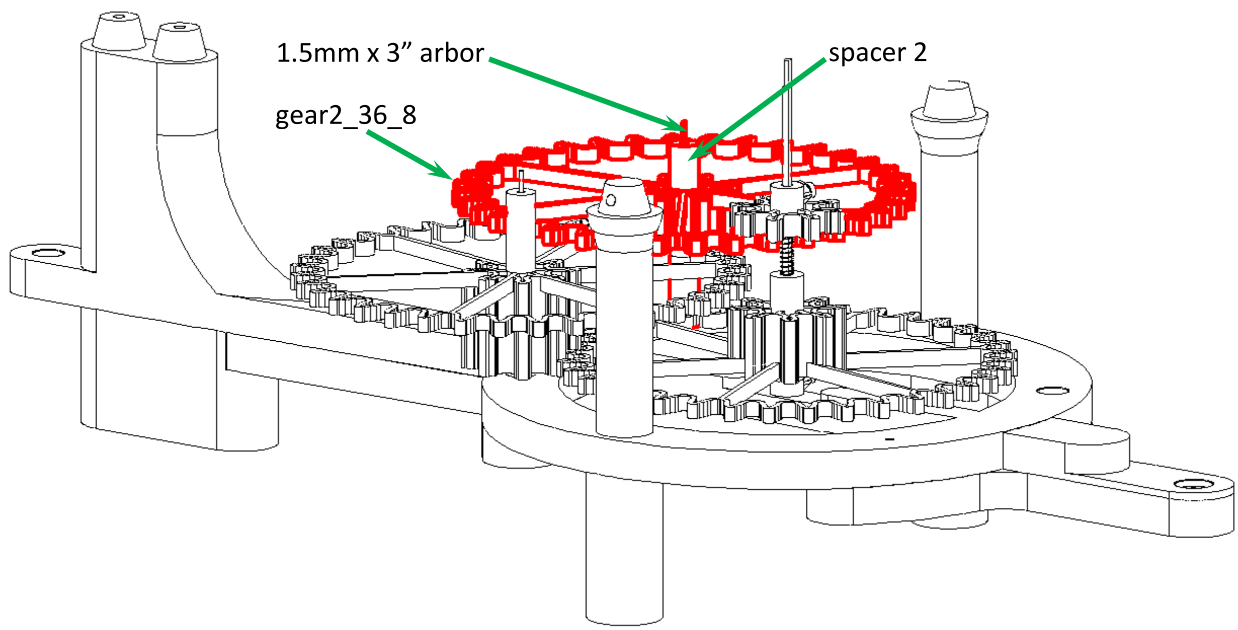

Figure 25: Gear 2

The escapement (gear1_25_8_esc) is added into the hole just above gears 2 and 3 using a 3" (75mm) arbor. It meshes with gear 2. Spacer 1 is added above the escapement.

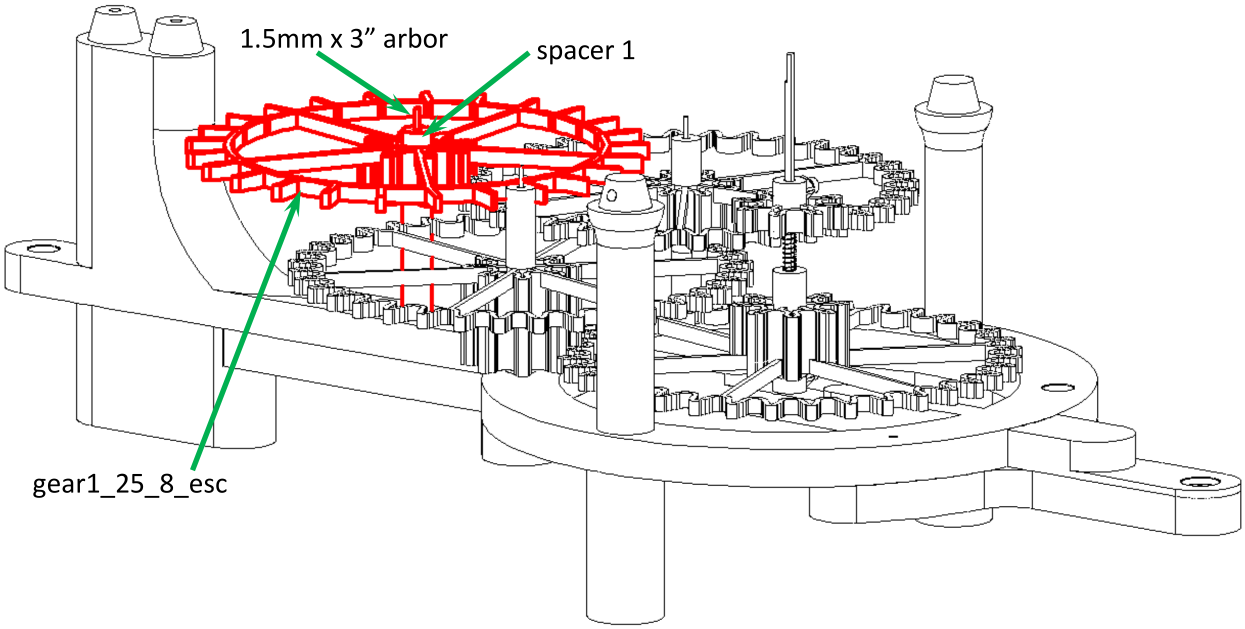

Figure 26: Escapement

The pallet is the final part on the top portion of the clock. It spans the central support column. The previously completed pallet assembly is inserted into the frame as shown below.

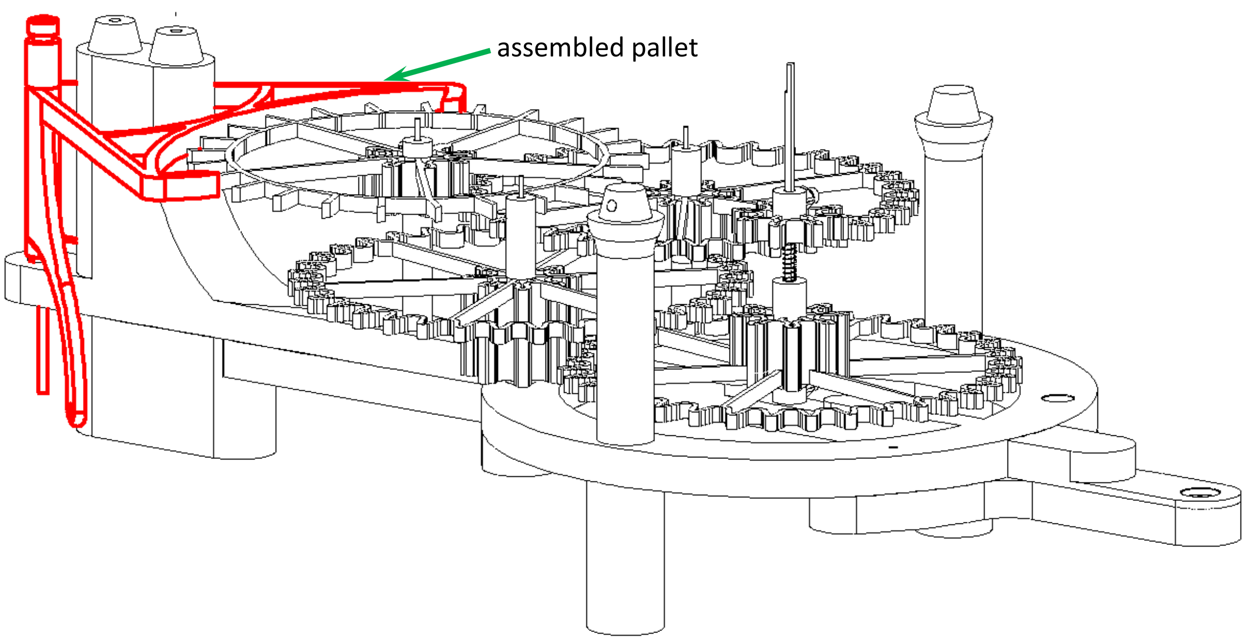

Figure 27: Pallet assembly

The upper portion of the pendulum arm (pendulum_arm_a) can be added behind the frame. Two M3x8mm set screws hold it steady with the pallet and another set screw attaches to the pallet arbor. Position the pendulum arm with the tapered pegs pointing towards the back of the clock as shown below. This will leave the cosmetic finial at the bottom of the pendulum facing the proper direction when the remainder of the pendulum arm is added later.

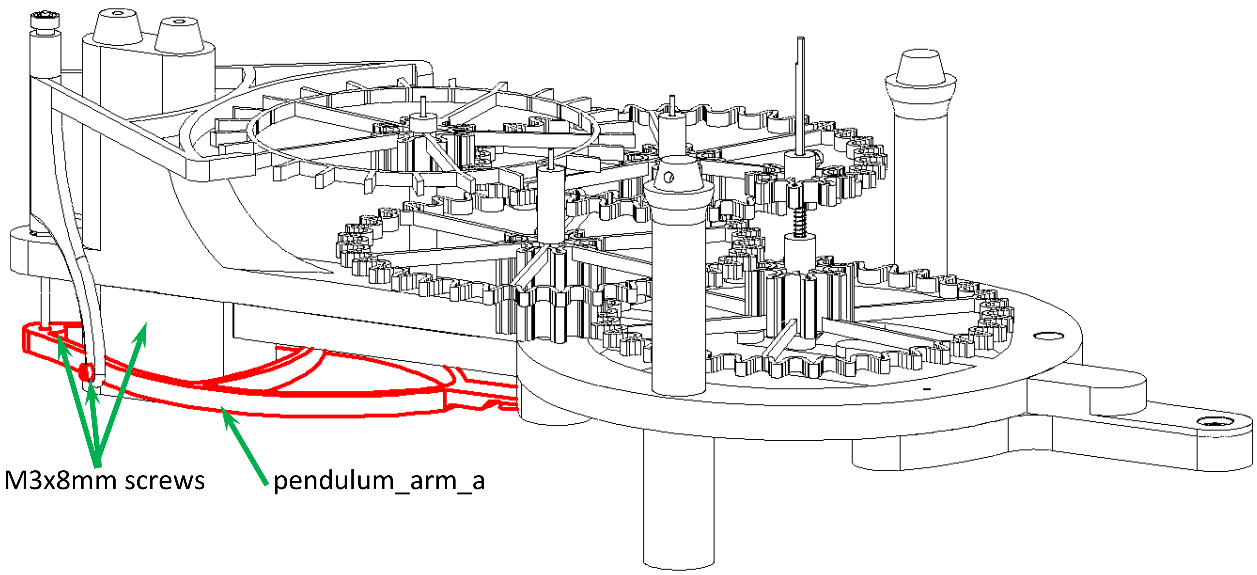

Figure 28: Pendulum top arm

We can now add the gears in the lower portion of the clock. The previously completed ratchet assembly is added as shown below. A 623 bearing fits in the frame pocket and another 623 bearing is on the top of the arbor.

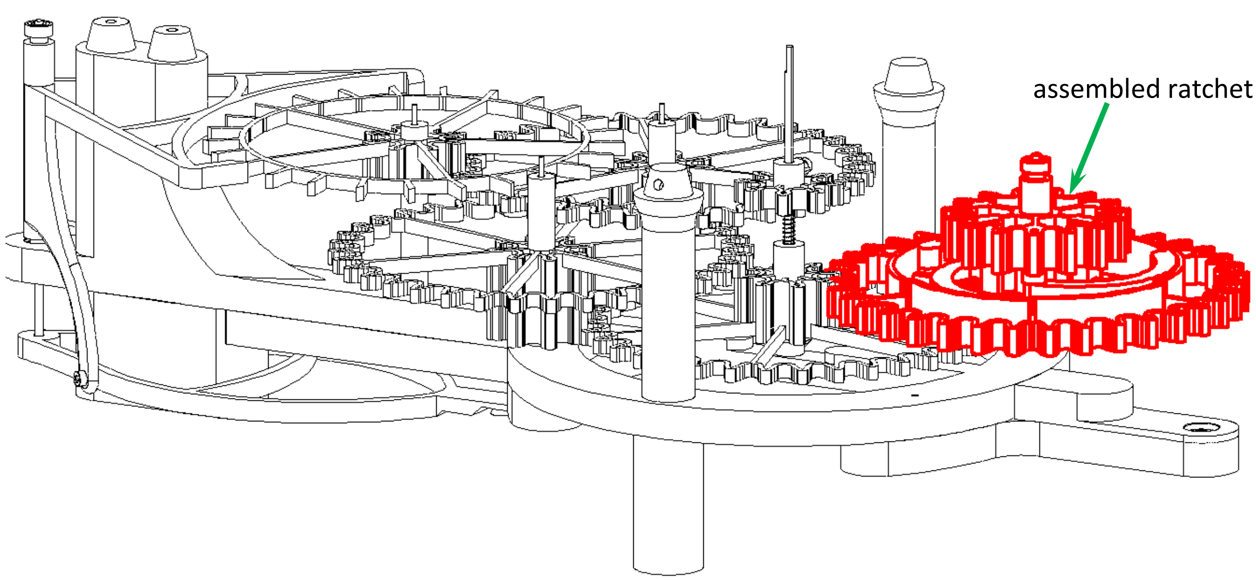

Figure 29: Ratchet assembly

The previously completed winding barrel assembly gets inserted into the large 608 bearing inside the frame. The long end of the rods sticks forward for the winding key.

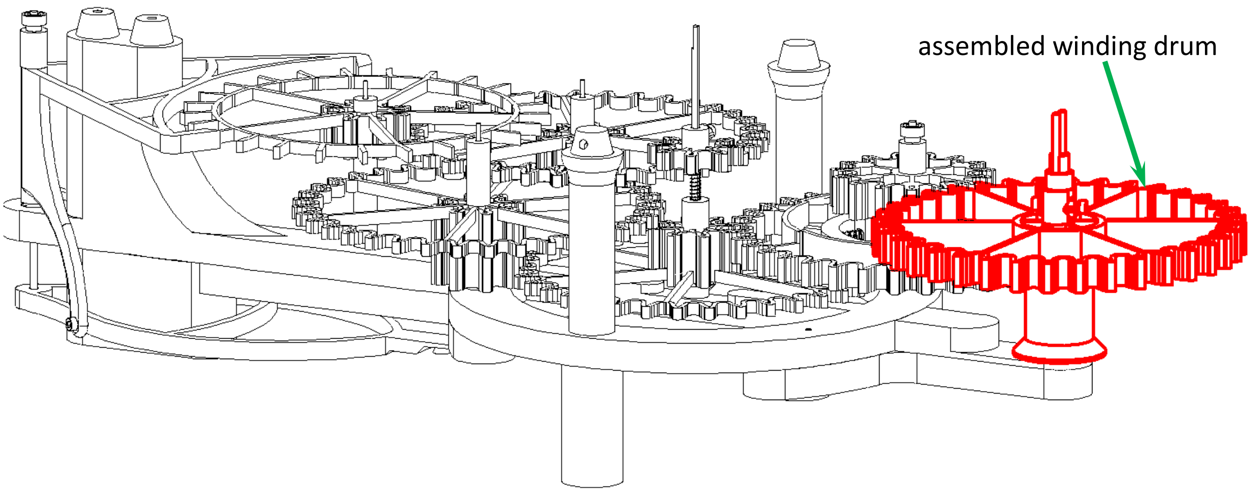

Figure 30: Gear 8 assembly

Gear5_36_12 gets added to the lower left arbor position. The arbor is 3.5” (90mm) long. Spacer 5 is added first. It has a large diameter “brim” built-in to keep it stable when printing. The brim can be placed in either direction at the top or at the bottom. Gear 5 is added above the spacer.

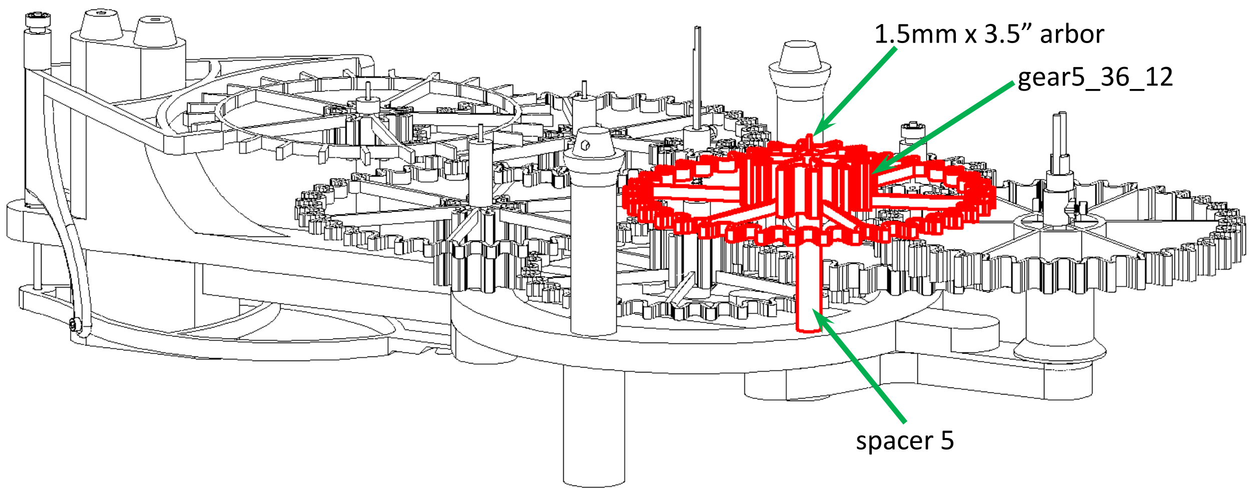

Figure 31: Gear 5

Gear6_32 is the final gear added into the clock onto the central gear 4 column.

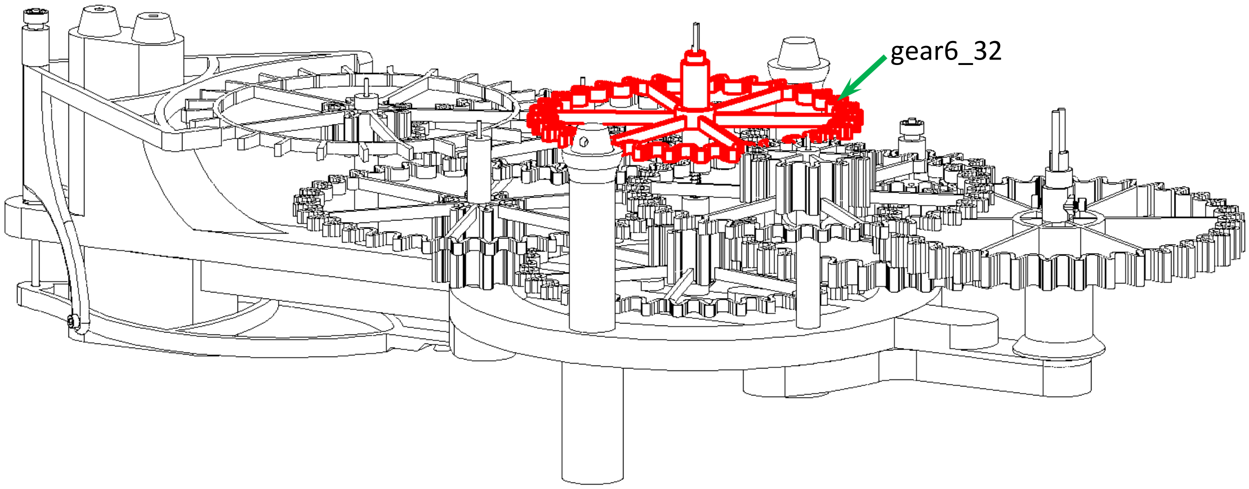

Figure 32: Gear 6

The front frame can be added now. There are eight arbors and four support posts to line up before the frame will drop into position. Most of the holes in the front frame are tapered to make it easier. Start by lining up the center of the dial and the winding drum arbor. Look from the side to see if the frame is resting on any of the arbors. Line up each arbor one by one and the frame will move closer to the final position. This clock assembles easiest from the bottom towards the top. It should drop into place when the top pallet bearing is lined up. Secure the frame using four #6x3/4" wood screws. The hands can be added now if desired. Everything should be starting to look like a clock at this point.

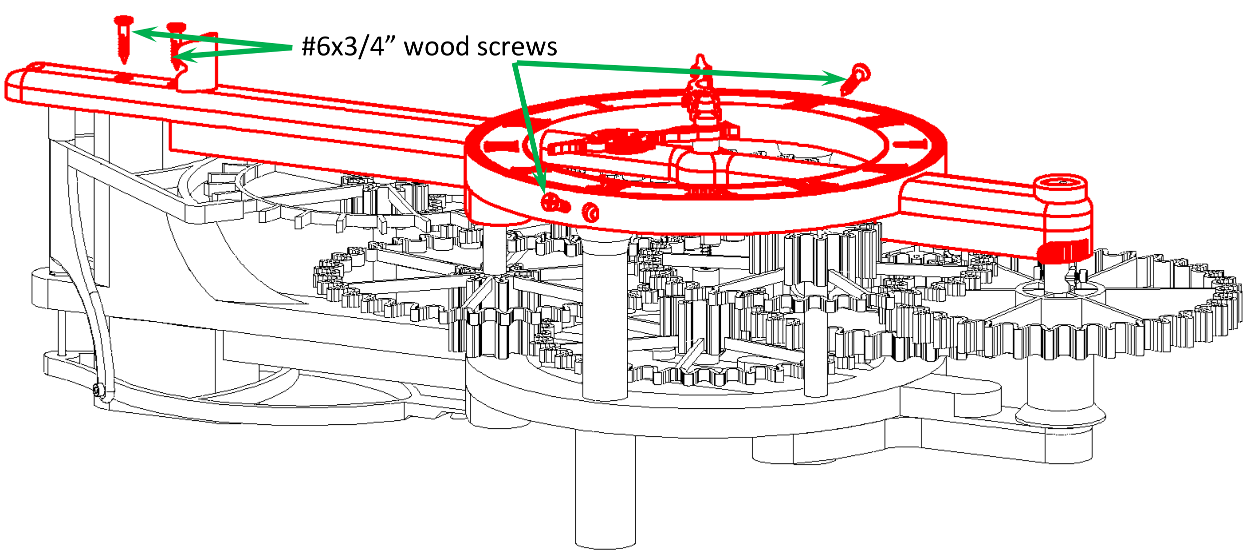

Figure 33: Front frame

Testing the Clock

The clock mounts on the wall using a single screw or nail driven into a wall stud. Placing the top screw 74” (1.88m) from the floor will give around 45” (1.15m) of drop on the weights. The dial will be about 63” (1.60m) high. Hang the clock on the wall and add the pendulum.

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 3-4 pounds or 1.5-2kg. The weight can be hanging directly on the cord for this first test. Eventually, the weight will need to be doubled when the weight shell with a pulley is added to the clock.

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 to the side. This is called setting the beat. Push the pendulum a few degrees to one side and release. The clock should continue ticking. You want the clock to make the sound of “tick…..tock…..tick…..tock…..” instead of “tick.tock………tick.tock………”.

Once the clock is running reliably, start removing weight until the clock stops working. Find the minimum weight required for the clock to run reliably. Double the weight to account for the pulley and add an additional 50% safety margin. This should be the target weight for your clock.

My test clock would run using 3 pounds directly on the cord in the 11 day configuration. Doubling it to account for the pulley and adding the safety margin brings the required weight to about 9 pounds. It should run great using the 3.0” diameter weight shell filled with lead shot (9.4lbs) or the 3.2” diameter shell filled with BBs (8.8lbs).

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 small hook just in front of the winding drum.

Different runtime options should require proportionately more or less weight. Your clock may need different weights depending on friction in your gears and pendulum bearings. Adding extra weight will make the clock run more reliably with a larger pendulum amplitude. It also gets slightly louder.

Set the time by rotating the minute hand.

Congratulations, you have completed your clock!!!

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 steady the frame when winding the clock to prevent it from shifting and changing the beat. I quickly check the beat after each winding, although the weight distribution on this clock makes it fairly stable.

The winding key can be stored by placing it on the hook near the top of the clock.

Adjusting the Rate

The clock should be reasonably accurate with the pendulum adjustment knobs around the middle of the range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. One complete rotation of the adjustment nut will add or subtract around 2.5 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. Wait to get past this break-in period before attempting the final timing adjustment. My clock is usually accurate to about one or two minutes per week. I consider this to be pretty amazing.

Debugging

Debugging the clock often involves isolating the pallet from the escapement so each portion can be tested independently. Remove the pallet to test the gear train and remove the escapement to test the pendulum. The pallet arbor can be removed through the back of the clock to test the gear train without taking everything apart. The clock will need to be taken apart to remove the escapement for the pendulum swing test.

I found that testing the gear train friction was an important first test while debugging this clock. The pallet arbor was removed through the back of the clock and the pallet moved aside. The weight shell was added to see how well the escapement rotates. Stop the escapement with a finger and test how quickly it starts spinning again. It should quickly come up to speed without appearing sluggish. Start and stop it from every tooth position to make sure there is no binding. My first prototype of the clock had a sluggish escapement that was improved substantially by simply re-printing the escapement using a 0.12mm layer height. I suspect that a 0.2mm layer height has more surface roughness than 0.12mm. Only the lightly loaded escapement needed to be re-printed. All the other gears run slower with more torque, so they run great with 0.2mm layer heights.

Let the escapement free spin after the gear train friction test. This is a great way to break in the gear train. It may take an hour for the weight to drop to the floor.

The second test is to check that the pendulum support bearings have low friction. Remove the escapement and allow the pendulum to swing freely until it stops. The clock will need to be taken apart to remove the escapement. Move the pendulum to one side and release it. If the pendulum does not swing for at least 10 minutes, then the bearings may have too much friction for the clock to work properly. The clock might run using a larger drive weight, but it is better to reduce the bearing friction instead. Take out the bearings and clean them again or swap them for better bearings. I never use expensive bearings. Sometimes one or two bearings out of ten will be slightly gritty. I use the best bearings for the pendulum. The higher friction bearings can usually be used in the ratchet or weight shell pulley without any issues.

Another test is to hang the weight shell directly on the cord without using the pulley. This effectively doubles the drive weight at the cost of cutting the runtime in half. If the clock runs in this configuration, then it might just need more weight. Try adding a 1/4 height weight shell extension.

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.

Observe the pendulum amplitude when the clock is running properly. The tips of each pallet should pass into the escapement teeth during each swing. Additional pendulum amplitude makes the clock run more reliably.

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. All of the best features from my earlier clocks were merged into this design along with a few new ideas. I designed this clock with the goal of making it reliable and as easy to build as possible.

I hope you enjoy building the clock as much as I enjoyed designing it.

Future plans may include porting this design to use wooden gears. The symmetrical layout of this clock would look great with wooden gears.

There are several ways to support me and encourage me to keep designing clocks:

Check out my other clocks at https://www.myminifactory.com/users/StevePeterson

My Patreon page is https://www.patreon.com/user?u=30981480 (Steve's Clocks) with additional clock design information.

The web site with the latest information about this clock is at https://www.stevesclocks.com/sp12

Feel free message me with questions during your clock build or just to say hi. You can reach me on MyMiniFactory, YouTube, or my web site forum at https://www.stevesclocks.com/forum

I created a Facebook group called "3D Printed Clocks" to share images or ask questions. Other Facebook groups with similar interests are "Wooden Geared Clocks" and "Clockmaking using a CNC".

Good luck with your clock build.

Steve

Here are a few of the other clocks I have built. Some designs have been released for others to build. Others are still works in progress. The first clock has a grasshopper escapement to replace the deadbeat escapement in my second clock design. It still needs a bit of fine tuning. The second image is a rendering of one of my designs as it may look after porting to use wooden gears.

Figure 34: 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 35: Wooden gear experiments

This is a family of desk clocks using an Arduino Nano and a stepper motor for the clock movement. The larger design has been released in addition to some that are even larger with more moving gears.

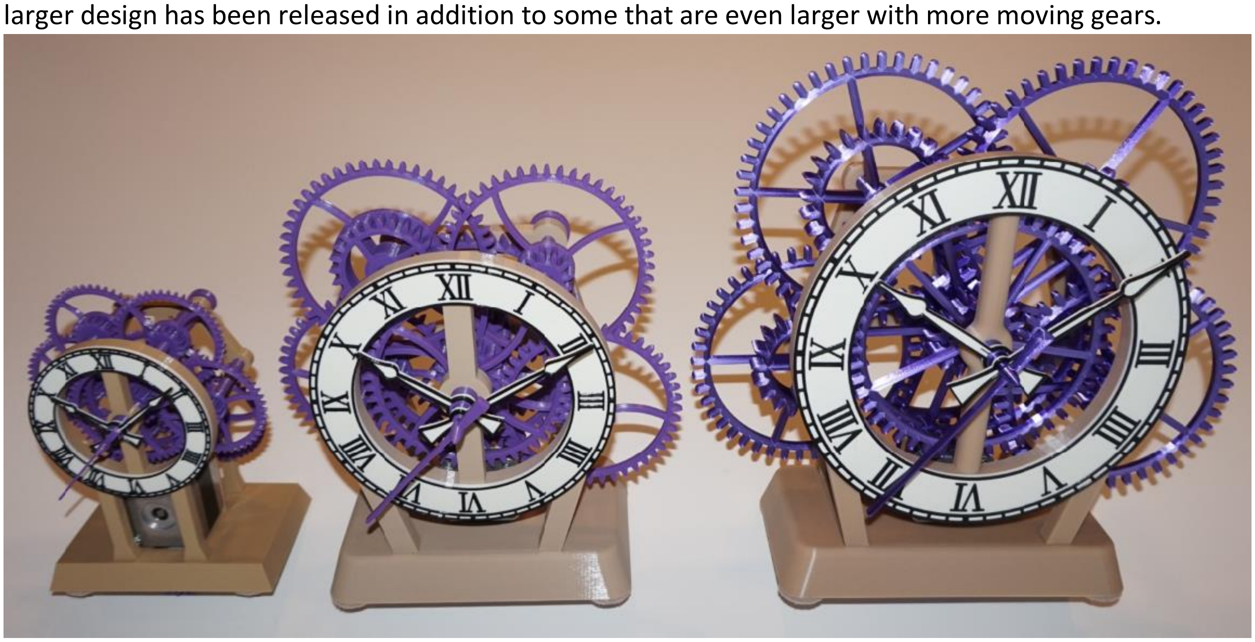

Figure 36: Desk clocks

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

Figure 37: Original Thingiverse design