3D PRINTED WALL CLOCKS

SP2B and SP3B Assembly Notes

A major refresh of SP2 and SP3

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Revision History

12-Dec-2024 Original version

Introduction

I started designing 3D printed clocks shortly after I received my first 3D printer in 2018. My first small clock was released on Thingiverse in 2019 and followed up with two larger designs on MyMiniFactory in 2020. They are good designs, and I suspect a fair number are still ticking today. However, there are many complicated assembly steps and several hard to find components. It was time to simplify these classic designs.

Two sizes of the same basic clock are included in this assembly guide. The components are similar enough to share a single assembly guide with comments as needed where there are differences.

SP2B is a replacement for the large SP2 wall clock. It requires a medium size printer with a print area of at least 205x205mm. An Ender3, Prusa MK4, or BambuLab A1 is capable of printing the large clock.

SP3B is a replacement for the medium size SP3 wall clock that can be printed on almost any modern 3D printer with at least a 175x175mm print area. A Prusa Mini or BambuLab A1 mini are capable of printing the medium clock.

The designs will be released as an update, so anyone who purchased the original clocks should be able to download the update. You need to be able to log into MyMiniFactory using the same account name that you originally used to purchase the plans. The original (outdated) version of the design will be included in the zip file if you still need to access the older components. If this is your first clock, then I highly recommend building the new design.

The bill of materials is significantly reduced compared to the original design. The only machining steps are cutting the arbors to length and drilling holes to fit the arbors. Parts kits are available on my Etsy store if you want to avoid tracking them down. Links are in the main description on MyMiniFactory. Many design features were borrowed from my latest SP14 Moon Phase Clock, and they even share the same parts kit. The Moon Phase Clock uses one extra spring and two additional screws. There isn't a big enough difference to justify creating a separate parts kit.

Description

Mechanical clocks have always fascinated me. Building a traditional brass clock requires specialized equipment, but 3D printers have made it possible for anyone to build their own clock. I try to simplify the process while still maintaining a classic look. These clocks are accurate within a minute or two per week with a runtime is 7.5 to 8 days per winding.

This guide shows the assembly process. Simple construction techniques require only a 3D printer and a few hand tools.

The design requirements for this clock are:

1) The clock must be accurate. This clock typically maintains an accuracy of 1-2 minutes per week.
2) The clock must be reliable. The deadbeat escapement used in this design has proven itself to be very robust. The clock often starts ticking as soon as the weight is applied. The new gear tooth profile appears to have less friction than the modified involute gears used in the original designs.
3) The clock must have a long runtime. Eight days is a reasonable length allowing for winding once per week. It could have been made longer, but this would come at the expense of less reliability.
4) The clock must look good. I like the classic look of these clocks. Hopefully, you also like them.
5) The clock should be easy to assemble. This clock can be built using a few common hand tools to cut the arbors to length. Most parts fit together using one standard screw size.

Quick Start

This clock is designed to be easy to print and assemble. This manual will walk you through the process. Here are the most important steps if you want to get started right away.

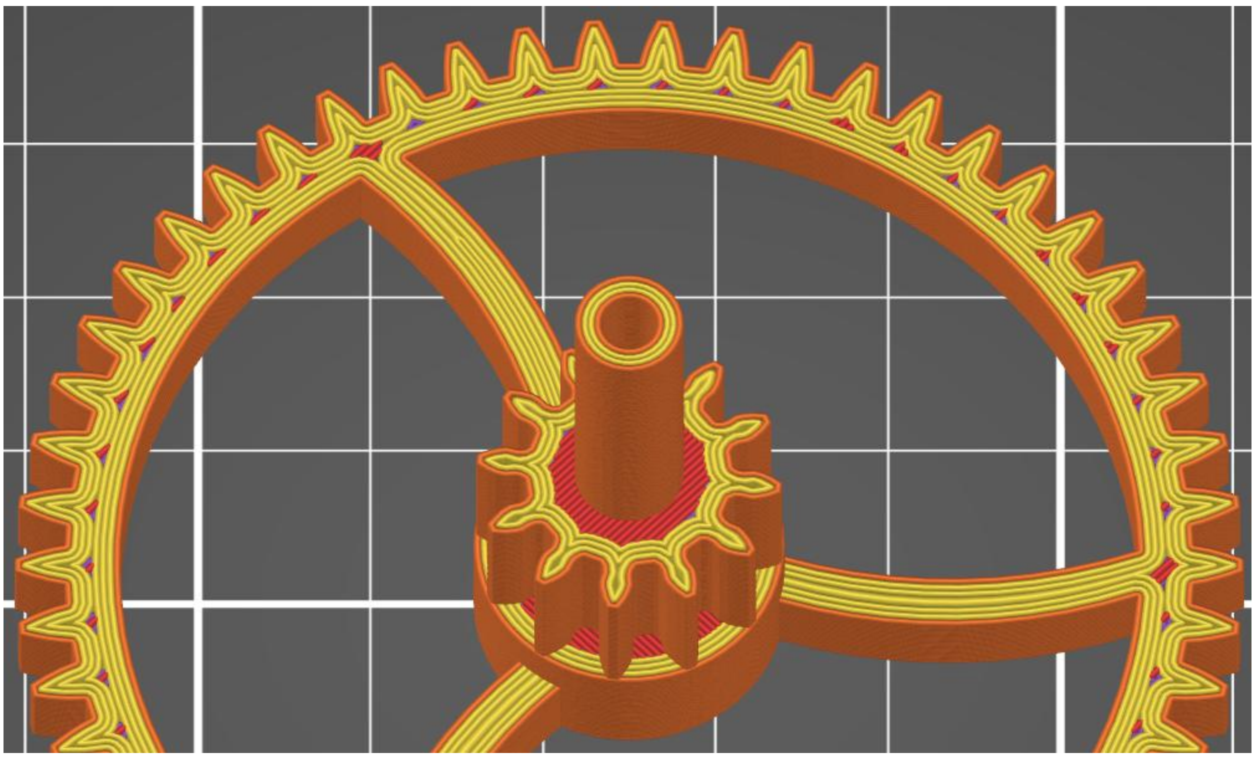
1) Order the non-printed components listed on page 16 and follow the cut list on page 17. A parts kit is available on my Etsy store if you want to save time ordering parts.
2) Print the frame components listed on page 12 using 0.2mm layer height and 4 perimeters.
3) Print the gears listed on page 12 using 0.15-0.17mm layer heights and 5 perimeters.
4) Refer to the gear and spacer cross reference diagram on page 15.
5) Follow the pre-assembly cleanup steps shown on pages 18-20.
6) Assemble the frame as shown on pages 21-22.
7) Component pre-assembly construction steps are on pages 24-27.
8) The step-by-step process of adding the gears is on pages 31-37.
9) Weight shell information is on pages 38-40 after determining how much your clock needs.
10) Additional debug steps are on pages 42-44.

Details

Gear Design

My first 3D printed clock was designed using reference books written in the mid-1900s. These are some of the most useful clock design reference books available today. The descriptions were appropriate to the technology available at the time the books were written. There was no way for the authors to have predicted 3D printers that allow any person to make their own clock in their living room.

The gears designed for my first clock were direct copies of a standard involute gear that would work great if it was manufactured with a brass main gear and a steel pinion. 3D printing allows the gear, pinion, and parts of the arbor to be made as a single monolithic component. This is what the gear looks like in the slicer.



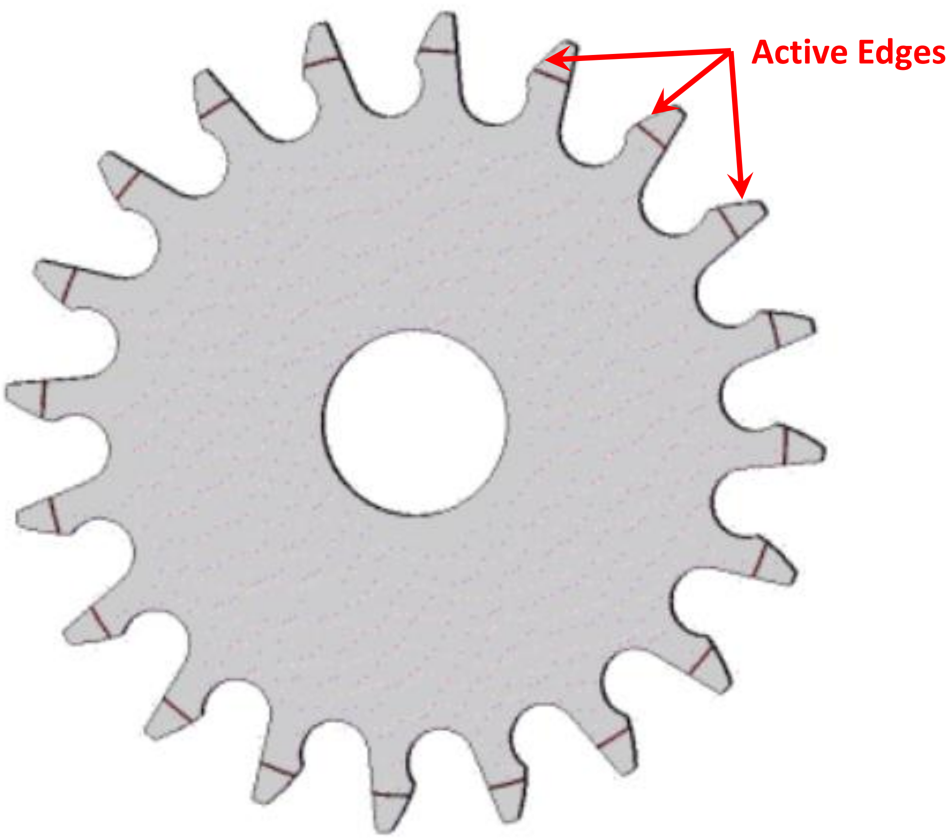
The gears were mostly functional but had several minor problems to be fixed. The elephant foot could be solved with better Z height calibration and slicer compensation. My early gears would still bind up slightly and had a lot of stringing. Reducing the tooth width to around 45-48% helped prevent binding.

The next concern was a large amount of stringing creating extra small blobs on the gear teeth. If you look at the gear slicer output, there is a small spot of infill at the root of every tooth. Each one of these infill spots requires a retraction and a move to the next location. All these extra retractions increase the likelihood of stringing or extra filament stuck on the nozzle that will land on the gear teeth. I went looking for ways to eliminate most of these extra retractions. “Fancy gears” were the solution.

Fancy gears

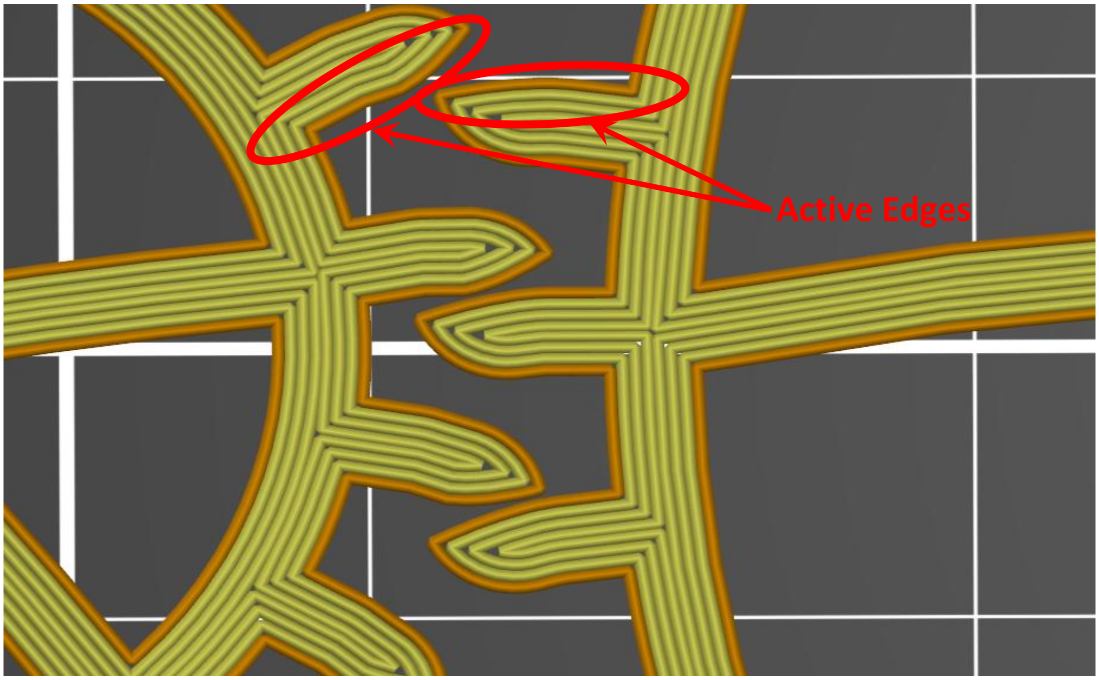
A long time ago, I saw a concept called fancy gears that describe an optimization for wooden clock gears. The website http://garysclocks.sawdustcorner.com/fancy-gears.html posted the original description and I expanded it further with optimizations for 3D printing. The basic premise is that clock gears 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. Unfortunately, Gary's website does not seem to exist anymore, so I am relying on memory for the basic concept. I emailed the original author, Gary Mahony, and he said it is OK to use the concept in my clocks and published works. I try to always give credit back to him.

Here is a picture of a "fancy gear" from the original website. It looks like it would be optimal for cutting with a scroll saw or CNC router. Notice that one surface of each gear tooth looks like a traditional gear. The opposite surface was simplified and additional clearance was added.

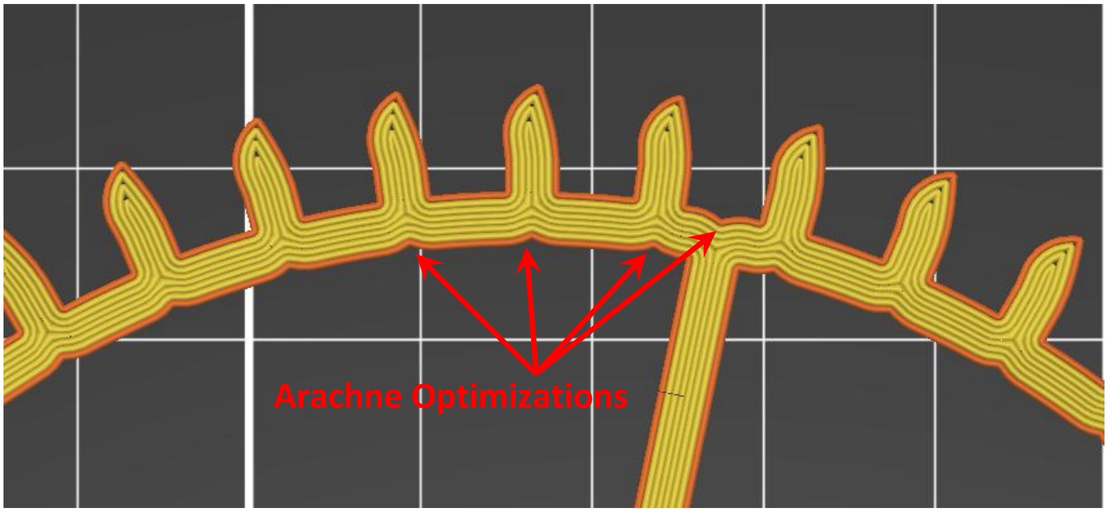


The fancy gear may be ideal for a wooden tooth gear cut on a scroll saw. Additional optimizations are possible when 3D printing. The active edge that interacts between gears holds the original involute tooth shape. The inactive back surfaces have been simplified for printing. SP2 and SP3 use this “fancy” gear tooth style.

This is a closeup view of the gears in the slicer. Notice that extra backlash has been added and the gears print using continuous print head movements. Very little retraction is needed so the gears come straight off the printer with minimal stringing. They also print significantly faster.



Another recent development is the Arachne slicing engine resulting in smoother filament patterns everywhere except the “T” shaped feature at the base of each tooth. Small divots can be added to optimize the gears for Arachne. A gear optimized for Arachne is shown below.



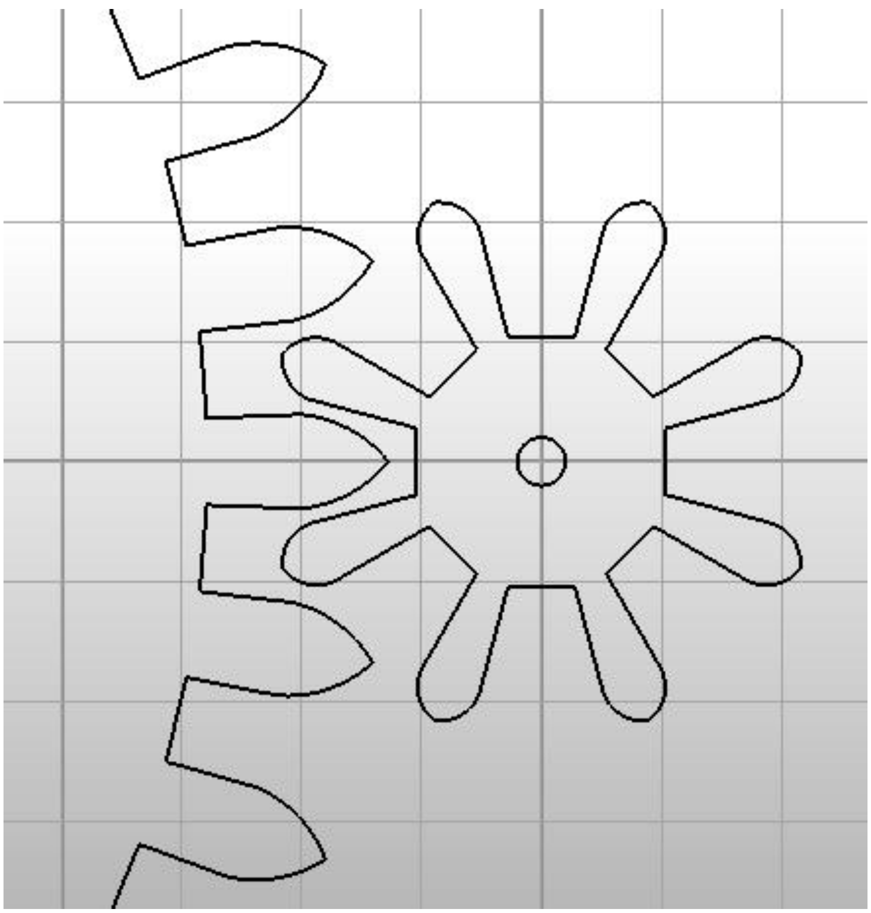
These gears work great, until the next small slicer update and then small infill dots can start appearing again. I could try to update the gears again to work with the newest software and it may only work until the next software update. It was time for another improvement in gear tooth design specifically for use in 3D printed clocks.

Perfect Print Gears

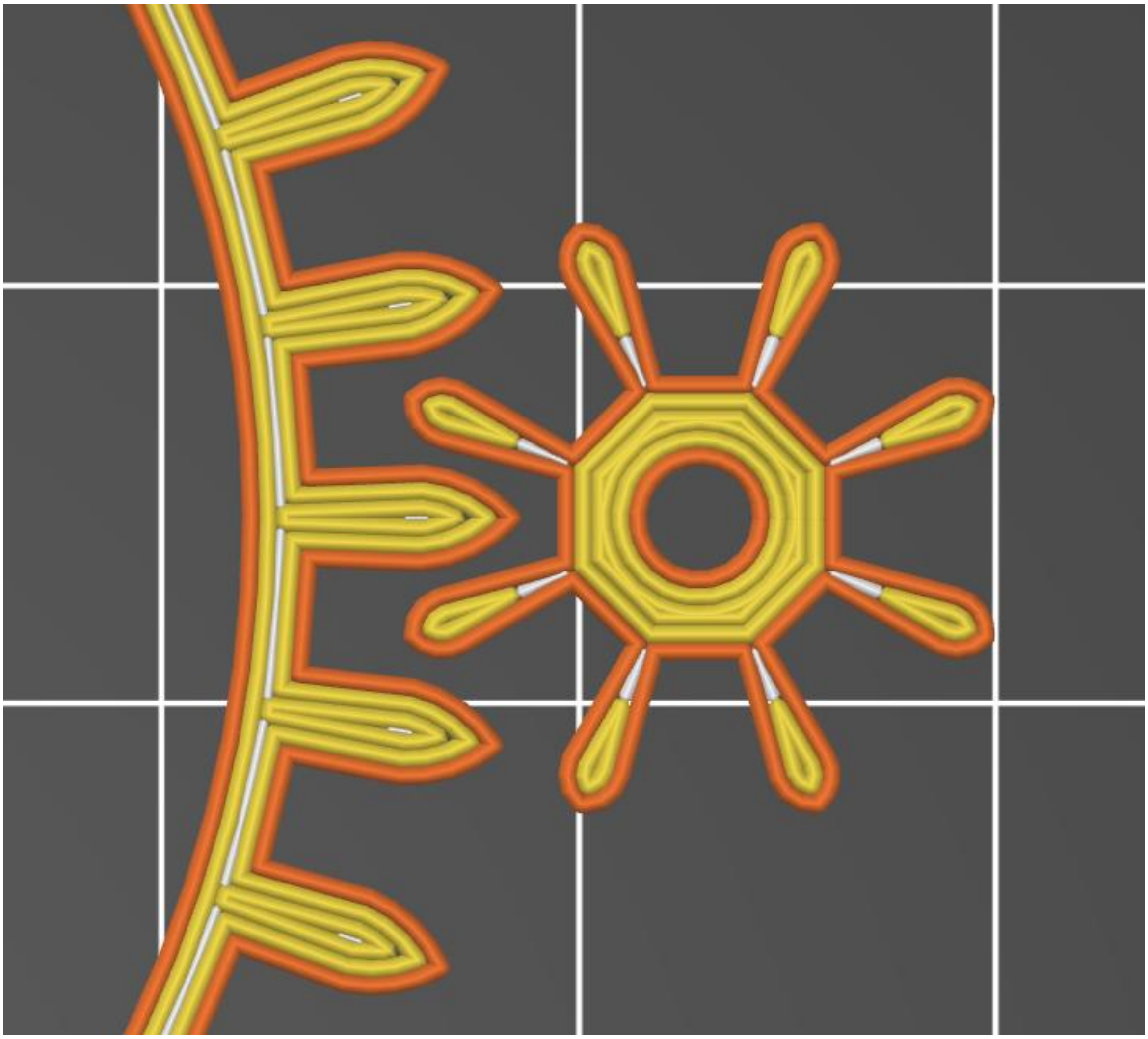
A new gear tooth profile that I call “Perfect Print Gears” is used in the updated version of these clocks. The original SP2 and SP3 designs use the “fancy gear” tooth profiles. The updated SP2B and SP3B use the new profiles. Here is a description about how these gear tooth profiles were developed.

The oldest known clocks used hand cut variations of cycloid gears. This style works great with traditional pinions and lantern style pinions. The traditional gear tooth profile has been optimized over many centuries for use in clocks. Some of these clocks are still in operation today, so obviously the gears are efficient. The typical usage in a clock has a large brass gear with a small steel pinion. The pinion teeth appear to be small and delicate, but they are made from hard steel that wears well against the large softer brass gear teeth. Brass against steel is somewhat self-lubricating so these gears can last for centuries when used in a clock.

Below is a closeup of a traditional 40 tooth brass epicycloidal gear meshing with an 8 tooth steel pinion. It works great in brass and steel.



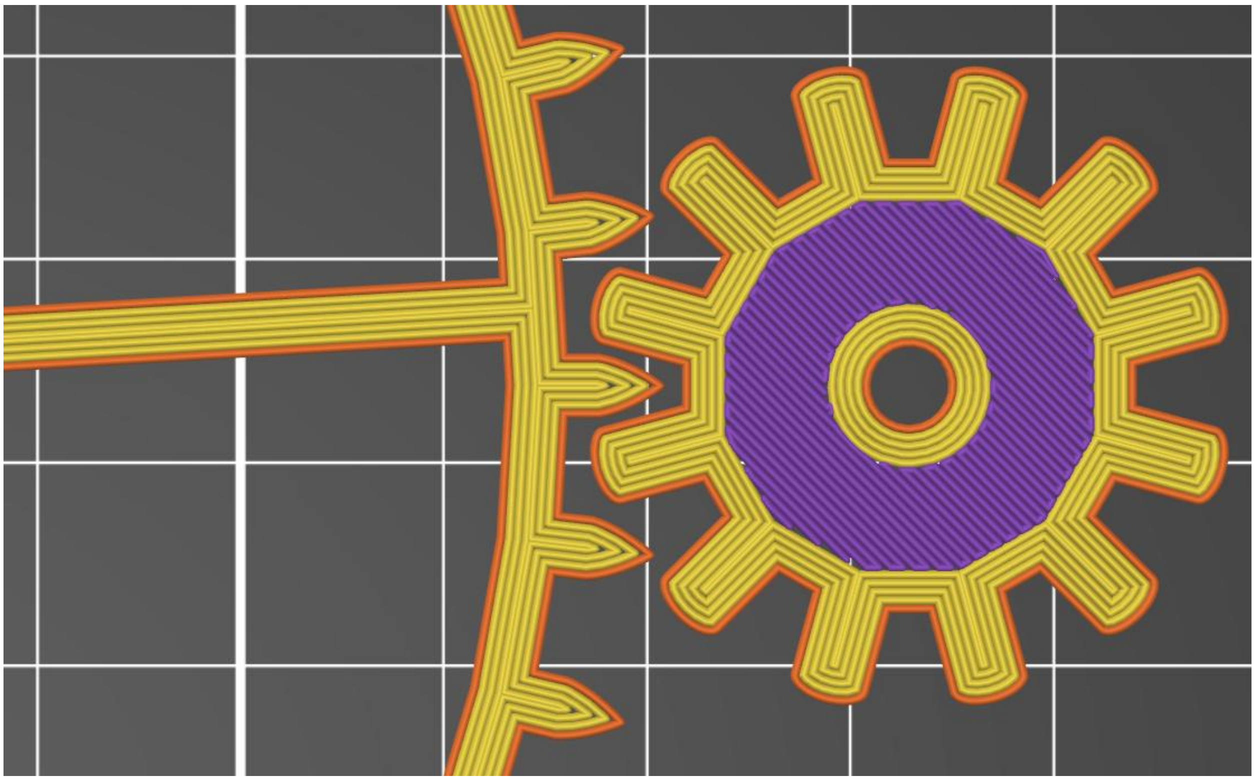
Unfortunately, the results are not so great when 3D printed. The slicer output is shown below. The large gear is acceptable, but the pinion is a mess. The pinion teeth are way too delicate and would certainly wear out quickly if they are made from the same material as the larger gears.



Several changes are required to make these gears work in a 3D printer. The pinion needs to be made much thicker to give it some strength. The main gear was made slightly narrower to give some extra space. Backlash was also reduced. The result is better, but not perfect. The pinion leaves are a bit weak at the base and each tooth requires several retractions while printing. The pinion would likely have extra stringing or blobs as it prints. Even the large gear has a few retractions to print the wide portion of each tooth.

The modifications for 3D printing were based on two primary criteria. The gears must have constant velocity and low friction. Constant velocity implies that if the input gear rotates smoothly, then the output gear must also rotate smoothly. Low friction is an obvious requirement for efficient power transfer. These two criteria work together. Gears designed with constant velocity will typically have low friction. A secondary design criteria is ease of printing. This is a desirable characteristic, but not necessarily required.

The gear tooth profile used in these clocks was designed with uniform width side walls that print cleanly and a tooth tip that provides constant velocity. The result is shown below. Notice the clean the filament paths. All the pinions in these clocks have at least 12 teeth so they do not need to extend into the primary gear. Most of the tooth engagement takes place with the primary tooth touching the pinion side walls after the line of centers, so friction is minimized. I call them “Perfect Print Gears”.

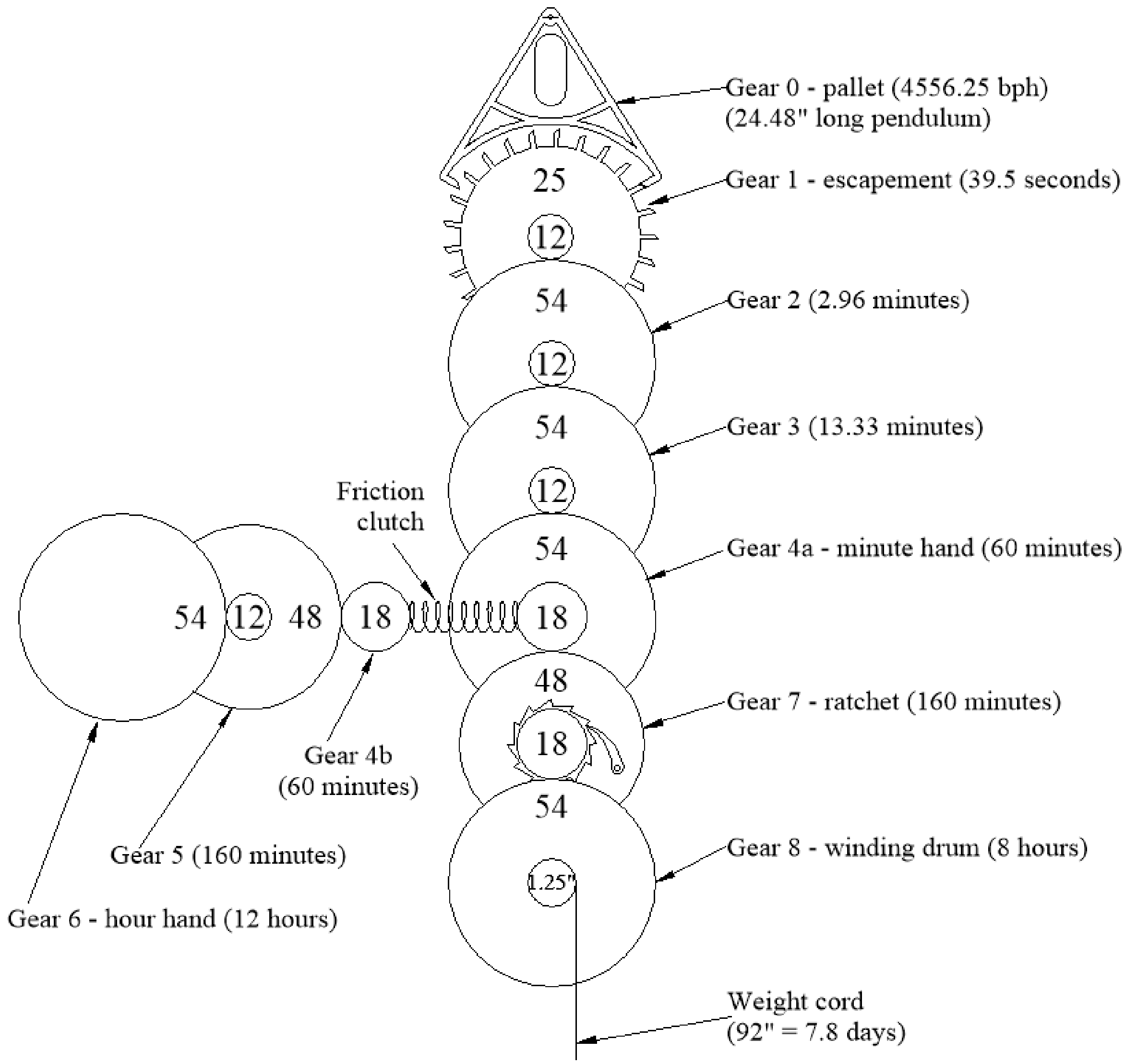


I built two sets of gears when prototyping these clocks. The first set used the same “fancy” gears that were used in the original designs. The second clock used “perfect print gear” tooth profiles. Both gear sets created functional clocks, but the fancy gear version stopped a few times with no motion on the escapement. I believe that this was caused by the additional friction when the involute gears engage before the line of centers. Brass and steel gears with this tooth profile would continue to work, but 3D printed gears can be slightly sticky. A quick fix is to grease the pinions, so the teeth slide past each other when engaging.

The perfect print gears appear to be much more reliable when used in a 3D printed clock. My goal is to migrate these gears to several of my other clocks in the next few months. The SP2 and SP3 clock designs were in need of a complete overhaul. The entire frame was re-drawn using a style similar to my “easy build” clocks. The pendulum design and winding key are borrowed from some of my newest clocks. And of course, the entire set of gears was replaced. Some of the other clocks will only need a new set of gears.

Clock Overview

This is the gear train structure in the large SP2B clock. SP3B is very similar. Notice the long chain of gears between the winding drum and the escapement. The winding drum rotates once every 8 hours by the large weight pulling on the cord. The gears increase in speed with a reduction in torque until they get to the escapement rotating once every 39.5 seconds. The rotating escapement pushes on the pallet, which in turn pushes the pendulum back and forth 4556.25 times per hour. The only break in this chain of gears is for the ratchet that allows winding the clock.



A small spring creates a friction clutch between gear 4a and gear 4b. This is a soft connection. The minute hand is driven by gear 4b with two more gears connecting to the hour hand. The friction clutch is allowed to slip when changing the time without disturbing the chain of gears between the winding drum and the escapement.

Clock SP3B uses a nearly identical diagram with a 27-tooth escapement allowing a 20.98” long pendulum beating at 4920.75 beats per hour.

Printing the Parts

The STL files in this release are broken into subdirectories by category in the ZIP file. The categories are frame, gears, weight_shell, and misc that includes everything else. There will also be a subdirectory called obsolete_reference if you want to print the original design, although I highly recommend printing the new and improved design.

Print Settings

Most default printer presets seem to be designed for printing small sculptures that look good but have minimal strength requirements. These clocks need to support heavy drive weights for extended periods of time without warping. I use the following settings when printing clocks. Many parameters are selected for increased strength.

Printer characteristics:

Material	PLA
Starting Preset	0.20mm STRUCTURAL in PrusaSlicer
Layer height	0.2mm for most parts (gears should use 0.15-0.17mm layers)
Perimeters	4 for most parts (gears should use 5 perimeters)
Top Layers	7
Bottom Layers	6
Seam Position	Random
Scarf Joints	Enable this feature if it is available in your slicer
Perimeter Generator	Arachne for most parts (gears should use Classic)
Fill Density	25%
Fill Pattern	Cubic or other strong infill pattern
Elephant Foot	0.25mm (look at the slicer to determine what works best)
Supports	Never needed for any parts in any of my clocks
Orientation	Usually already optimal. Some parts may need to rotate to fit the bed.

Some of these settings may be overkill, but you only need to print the parts once and you will be able to enjoy the clock for many years. There is a preset for SPEED that is about 20% faster than STRUCTURAL, but I recommend STRUCTURAL for higher accuracy.

I print all my clocks on Prusa machines. Any modern printer can print these clocks as long as the bed is large enough. The large clock needs a 205x205mm bed size to print the frame. The medium clock only needs a 175x175mm bed size. I use two printers working together to make everything go faster. One printer makes the frame and the other printer makes the gears. The first printer to finish starts printing the miscellaneous parts. The weight shell can be saved until after you test how much weight your clock needs.

Below is the lists of parts to print. The colors listed are what was used to print the clocks shown on the first page. You are free to go wild with any other colors you like.

Frame Parts

Select one of the two different dial styles and print one of each of the other files in the "frame" directory. Both clock sizes use the same file names with different size parts that are not interchangeable. Strength is important for these parts, so I always use 4 perimeters.

Part Name	Color	Print	Notes
frame_back_center	tan	1	
frame_back_lower_a	tan	1	
frame_back_lower_b	tan	1	
frame_back_standoffs	tan	1	All the back frame standoffs in one file
frame_back_upper_a	tan	1	
frame_back_upper_b	tan	1	
frame_dial_numerals	tan, white, black	1	Print one of either style. Needs a layer change at the start of the solid dial color and another layer change for the numbers
frame_dial_roman	tan, white, black		
frame_front_lower_a	tan	1	
frame_front_lower_b	tan	1	
frame_front_upper_a	tan	1	
frame_front_upper_b	tan	1	

Gears

Most gear names are the same for both clocks. The larger SP2B clock has fewer escapement teeth to allow a longer pendulum that is more proportional to the size of the clock. Gear 7b is also slightly different between the two clocks. All other gear names are the same. Print one of each of the following files. The most important print parameters are the Classic slicing algorithm using 5 perimeters so the gear teeth are completely solid. Look at the slicer to ensure the gear teeth print with minimal retractions. Silk PLA and especially dual color silk PLA looks great for the gears.

Part Name	Color	Print	Notes
gear_spacers	purple	1	All the gear spacers in one file
gear0_pallet	purple	1	
gear1_25_12_esc (SP2B) or gear1_27_12_esc (SP3B)	purple	1	SP2B has a 25 tooth escapement to allow a longer pendulum length than SP3B with 27 teeth
gear2_54_12	purple	1	
gear3_54_12	purple	1	
gear4a_54_18	purple	1	
gear4b_18	purple	1	
gear5_48_12	purple	1	
gear6_54_6	purple	1	
gear7a_48_ratchet	purple	1	
gear7b_18 (SP2B) or gear7b_24 (SP3B)	purple	1	SP3B has smaller gear teeth, so gear7b was increased to 24 teeth to allow more room for clicks
gear7c_clicks	purple	1	
gear8_54_8days	purple	1	

Misc Parts

The "misc" directory of parts includes all the remaining parts except the weight shell. Select a hand style and print the minute and hour hands. Each of the hands have 4 different tightness levels to account for different printer tolerances. The hour hand is a press fit onto the hour hand arbor. Select a size that fits snuggly. The minute hand also has various sizes for different depths of the flat on the minute hand arbor. They print fast, so you could just print them all and test which one fits the best. The spade style hands should have a color change to add some highlights.

The pendulum arm is designed to use two mid-section segments. They are of unequal length and the clock rate should be properly adjustable with one of each segment. However, if your pendulum bob has a different weight than mine, then you may need a little bit of extra adjustment range. The simple solution is to use two of the shorter arms if you need the clock to run faster or two of the longer arms if you need the clock to run slower. The default starting position uses one of each length and the adjustment nuts near the center of the adjustment range.

Part Name	Color	Print	Notes
hand_gothic_hour_?????	copper	1	Select the style you like and print one that fits properly onto the hour hand arbor
hand_spade_hour_?????	white, purple		
hand_gothic_minute_?????	copper	1	Select the style you like and print one that fits properly onto the minute hand arbor
hand_spade_minute_?????	white, purple		
pendulum_arm_lower	tan	1	
pendulum_arm_mid_a	tan	1	The clock should run properly with one of each of these mid-section pendulum arms
pendulum_arm_mid_b	tan	1	
pendulum_arm_upper	tan	1	
pendulum_bob_back	copper	1	
pendulum_bob_front	copper	1	
pendulum_nuts	tan	1	
winding_key_arm	tan	1	
winding_key_knob	purple	1	

Weight Shell

The weight shell parts are listed here, but you may want to print them after the clock is assembled and debugged. Friction can be a mysterious variable and any clock with a long runtime is going to be sensitive to differences in friction. Your clock may need more or less drive weight than mine if your friction is different. The ideal solution is to build the clock and test how much weight is needed for your clock.

My clocks run reliably with 7.5 pounds (3.4kg) for the larger SP2B clock and 6.5 pounds (3.0kg) for the smaller SP3B clock. Both would still run with smaller weights, but the pendulum amplitude would be weaker, and they would be susceptible to disturbances from drafts. If you want to print the weight shell now, then it should be reasonably safe to start with the weights I use and add an extension if you need additional weight to keep your clock running.

There are five different diameters of weight shells included with the design. The smaller diameters are only appropriate if you plan to fill them with lead shot. The larger diameters work best with steel or copper. I have switched from lead shot to the much safer steel shot to fill weight shells. Copper plated BBs are an acceptable alternative and sometimes only slightly more expensive than steel shot.

Each weight shell diameter includes a “bottom” plate, a full size “top” portion, an optional “short” top portion, and an optional “quarter” length extension. The short top portion can be used if your printer does not have enough Z-height to fit the normal full-size portion. Any number of optional quarter length extensions can be added to increase the total weight. All sizes of weight shells need one weight shell pulley.

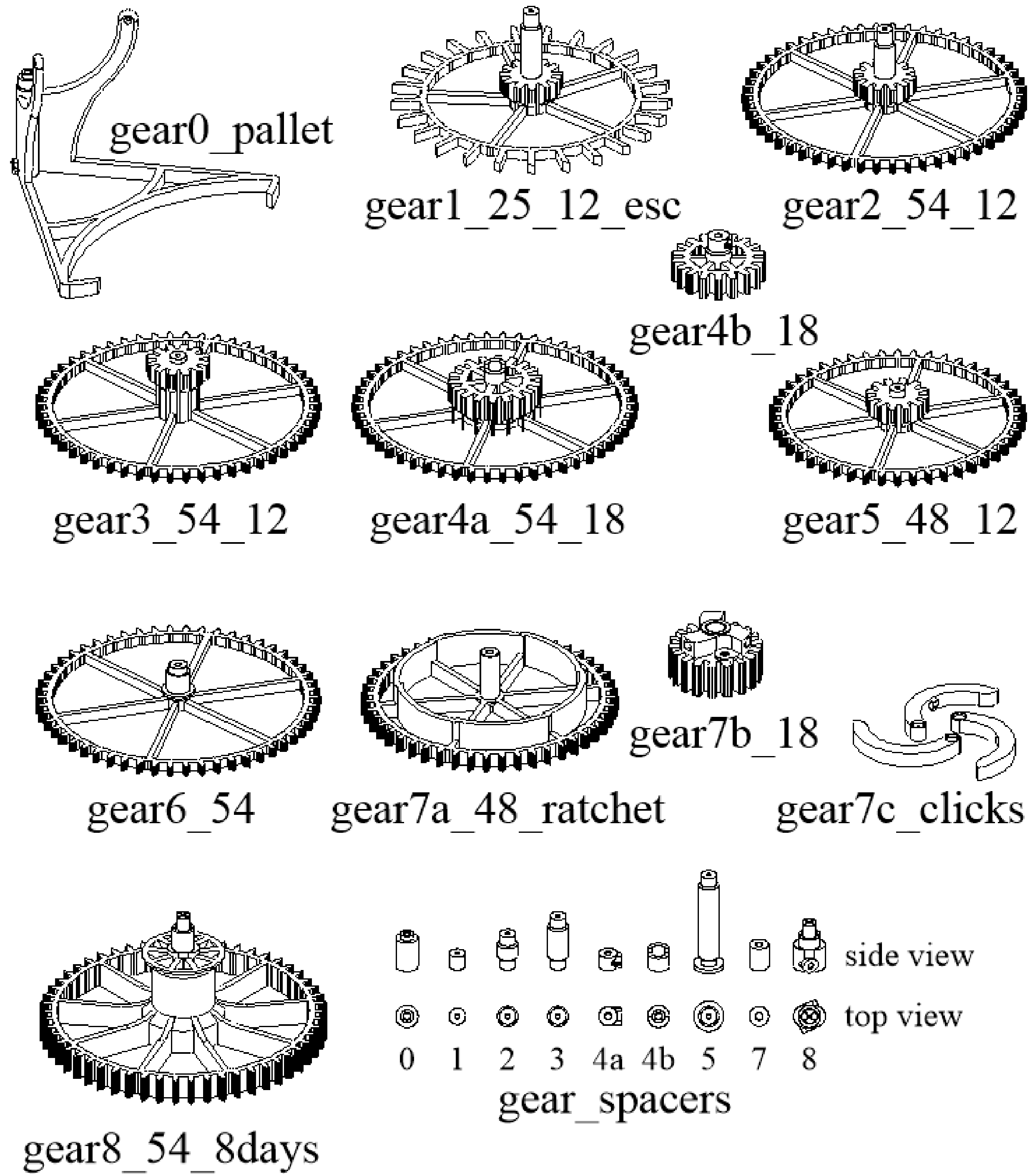
Here are the files to print if you are building a 2.8” diameter shell with one extension. The next table shows that it should weigh approximately 7.8 pounds (3.6kg) when filled with copper plated BBs.

File Name	Color	Print	Notes
weight_shell_bottom_2p4	Copper	0	2.4” diameter weight shell
weight_shell_top_2p4	Copper	0	
weight_shell_short_2p4	Copper	0	
weight_shell_quarter_2p4	Copper	0	
weight_shell_bottom_2p6	Copper	0	2.6” diameter weight shell
weight_shell_top_2p6	Copper	0	
weight_shell_short_2p6	Copper	0	
weight_shell_quarter_2p6	Copper	0	
weight_shell_bottom_2p8	Copper	**1**	2.8” diameter weight shell
weight_shell_top_2p8	Copper	**1**	
weight_shell_short_2p8	Copper	0	
weight_shell_quarter_2p8	Copper	**1**	
weight_shell_bottom_3p0	Copper	0	3.0” diameter weight shell
weight_shell_top_3p0	Copper	0	
weight_shell_short_3p0	Copper	0	
weight_shell_quarter_3p0	Copper	0	
weight_shell_bottom_3p2	Copper	0	3.2” diameter weight shell
weight_shell_top_3p2	Copper	0	
weight_shell_short_3p2	Copper	0	
weight_shell_quarter_3p2	Copper	0	
weight_shell_pulley	Copper	**1**	Pulley used for all sizes

Here are the approximate weight shell capacities at the various sizes when filled with either lead shot or BBs. Steel washers or lots of pennies may also work, but you may need to experiment with the size if they do not pack as well as small round BBs.

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)

Here is a summary of the gears used in both clocks. SP2B is shown. The image for SP3B would look very similar, with the escapement having 27 teeth and gear 7b having 24 teeth. The names for each gear include the arbor number and gear tooth counts to help identify them.



Additional Components

These clocks consist mainly of 3D printed parts, but a few metal components are required to minimize friction. The bill of materials has been reduced as much as possible. Several hard to find parts have been eliminated and the screws have been consolidated to a small number of sizes.

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

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

Parts kits for all the non-printed parts except the weight are available on my Etsy store if you want to avoid tracking down all the various components. Check the main description where the model was purchased for a link to my Etsy store.

Qty	Component	McMC Part No.	Notes
~37	#6x3/4" flat head wood screw or flat head sheet metal screw	90031A151	Metric equivalent is M3.5x20mm (M3x20mm should also work)
1	#8x1-1/2" or #8x1-1/4" pan head wood screw	90190A203 90190A201	For mounting clock on wall, metric equivalent is M4.2x32-38mm
8	M3x8mm socket head screws	91292A112	M3x10mm may also work
24" (60cm)	3mm stainless rod	1272T33	Brass or plain steel rod should be OK. See cut list
14" (36cm)	1/16" or 1.5mm music wire	89085K85	Either 1/16" or 1.5mm diameters can be used. See cut list
12' (3.6m)	microfilament fishing line		I use PowerPro Spectra Fiber braided fishing line 65 lb. test. Other brands of braided line are OK
~8 lb.	lead shot or BBs		BBs are safer than lead shot and only need a slightly larger weight shell
2	608 bearing		Generic skateboard bearings
3	623RS bearing (3x10x4mm)		Used to support the pendulum.
4	click pen springs		Used for ratchet and friction clutches

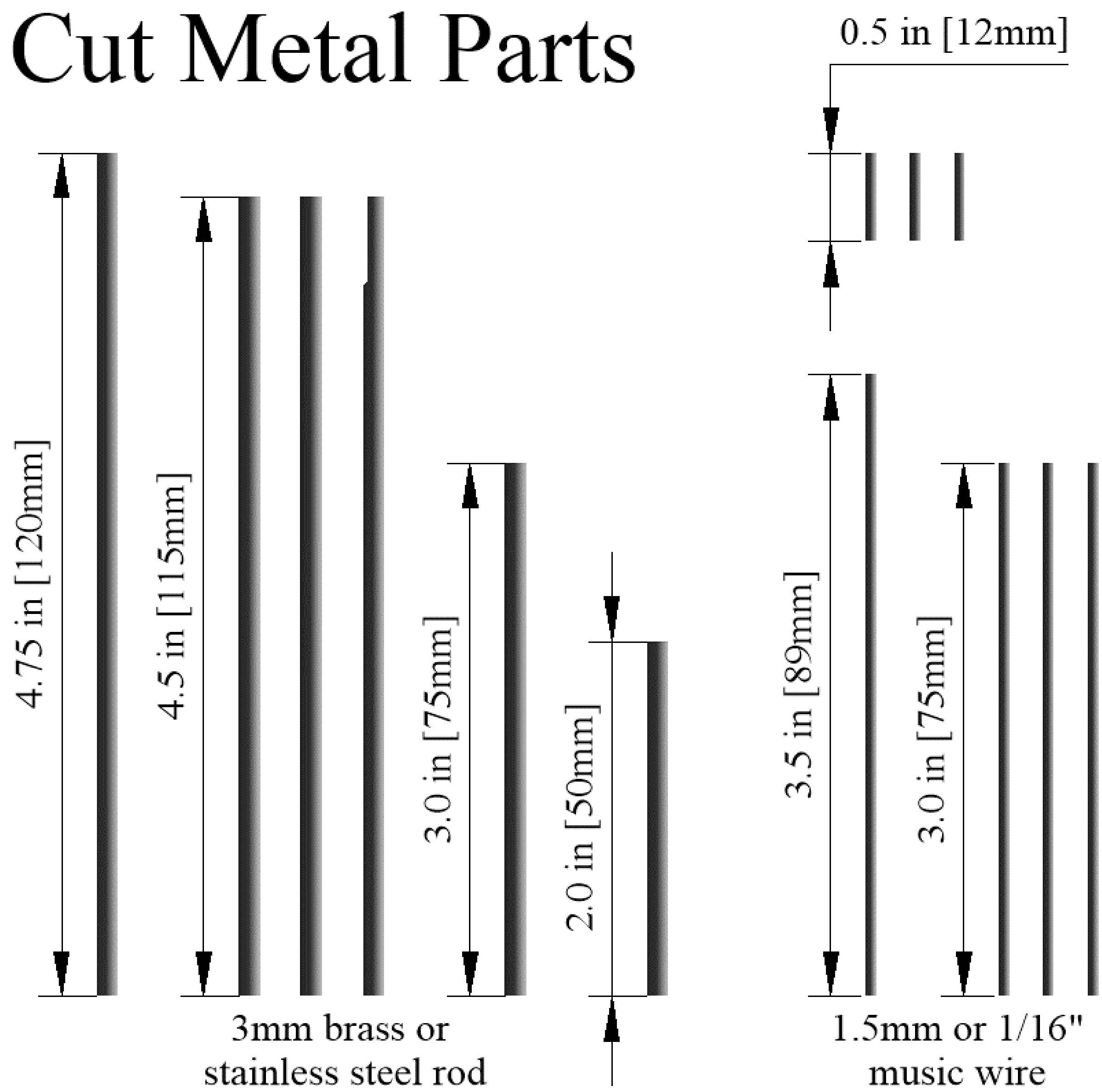
Low friction bearings used to support the pendulum are critical to reduce friction on the fastest moving part. I find that cheap 623RS bearings available for around US$8 for 10 work great. The rubber seal is easy to remove for cleaning out the thick factory grease. The larger 608 bearings used in the winding barrel are commonly called skateboard bearings. Any quality is acceptable since they rotate very slowly.

Metal Cut List

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

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

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



Component Pre-Assembly

IMPORTANT: This section will guide you through the process of getting the components ready to build the clock. You may be eager to rush in and start putting the clock together, but more effort spent in this section of the assembly process will reduce debug time later.

You will need:

3D printed frame parts
3D printed gears
3D printed pendulum arm and bob
Pennies or small weights for the pendulum bob
Screws and bearings from the "additional components" list
Phillips head screwdriver and hex key to match M3x8mm screws
Cut metal arbors with the ends de-burred
1.6mm (1/16") drill bit
3.2mm (1/8") drill bit
Pin vise or slow speed hand drill

Optional tools:

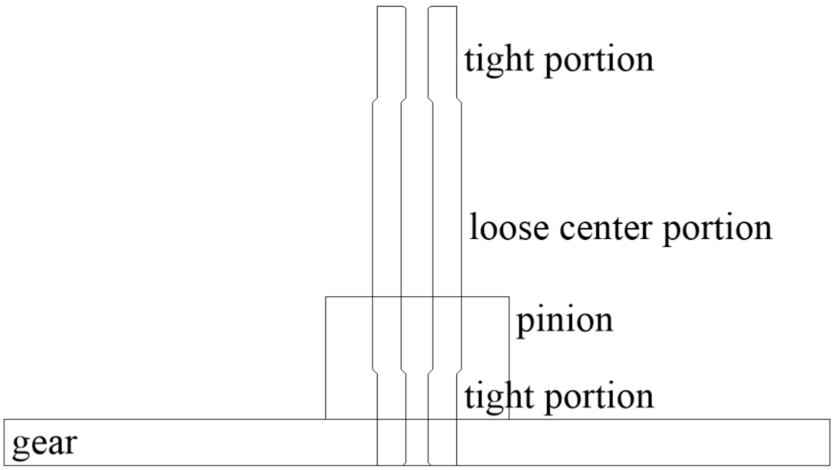
Sandpaper or small hand files

Most of the 3D printed parts will be will be assembled in this section, with the exception of the weight shell. It can be printed later after the clock is hanging and you can determine how much weight your clock needs to run reliably.

Component Pre-fit

The most important step in reducing friction is to dry-fit the components and make adjustments as needed before assembling the entire clock. The first step is to drill the arbor holes to the proper sizes. 3D printers often make holes smaller than expected. The easiest solution is to drill them to the proper size. I use small pin vises to manually drill through the center of each gear. A power drill will also work, but go slowly to avoid melting the part and be careful to not drill too deep.

The gears are designed so only a short portion from each end needs to be drilled out. The middle portion opens up to provide extra clearance around the arbor. Use a 1/16" or 1.6mm drill bit for the 1.5mm arbors and a 1/8" or 3.2mm drill bit for the 3mm arbors. This provides the proper amount of clearance without being too loose.

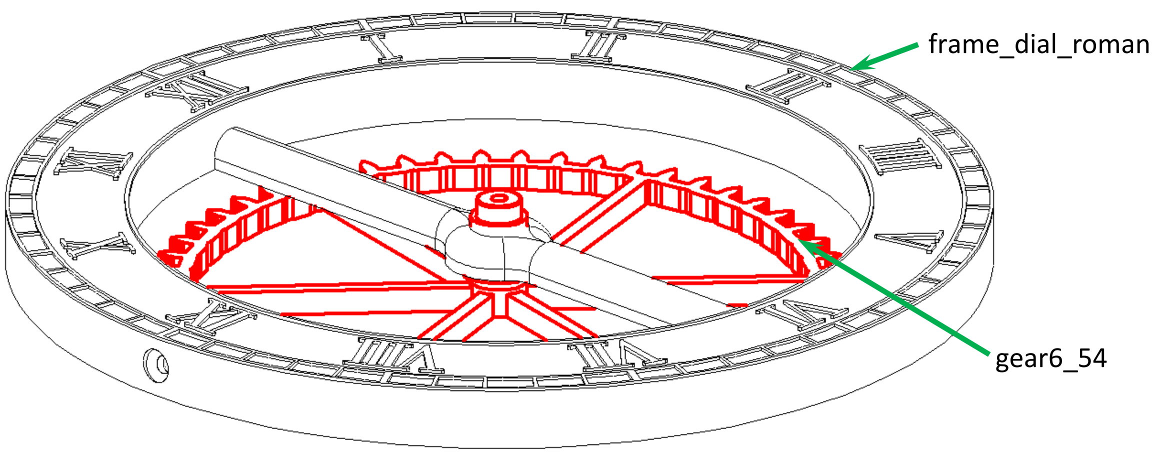


Drill both ends and blow through the hole to clean out the swarf. Test each gear by spinning it on an arbor. Gears with properly sized holes should spin for 10-20 seconds. If it slows quickly, then drill it again. It will be obvious when the hole has enough clearance.

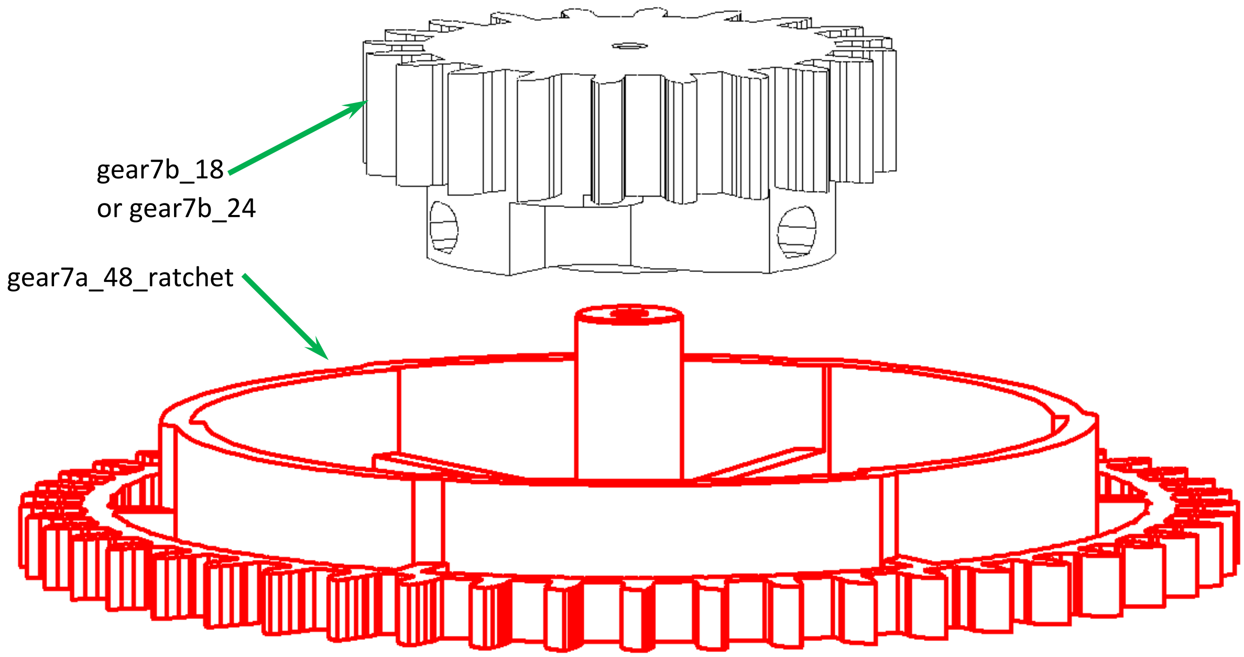
There are a few 3D printed parts that need to move inside other printed parts when the clock is running. They need to be checked for the proper fit and adjusted if needed. Use hand files or sandpaper to adjust the sizes of either component until the parts rotate smoothly. These parts involve PLA rubbing against PLA, so feel free to add a light coat of lithium grease to the sliding parts.

Check the following 3D printed parts for proper fit. Sand or file the gear shafts until they fit easily. A light coat of grease is acceptable.

The hour hand gear needs to spin freely where it passes through the dial. Gear 6 is highlighted in red. It rotates slowly, but excess friction here may allow the pendulum to swing, but the time will not change.



Gear 7b needs to fit over the center post of gear 7a (highlighted red). It must be able to rotate.



Notes on Friction

It is worth stating how important it is to reduce friction in a mechanical clock. These clocks run for nearly 8 days using less than a pound of weight per day to provide power. The pendulum ticks nearly a million times before the weight reaches the floor. The pendulum needs to tick more than 18,000 times for every inch of weight drop. There is not much room for wasted friction.

Make sure to complete the component pre-checks to minimize friction before moving on to building the clock. Another equally important friction test on the pendulum support bearings will be done later.

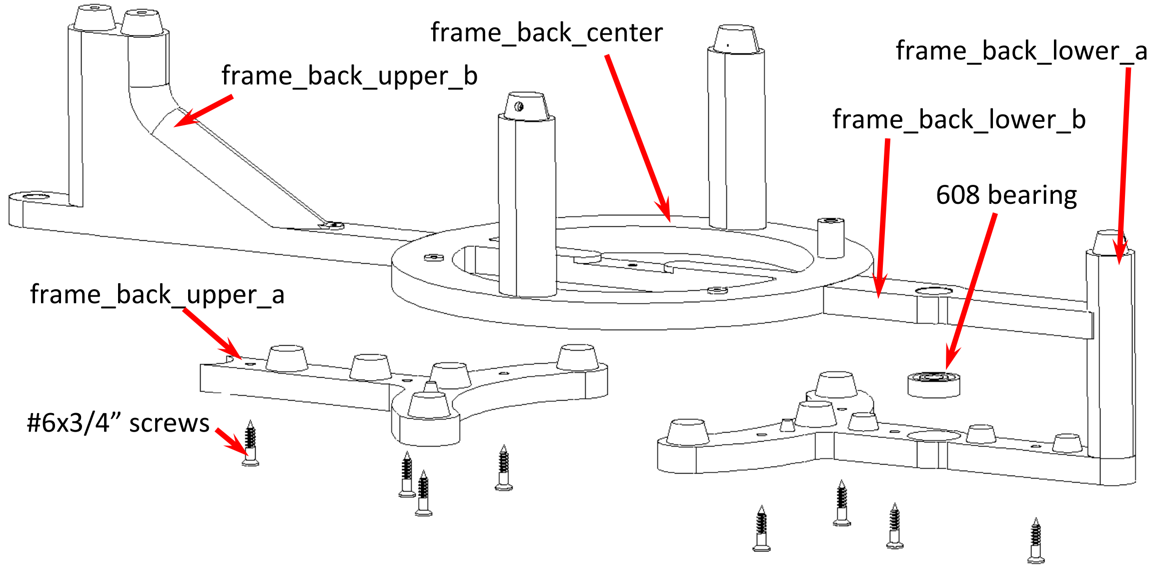
I sometimes add dry Teflon lubrication to all of the moving parts of the clock, but the clock also seems to run just fine without any lubrication. I have also used lithium grease on the pinions and pallet arms on some of my clocks. Just a tiny bit is needed. Apply it with a toothpick and wipe away most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

The small 623 bearings used to support the pendulum work best with the thick factory grease removed to minimize friction. Remove the rubber seals using a needle and wash the grease using solvent (paint thinner, mineral spirits, acetone, 90%+ alcohol, etc.). 91% isopropyl alcohol used for cleaning the print bed works great for removing the factory grease from the bearings. Let them soak overnight and brush out the grease or use a blast of compressed air, then let them soak again in fresh alcohol. Add a drop of dry Teflon lubrication or lightweight oil to minimize rust if desired.

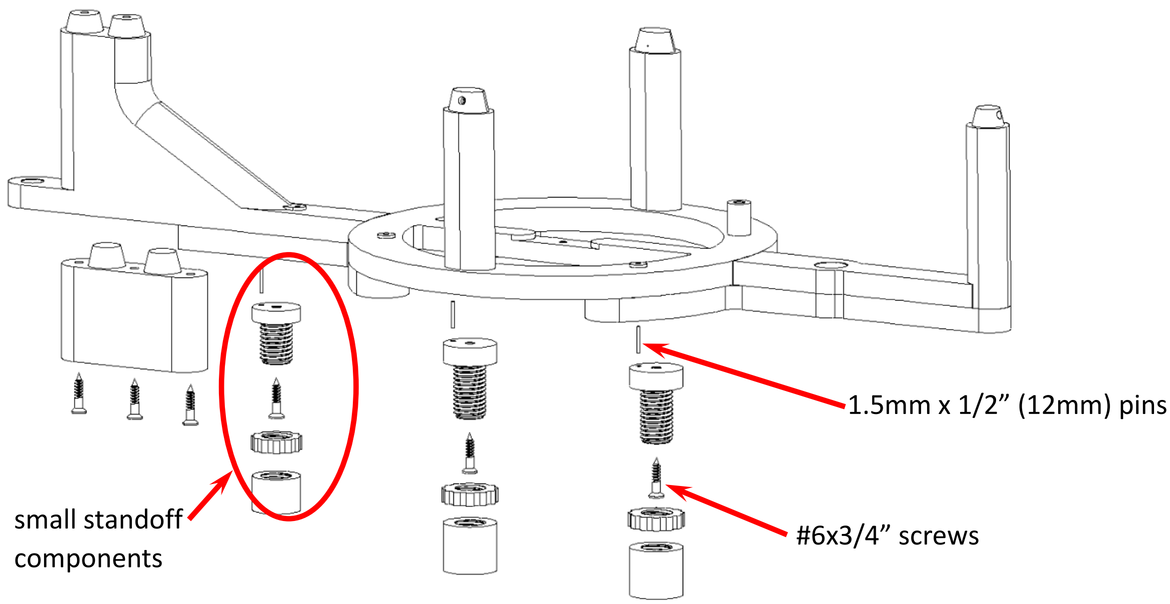
Frame Assembly

Both clocks have similar named frame parts. SP2B is shown, but the assembly for both styles is identical.

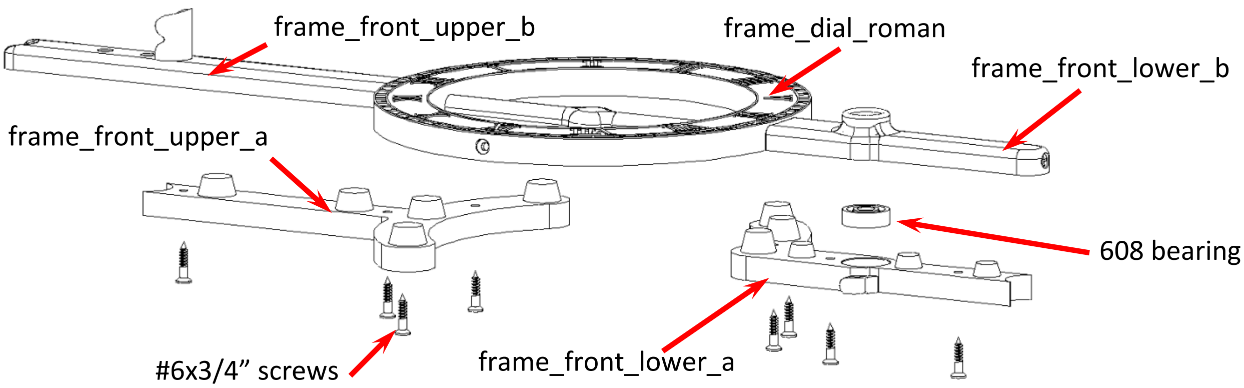
The frame is designed to fit together easily using tapered alignment pegs and screws to hold things together. The alignment pegs do most of the work, so the screws only need to keep the parts held together. Assemble the components shown below using #6x3/4" (M3.5x20mm or M3x20mm) flat headed wood or sheet metal screws. A 608 bearing is enclosed between the lower frame components.



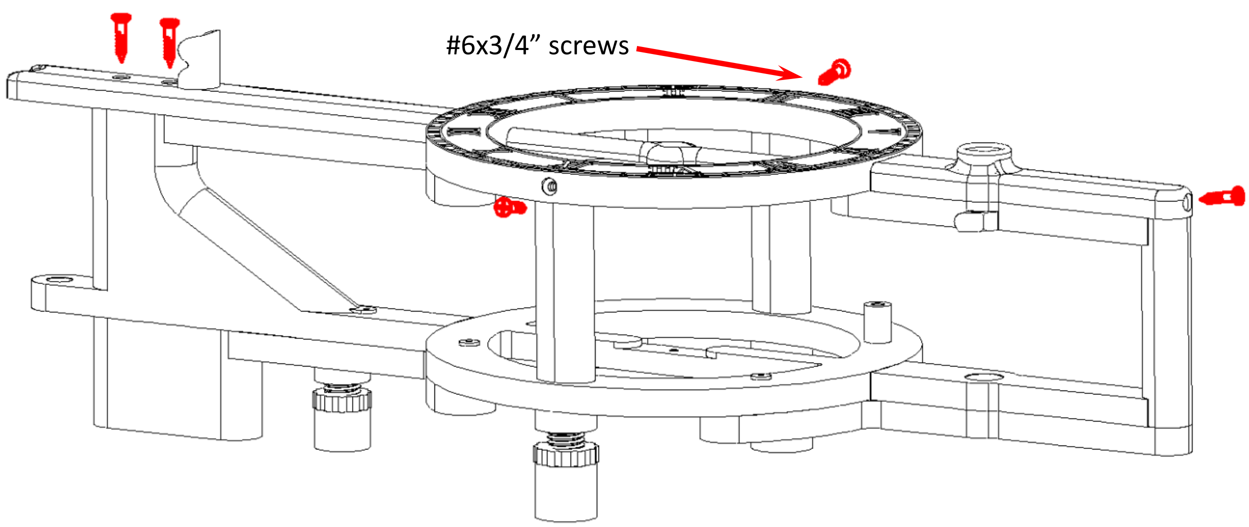
The standoffs are all in one file, frame_back_standoffs. Attach them according to the diagram below. The large upper standoff needs to be oriented so the narrow portion of the built-in keyhole hanger is near the top. The lower standoffs use a short pin to keep from spinning when tightening the nuts. The shorter standoff goes near the top.



The front frame assembles using 5 pieces, one 608 bearing, and eight #6x3/4” wood screws to match the diagram below.



The completed front and back assemblies join together using five #6x3/4” wood screws (highlighted red). The lower three screws go in at an angle to spread out the forces on the small tapered pegs to help prevent splitting. These screws do not need to be very tight, just enough to keep the dial from falling off. Check that the frame halves go together. The front frame will need to be removed to add the gears.

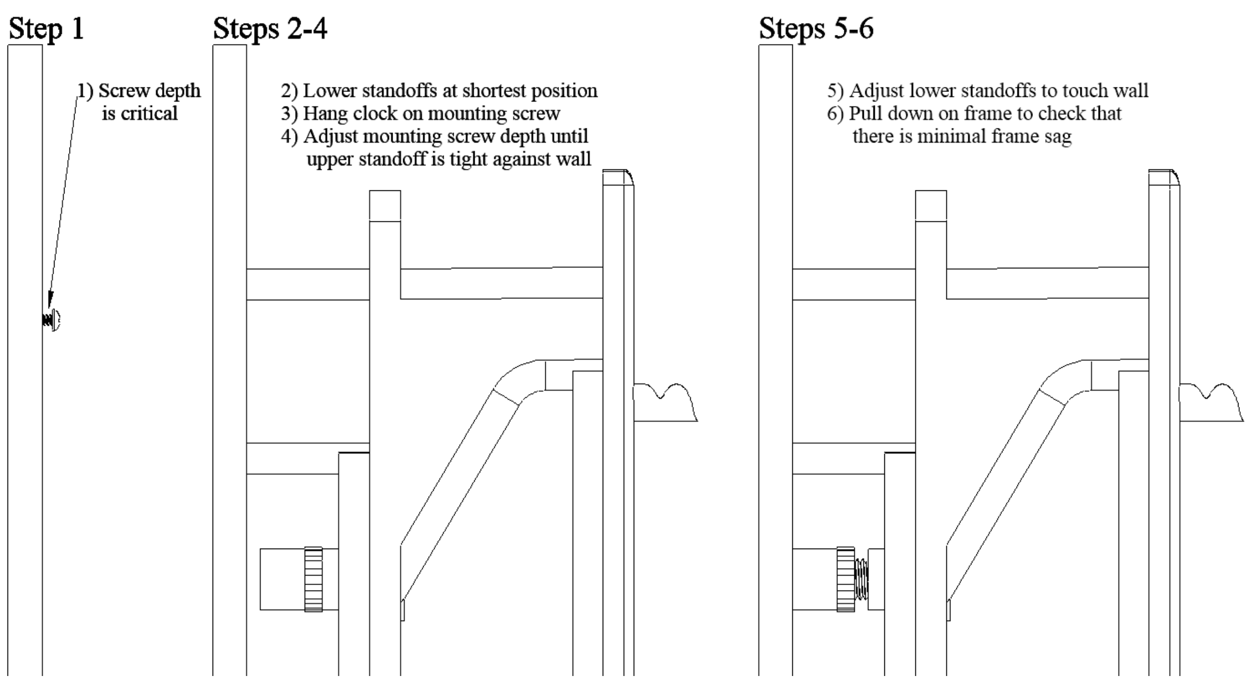


Hanging the Clock

IMPORTANT: The clock frame is designed to support a heavy weight shell without sagging. The weight distribution has about 40% of the weight hanging on the back frame and 60% hanging on the front frame. There is a strong horizontal support beam holding up the front of the clock and it is critical to set it up properly so the beam can function as intended.

The steps to hang the clock are:

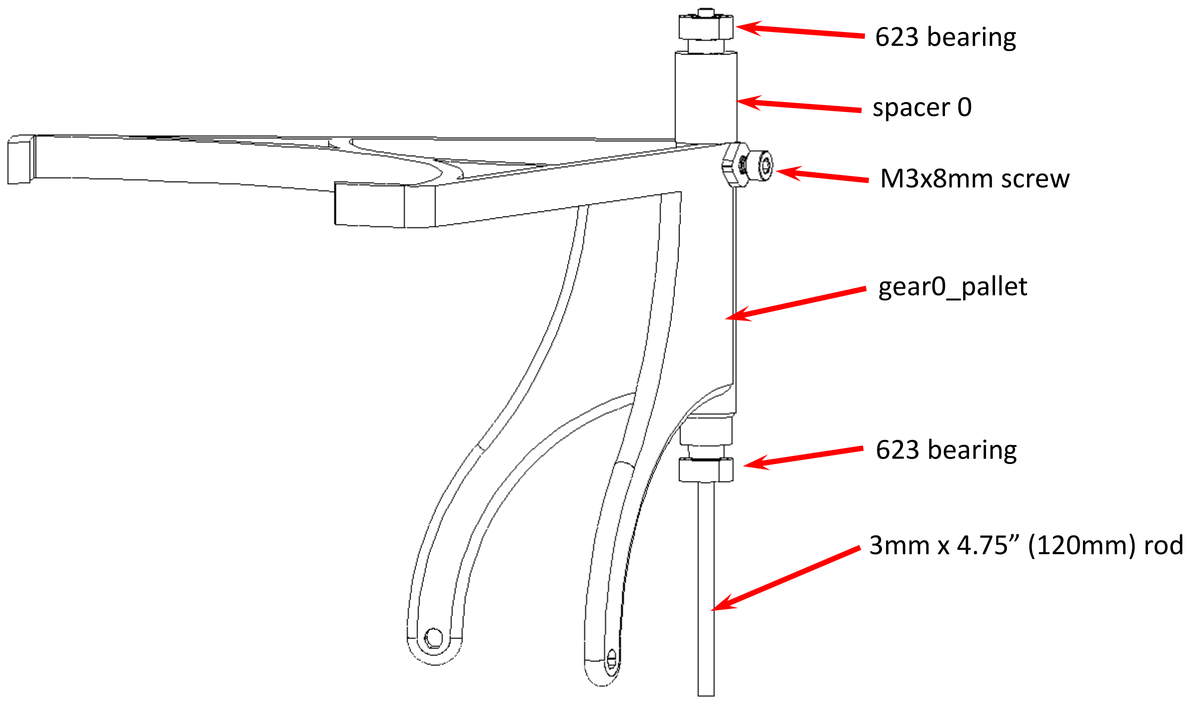
1) The most important step is to adjust the mounting screw depth so the upper standoff is held tight against the wall. This will allow the support beam to stay horizontal as it is intended. The screw should go into a wall stud so the screw does not pull away from the wall.
2) Move the adjustable lower standoffs to their shortest position close to the back frame.
3) Hang the clock on the mounting screw.
4) Adjust the mounting screw depth until the upper standoff is tight against the wall. You should be able to gently pull down on the front frame without creating a gap between the upper standoff and the wall.
5) Adjust the lower standoffs so they touch the wall. They should not push the frame away from the wall.
6) Pull down the front frame to make sure there is minimal frame sag.



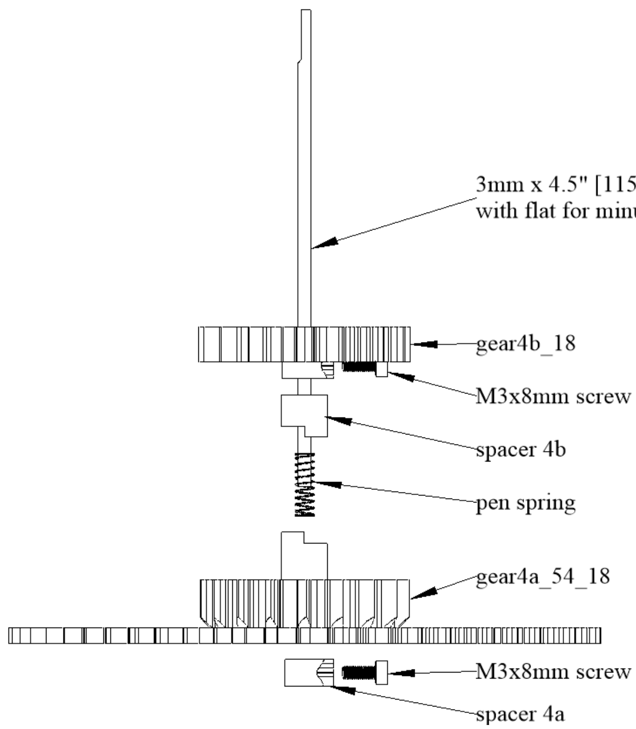
Gear Pre-Assembly

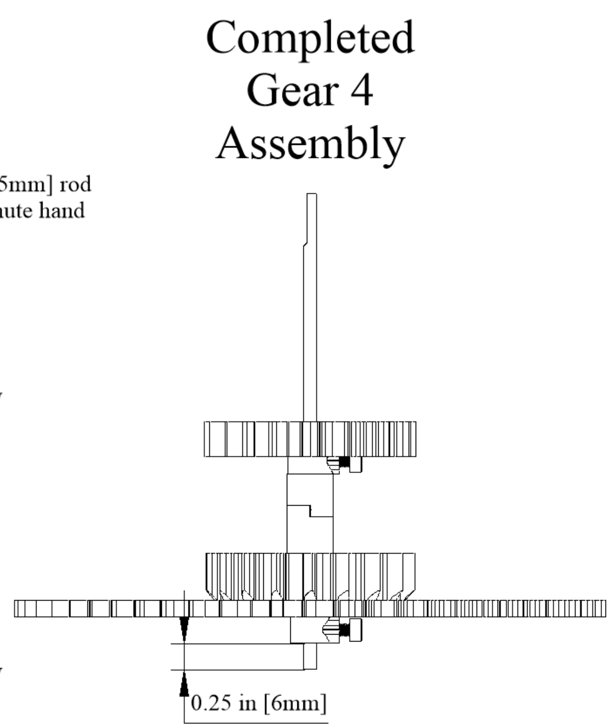
A few gears should be assembled into larger modules before adding them into the clock.

Add the pallet components in the order shown with a tiny amount of the rod extending through the bearing. Secure the arbor position using a M3x8mm set screw. Make sure the 623 bearings can slide over the rod. Some 3mm rod is oversized so it will not fit into the 623 bearings without reducing the diameter. The easiest solution is to spin the rod in a hand drill and hold some sandpaper around the shaft. You only need to reduce the ends enough for the bearings to fit.



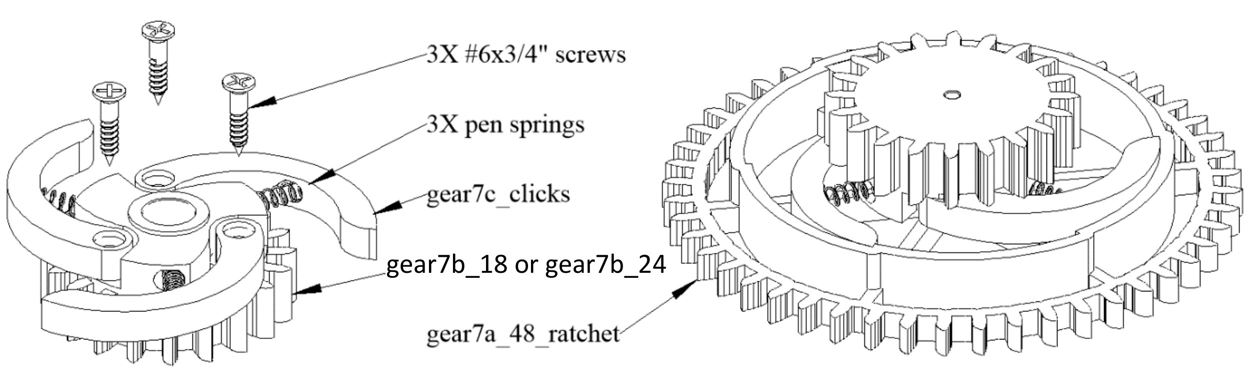
The gear 4 assembly includes the friction clutch used to change the time while the clock is running. Insert the components in the order shown and secure the positions using two M3x8mm set screws. The arbor should extend through the bottom by about 0.25” (6mm). Spacer4b should completely interlock with the notch in gear4a_54_18. You should be able to hold gear4b_18 and rotate gear4a_54_18 with a small amount of resistance.



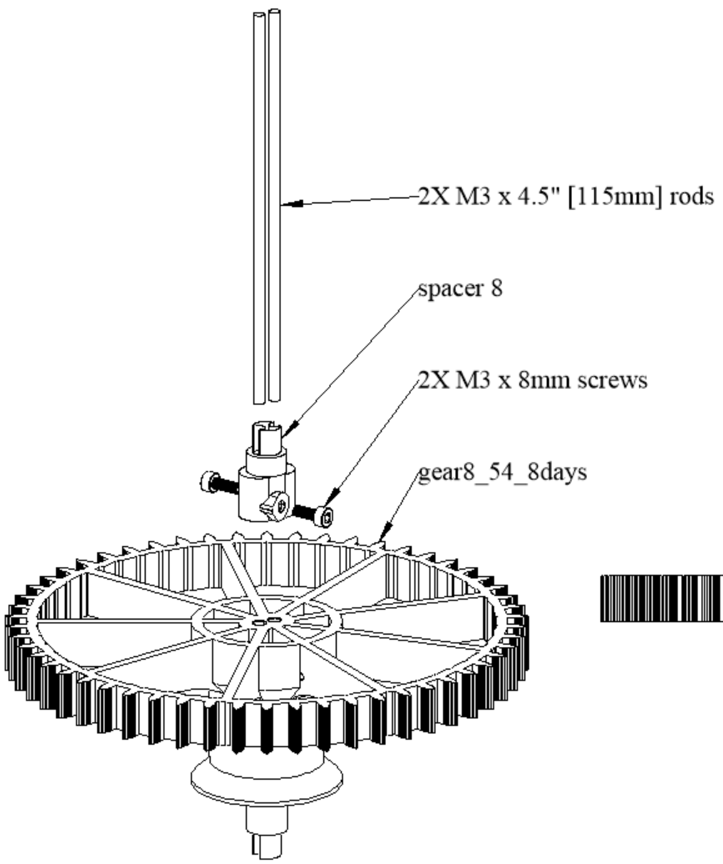


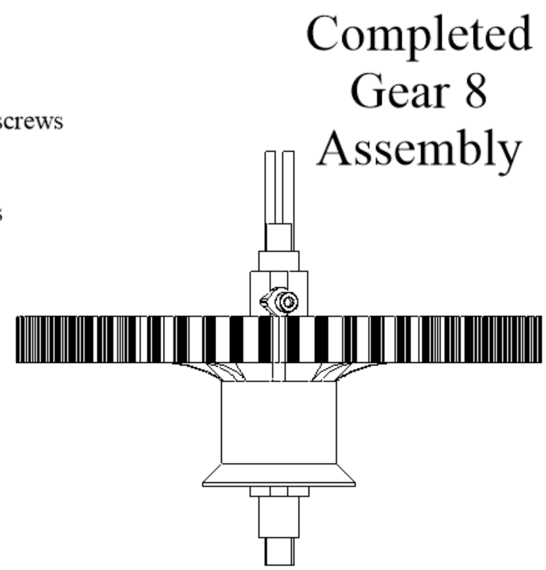
The ratchet assembly starts by adding the three clicks onto gear7b_18 (SP2B) or gear7b_24 (SP3B) using #6x3/4” wood screws. The clicks need to spin freely on the screws. Drill the holes so the clicks move freely around the screws if needed.

Add the clicks to gear7b_18 using three #6x3/4” wood screws. Tighten the screws then back them off so the clicks swing freely. Add three pen springs into the holes. Turn everything over being careful not to lose the springs and place it into the ratchet. It should rotate easily in one direction and hold in the other direction. Add a small amount of lithium grease to the tips of the clicks if they feel sticky.

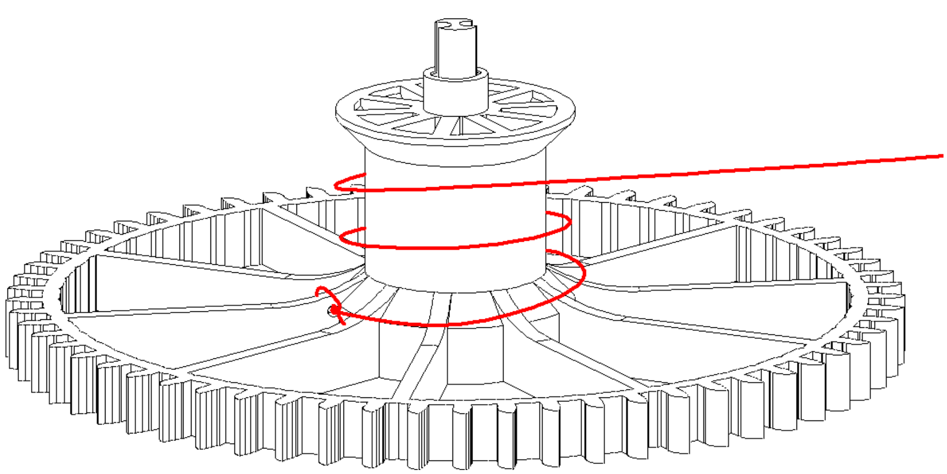


The gear 8 assembly includes the winding drum and two arbors for the winding key. Insert the rods through the spacer and gear 8 so the rods reach the tip of gear 8. Secure the rods using two M3x8mm set screws. Check that a large 608 bearings will slide completely over the rods and onto the small extensions on the spacer and gear 8. If needed, the rods can be filed down so the bearings will fit.

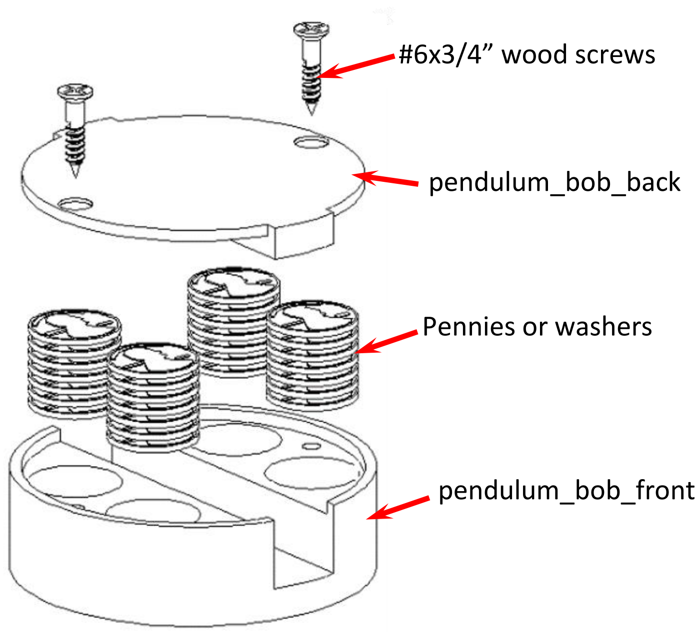




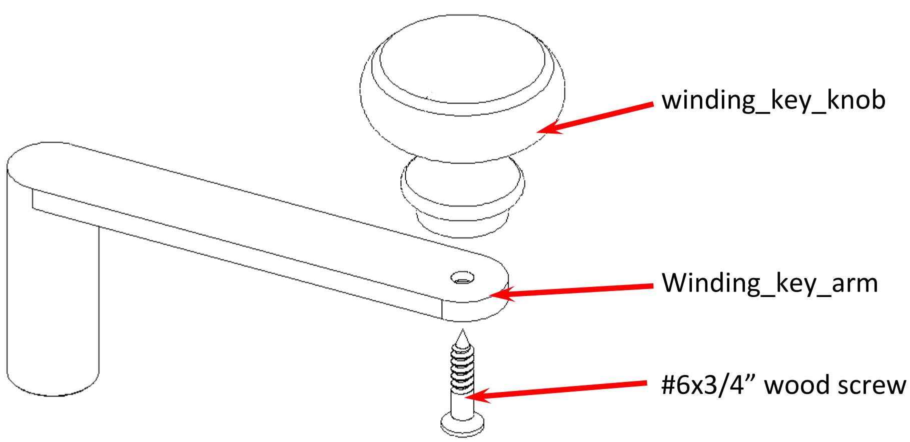
Tie one end of the fishing line around the hole in gear 8. Wrap the line around the drum in the direction shown.



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



The winding key is a simple part that should have obvious assembly. Attach the winding_key_knob to the winding_key_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.



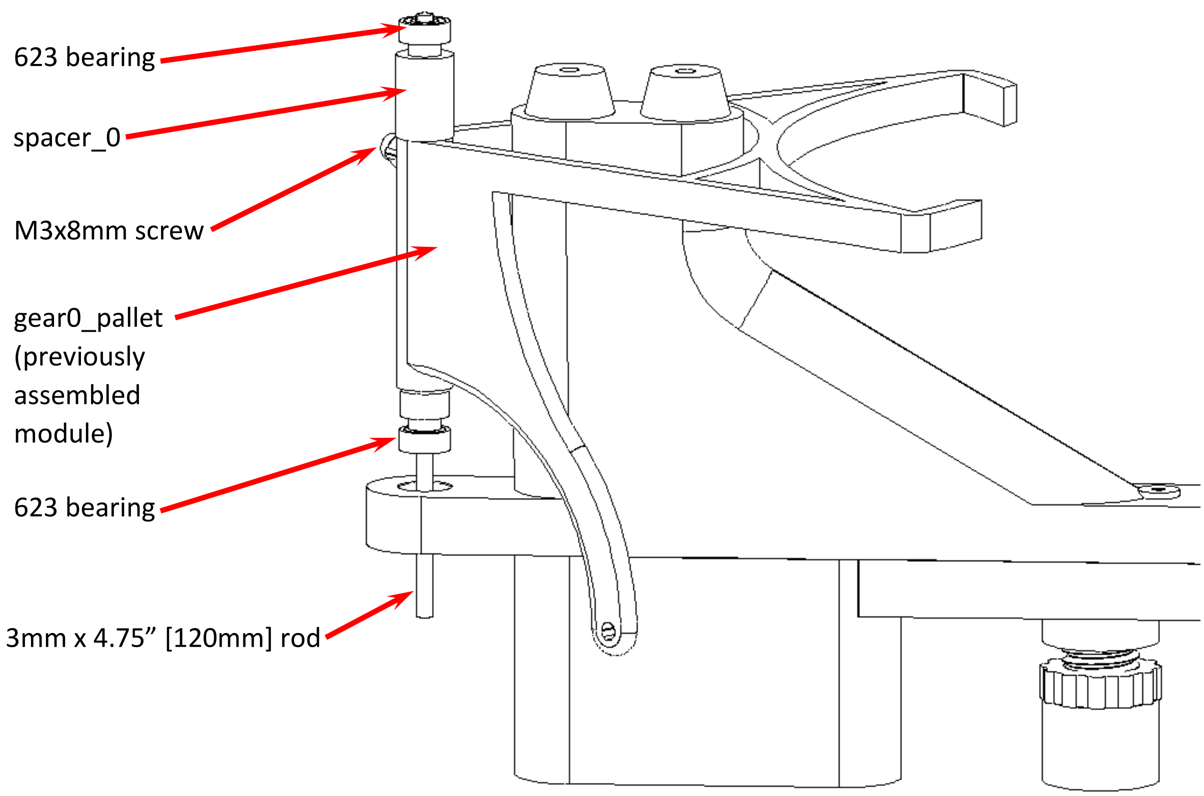
Pre-Assembly Checks

It is a good idea to test a few things before assembling the entire clock. We will be testing the pendulum free swing time and checking for proper clearances in the gear stacks with the most components. If these tests pass, then there is a greater chance of having a functional clock. Any adjustments that need to be made are easier to finish before the entire clock is assembled.

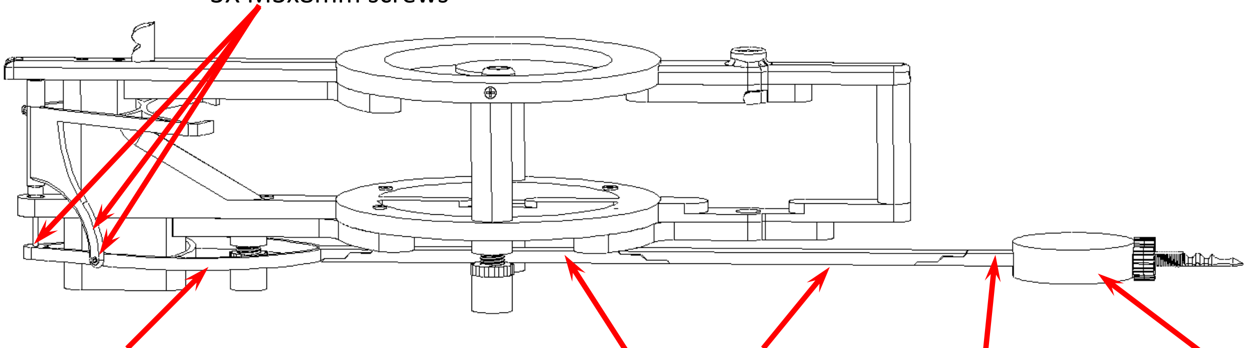
The pendulum support bearings are an important feature in all of my clocks. I believe that if small ball bearings with modern quality were available 500 years ago, we would see a lot of them supporting pendulums. They are extremely durable when operating well below their maximum load capacity. My oldest clock is over 5 years old using a ball bearing pendulum support with no signs of wear. The pendulum amplitude is still as strong as it was 5 years ago.

The first step is to remove the thick factory grease to minimize friction. Use a pin to remove the rubber seal from the 623RS bearings and soak them in alcohol or mineral spirits to remove the grease. A coat of Teflon dry lube or very light weight oil can be added to minimize rust.

Add a 623 bearing into the back frame and insert the previously assembled pallet module. Add spacer_0 and another 623 bearing. Add the front frame and secure it with the upper screw. The other frame screws are not important at this point.



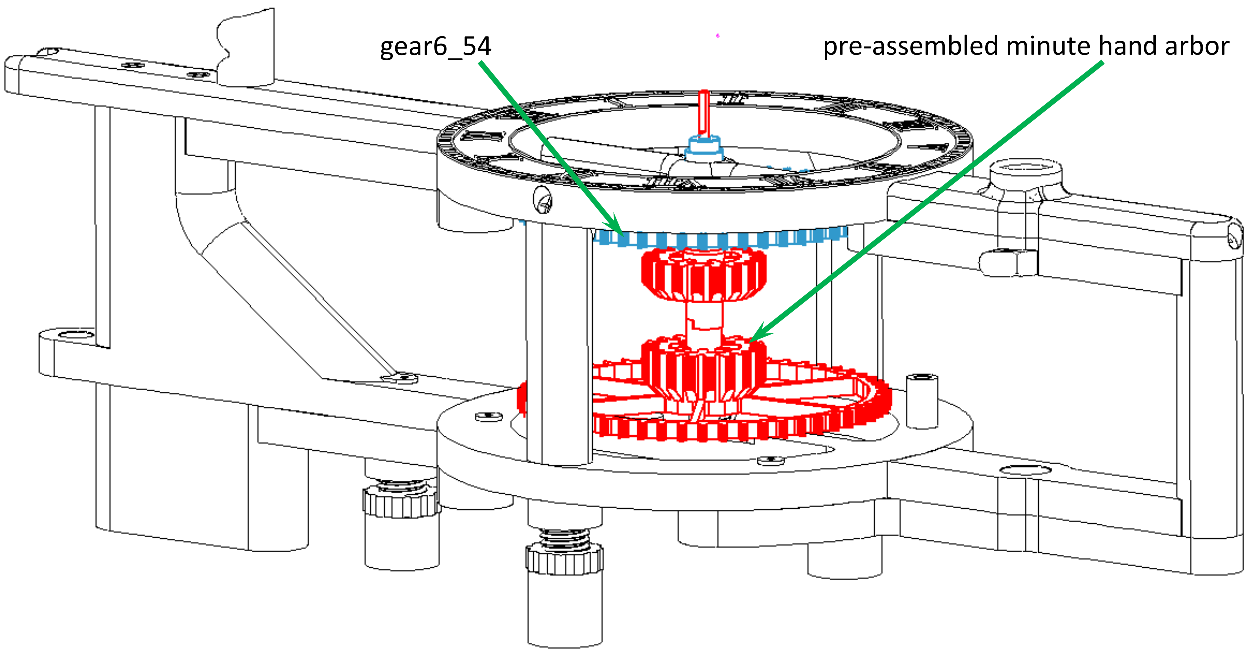
The pendulum arm consist of four segments. Pendulum_arm_upper goes onto the pallet arbor using with three M3x8mm screws. Hang the clock on the wall using a #8x1-1/2" or M4.2x38mm pan head wood screw. Other screw sizes will work as long as they fit into the upper standoff and are long enough to go into a wall stud. This single screw will eventually need to support 8-10lb (4-5kg) without pulling away from the wall. It needs to be fairly strong.



Hang the clock frame on the wall and add the pendulum arm and pendulum bob. Each pendulum arm segment hangs on the segment above it. This makes it easy to remove the pendulum when moving the clock. Swing the pendulum to one side and measure how long it takes for the amplitude to degrade to a negligible amplitude. It should swing for at least 5 minutes, preferably 10 or up to 20 minutes. Bearings that degrade in amplitude in less than 5 minutes will not make a reliable clock without an extremely large drive weight. Swap the bearings or clean them again before proceeding.

I have purchased many 323 bearings from multiple vendors and have never seen a batch of 10 bearings without at least 9 perfect bearings that swing for over 10 minutes. Most swing for around 18-20 minutes. I have not found a better method of supporting the pendulum that is easily available without going to a specialty clock shop. This assumes that the rubber seals have been removed and the thick factory grease has been removed. The free swing test does require a properly weighted pendulum bob and bearings that fit properly in the frame so the rod is not binding. I usually purchase the cheapest bearings from Amazon, eBay, and AliExpress. They all have good enough quality to work as a pendulum support bearing. The few rare bad bearings will feel gritty, as if they were dropped in sand. I suspect that even they would start to work if they were cleaned again, but bearings are cheap enough that I throw them out and use the remaining good ones.

The minute hand arbor has the most components stacked in one place. If each component prints slightly taller than expected, the stack can be pinched when the front frame is attached. Add the previously constructed gear 4 assembly and gear6_54 into the frame. Add the front frame and test that there is a small amount of vertical movement in the gear stack. This is called “end shake”. The target is more than 0, but less than 1mm of end shake. If the frame pinches the gear stack, trim a tiny bit from the tips of gear4a_54_18 and spacer_4b to make the stack thinner. Test that gear6_54 spins independently from the gear 4 assembly.



Don’t start assembling the clock until all of the previously listed pre-checks have been completed.

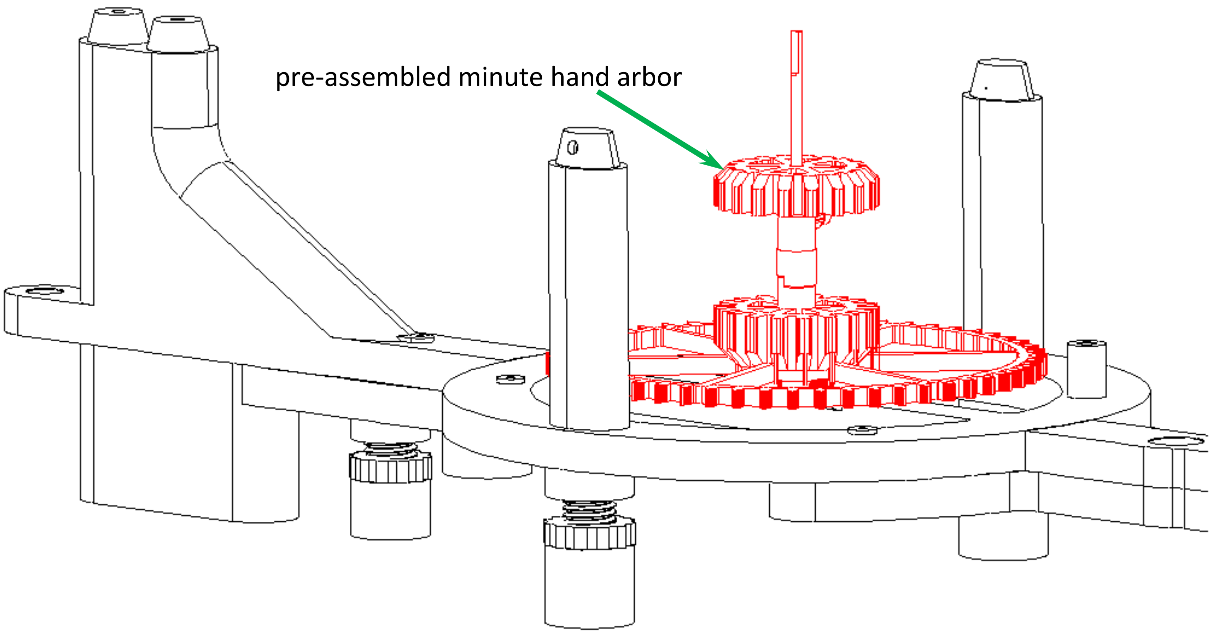
Pre-check summary:

1) Visually inspect the gears for defects like elephant foot or excess stringing
2) All gears spin on their arbors
3) All arbors spin in the frame arbor holes
4) Gear 6 fits through the front dial and spins easily
5) Gear 7b spins on gear 7a and the ratchet is working
6) Pendulum bearing free swing test runs for at least 5 minutes, preferably 10-20 minutes
7) The gear 4 assembly and gear 6 has some end shake inside the frame

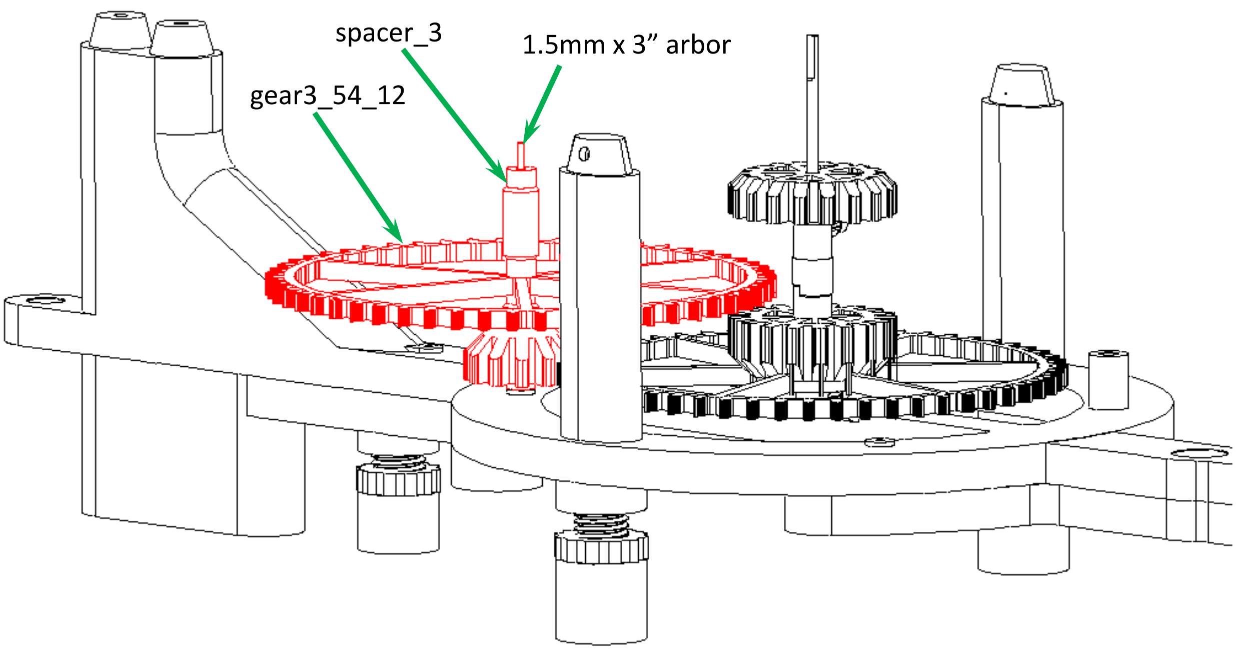
If all of these pre-checks are good, then it should be OK to start the final clock assembly. The most common issues that might cause the clock to be non-functional are the bearing free-swing test, excess friction on arbors, or lack of end shake.

Building the Clock

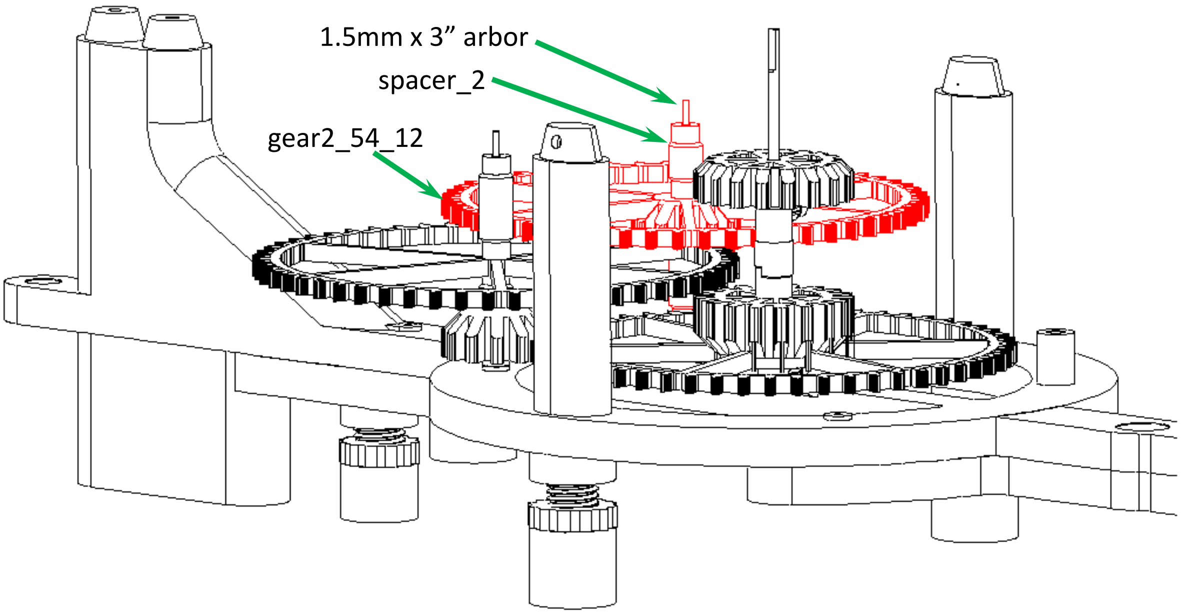
The gears are easiest to add from the bottom layer and working towards the top. Start with the back frame sitting on a workbench. Place the pre-assembled minute hand arbor into the 3mm hole in the center of the clock.



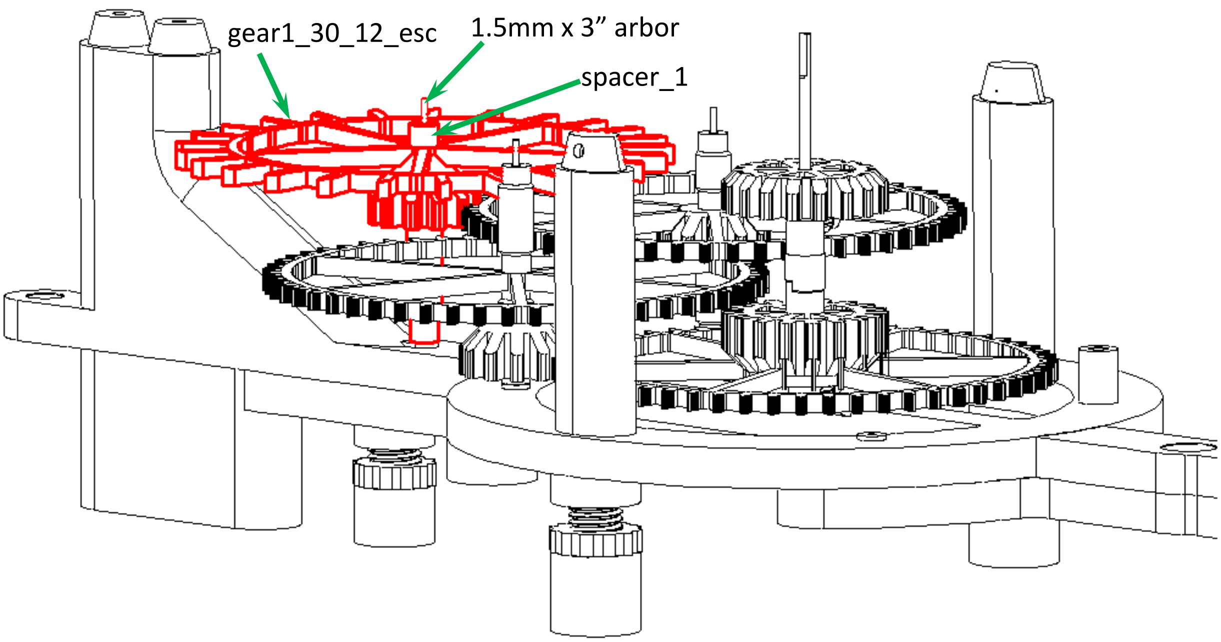
Add a 1.5mm x 3" (75mm) arbor, gear3_54_12, and spacer_3 into the upper left position. Both gears should spin easily.



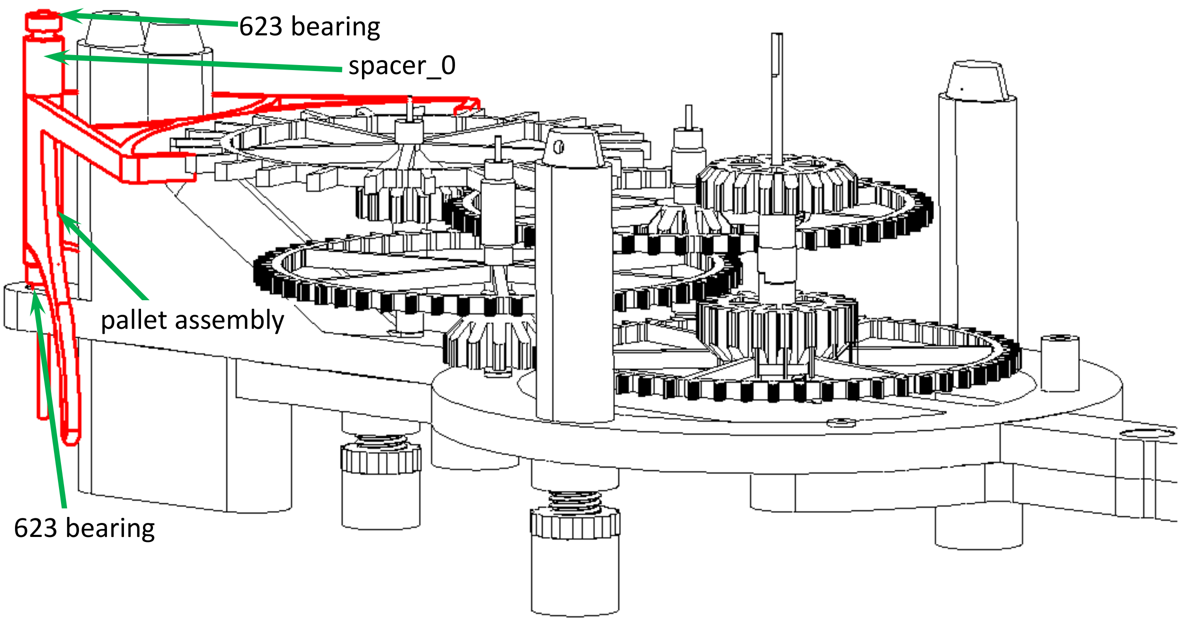
Add a 1.5mm x 3” (75mm) arbor, gear2_54_12, and spacer_2 into the upper right position.



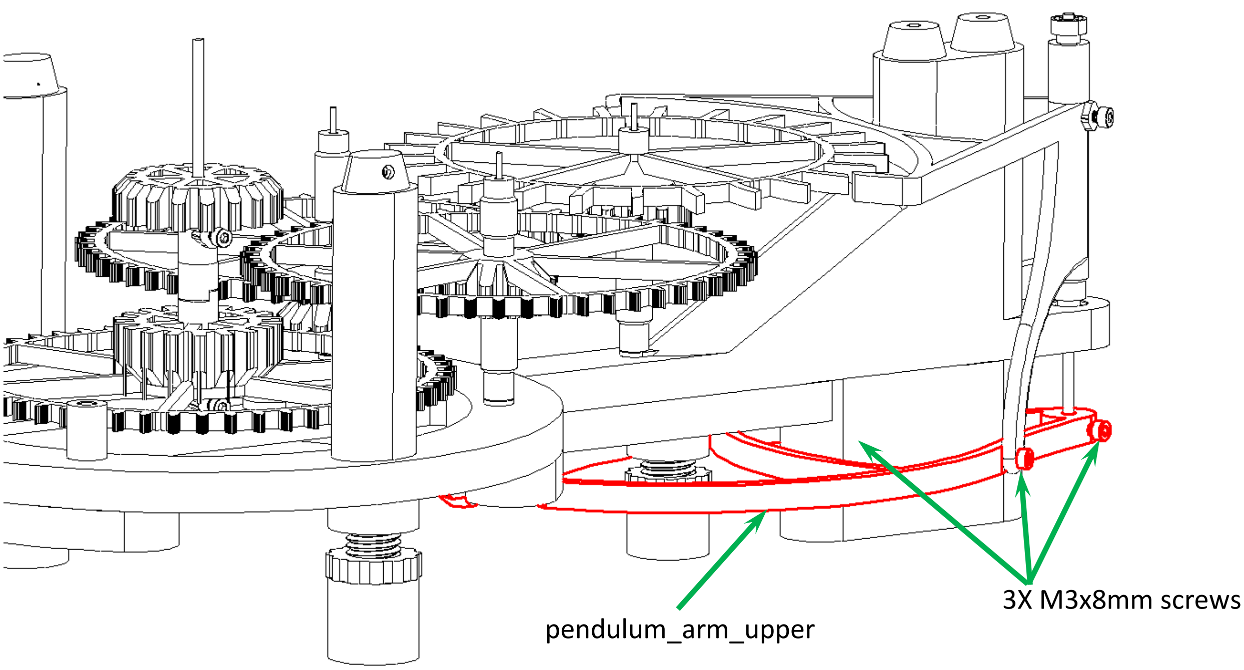
Add a 1.5mm x 3” (75mm) arbor, gear1_30_12_esc, and spacer_1 above gears 2 and 3.



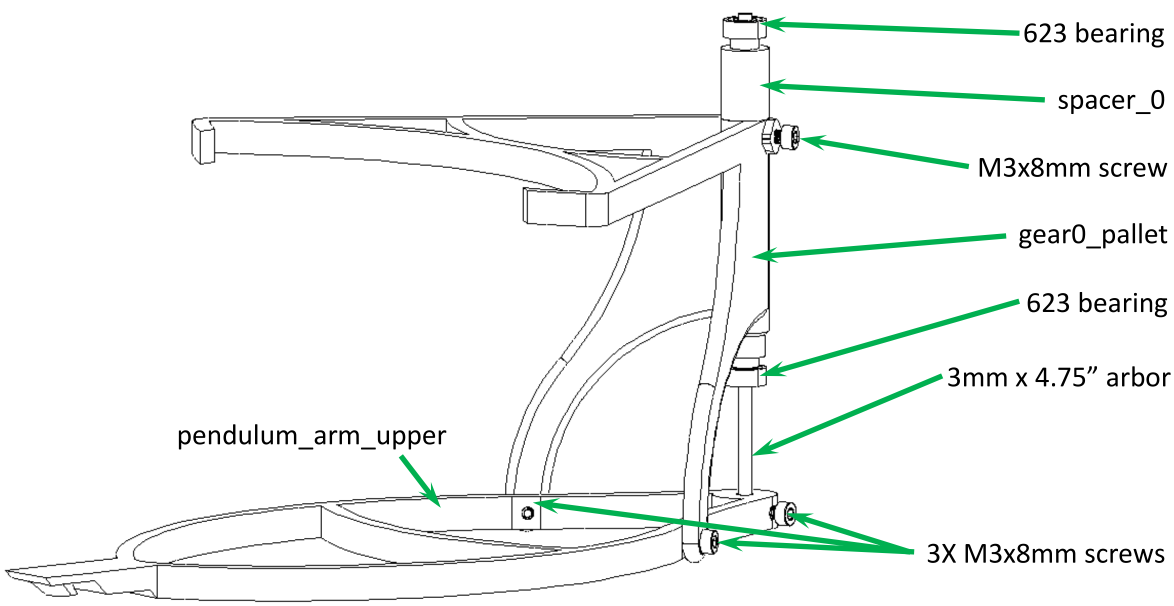
The pallet assembly has several components. Put them back in the same order that were used in the pendulum free swing test. A 623 bearing should be in the hole in the back frame. Spacer_0 and a 623 bearing should sit on top of the pallet arbor with a tiny bit of arbor extending through the bearing.



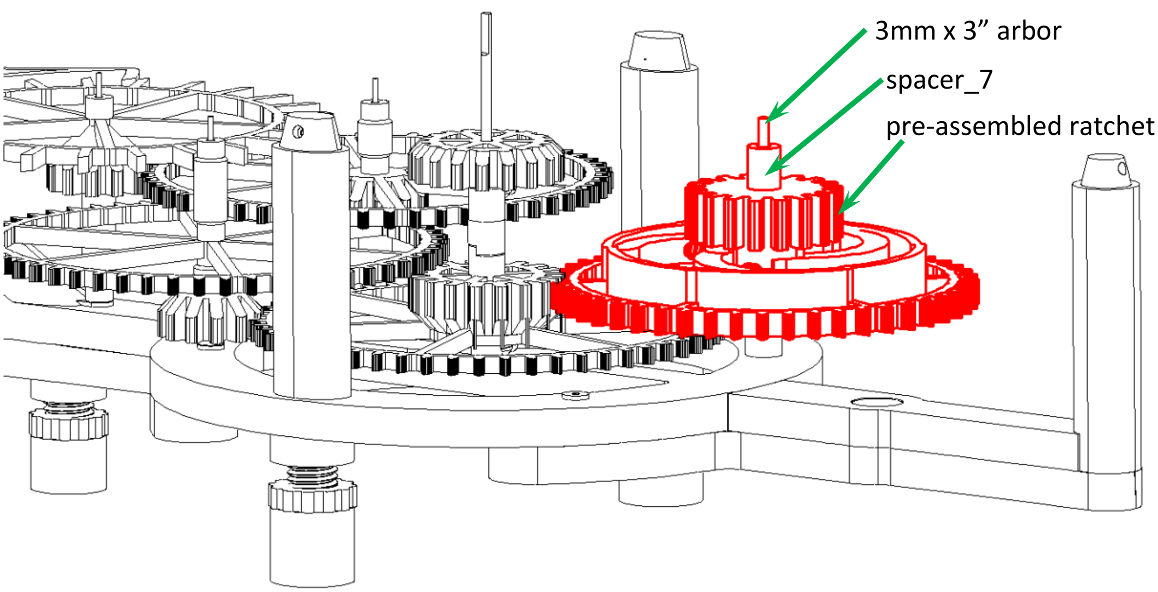
The pendulum_arm_upper can now be attached to the pallet arbor using three M3x8mm screws. Here is a view from a different perspective with pendulum_arm_upper attached.



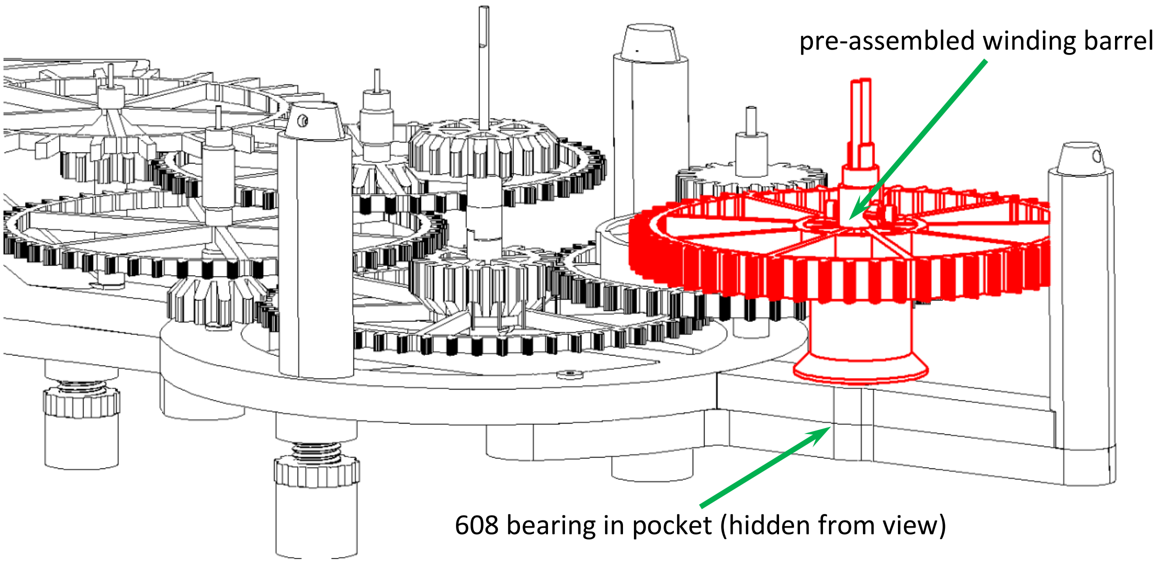
Here are all of the added components from the previous diagram shown at a different angle and without the frame cluttering the image. Of course, the arbor will pass through the back frame before the pendulum arm can be added.



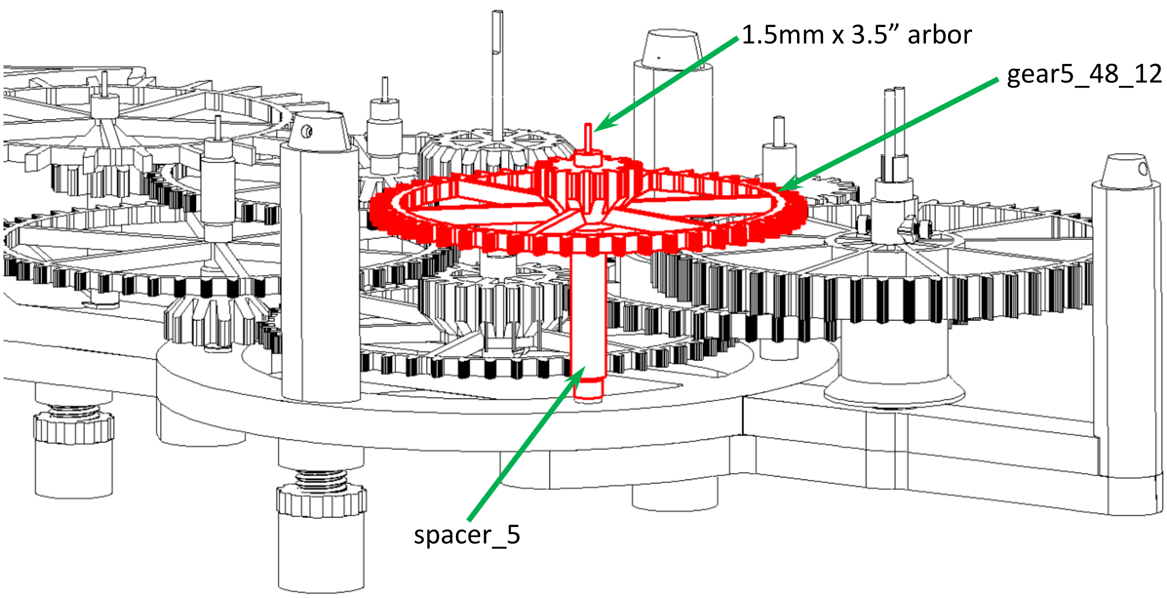
The previously assembled ratchet assembly is added to the lower right position.



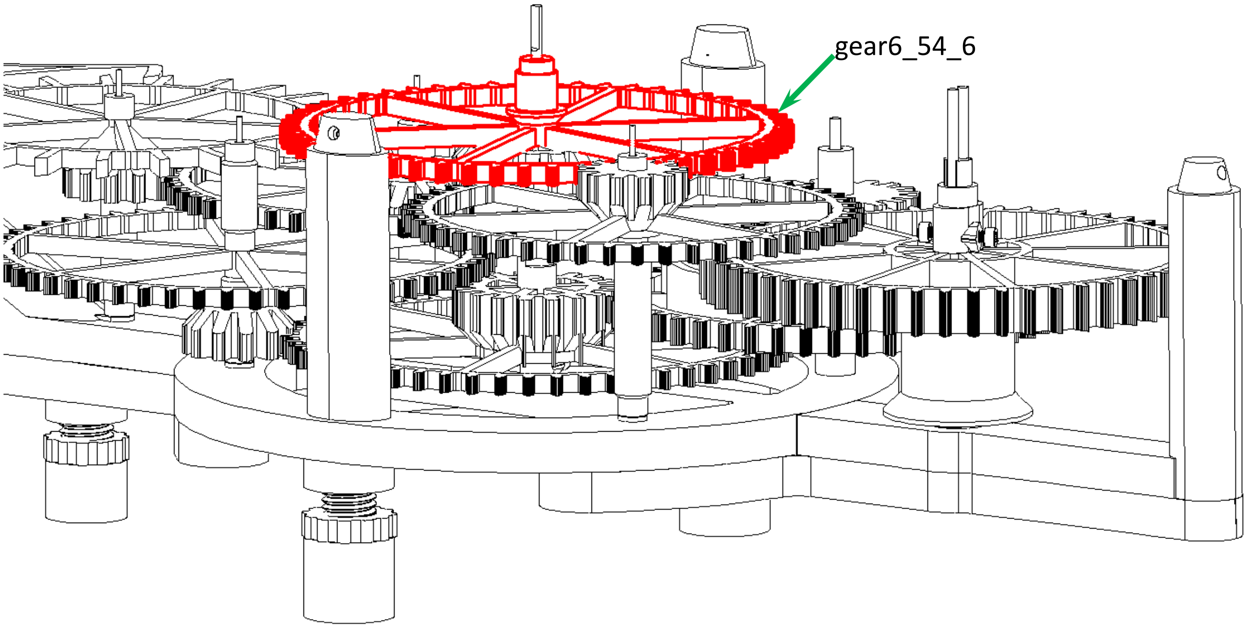
Add the pre-assembled winding barrel into the lower frame position. The two lengths of 3mm rod should fit into the 608 bearing.



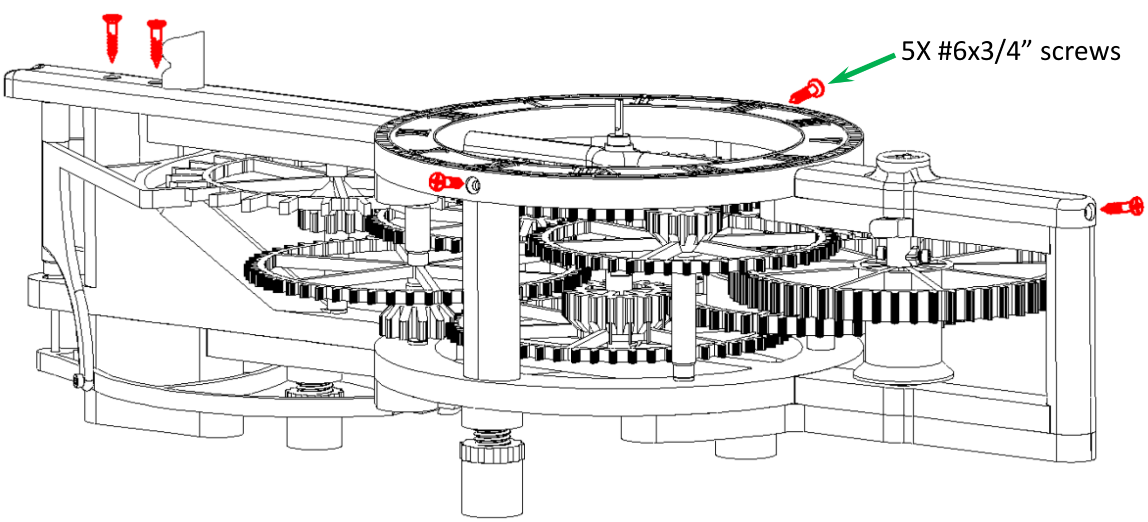
Add the longer 1.5mm x 3.5” arbor into the lower left position. Add spacer_5 and gear5_48_12.



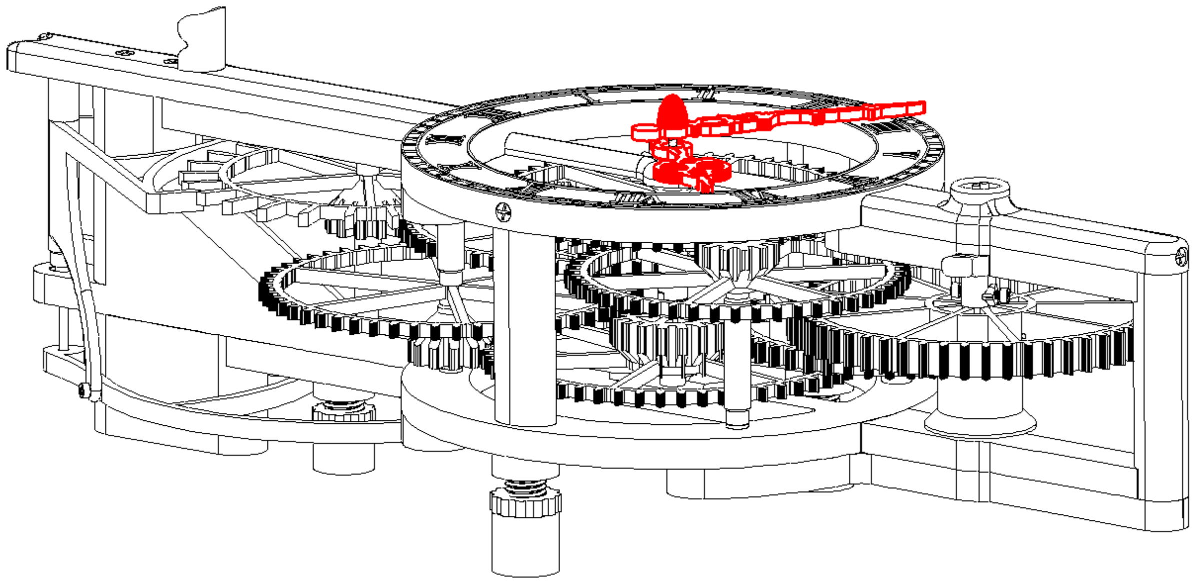
Add gear6_54 onto the gear 4 minute hand arbor.



The front frame can finally be added. Start by placing the dial over the minute hand arbor and wiggle each arbor into position one by one. The arbor holes in the front frame have large tapers to assist in lining up the arbors. Eventually, the frame should drop into position when all the arbors are lined up. Secure the frame using five #6x3/4” wood screws. The lower three frame screws have a steep angle to help keep the back frame posts from splitting.



Everything is starting to look like a clock now. Add the hands and test the friction clutch to see that the time can be changed by rotating the minute hand. There are options for hands that fit tighter on the shafts if needed. The hour hand can be placed in any orientation and can be rotated to match the minute hand position.



Testing the Clock

The clock mounts on the wall using a single screw driven into a wall stud. I use an #8x1-1/2" or #8x1-1/4 pan head wood screw, but anything that fits securely in the keyhole hanger should work. Placing the screw 74" (1.88m) from the floor will give around 46" (1.17m) of drop for the weights to fall during 7.8 days of run time.

It is very important for the hanging screw depth to be set properly for the clock frame to be supported without sagging. Follow the procedure on page 23. The horizontal support beam at the top of the clock frame is very robust, but needs the upper standoff to be tight against the wall for it to work properly. Start with the adjustable standoffs adjusted to a short position so they are not touching the wall. Hang the clock on the mounting screw and keep adjusting the screw depth until the upper standoff is tight against the wall. Then adjust the lower standoffs so they are flush against the wall. You should be able to pull down on the front of the clock without seeing any sagging. If there is any sag, the clock hanging screw depth probably needs to be tightened further.

The pendulum on this clock uses simple drop-in components. Hang the pendulum on the clock according to a previous diagram. The pendulum_arm_mid_a and pendulum_arm_mid_b segments have different lengths that can be changed if needed for further range of adjusting the time. Two copies of mid_a creates a shorter pendulum to speed up the clock. Two copies of mid_b can be used to slow down the clock. The two pendulum_nuts should start just below the center of the threaded portion on pendulum_arm_lower.

Hanging the Weight

Printing the weight shell has been delayed until now so you can determine the exact size needed for your clock to operate properly. My SP2B clock will run with a very shallow pendulum amplitude using a 5lb (2.3kg) weight. It is very robust using a 7.5lb (3.4kg) weight. Your clock may need more or less depending on the overall gear train friction.

Tie a loop at the end of the line for the weight. It needs to be able to slip over the small hook on the side of the clock. It is easier to thread the line through the weight shell pulley if the loop is a few inches long. Using a pulley on the weight shell keeps the weight balanced near the center of the clock.

Hang various size weights on the line to see how much your clock needs to stay running. An easy method is to use a water jug where you can easily add or take away weight while testing. Start with around 3lb (1.4kg) directly on the line. This amount will later be doubled when the pulley is used. Make sure the frame stays vertical during this test so the clock stays in beat.

Move the pendulum to the side and release it. The escapement should turn one tick with each beat of the pendulum. Watch how the escapement moves. It should start to rotate as soon as the pallet tips move past the escapement teeth.

If the escapement is sluggish, it will not add any energy into the pendulum and the clock will quickly stop. Try adding more weight or reduce friction in the gear train until the escapement responds quickly with each tick.

Once everything is working reliably, start reducing the weight to see the minimum amount needed to keep the clock running. We can use this value to determine what size weight shell to print. Take the minimum working amount and double this value to account for the pulley, then add a 50% safety margin, for a total increase of 3X. My clock will run for hours with 2.5lb (1.1kg) directly on the line. Tripling this to 7.5lb (3.4kg) makes the clock extremely reliable.

Weight Shell

The weight shell assembly portion of the manual has been moved to the end with the expectation that you should build the entire clock before you can determine the required drive weight for your clock. The classic clock design books with hundreds of years of experience say there is no way of knowing the exact amount of weight needed. They can give a target range, but there are too many variables and the best way to determine the value is to test it in the completed clock.

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

Copper plated steel BBs have around 80% of the density of lead shot, so a weight shell filled with BBs would only need to be 25% larger than one filled with lead shot to achieve with the same weight. BBs are less toxic and easier to find than lead shot, so it makes sense to use BBs to fill the weight shells. Another option is steel shot ballast used for adding weight to boats. Scuba diving shops may also have ballast material that you can pick up cheaply. Make sure it has the density of steel or copper. Bags of sand will not be dense enough.

This is my new favorite weight shell material from Amazon. The cheapest option is the 50lb bag with enough to build about six clocks. It consists of small BB sized steel balls, essentially BBs without the copper plated shell. They have a slight oil coating, but they are perfectly fine inside the weight shell.

Click image to open expanded view

Roto Metals Ballast (50 Lb. Weight Filled) Steel Shot for Wakesurf Boats, 50 pounds Weight Bag, Yacht and Airplane Ballast. Made in USA

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Size	50 pounds
Color	silver
Material	Metal
Sport	wakesurfing
Brand	Roto Metals

BBs can be a cheap option if you only want to build one clock. 6000 BBs weighs around 4.5 pounds (2.0kg), so two containers should be plenty. The price moves around a lot and some brands are 10X more expensive, so shop around. Also make sure to get copper plated steel, not plastic airsoft BBs.

Roll over image to zoom in

Crosman Copperhead 4.5mm Copper Coated BBs In EZ-Pour Bottle For BB Air Pistols And BB Air Guns

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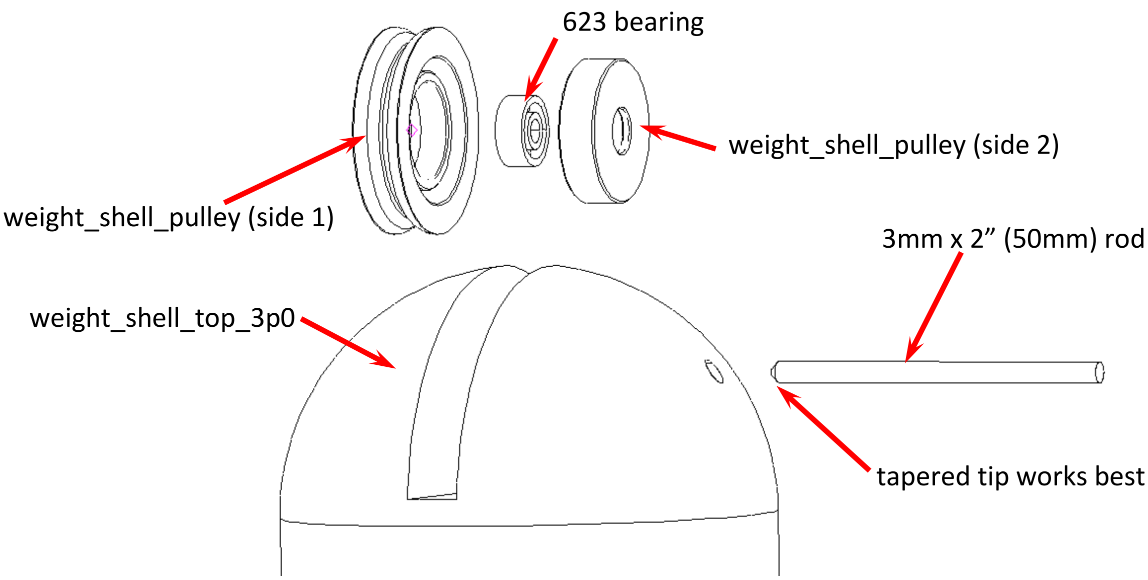
- 6000-COUNT EZ-POUR BOTTLE - Ideal for the BB air gun enthusiast or backyard plinking fun
- MADE WITH QUALITY MATERIALS - For consistent and reliable performance
- RECOMMENDED FOR USE WITH CROSMAN BB AIR GUNS AND BB AIR PISTOLS - (Not compatible for airsoft)
- AIRPOWER ADVENTURES - Start with CROSMAN

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 also 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)

My SP2B clock runs very reliably with the 3.0” shell filled with the steel shot shown above.

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.



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

Setting the Beat

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

The clock should tick with a minimum pendulum amplitude of about 1 degrees to either side, however the clock becomes much more reliable with larger amplitudes. The deadbeat escapement allows the pendulum to swing several degrees above the required minimum. My clock has a swing of about 2 degrees on each side for a total amplitude of about 4 degrees.

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

Set the time by rotating the minute hand.

Congratulations, you have completed your clock!!!

Adjusting the Rate

The clock should be reasonably accurate with the pendulum nuts near the middle of the adjustment range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. Every 0.035" in change in pendulum length should change the rate of the clock by about a minute per day.

The threads below the bob have around 12.3 threads per inch. One full rotation changes the length by 0.081". This would change the time by about 2.3 minutes per day. It is relatively easy to make small adjustments to get the time accurate to a minute or two per week.

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

Winding

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

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

Debugging

This clock was designed with the intention of being easy to assemble. Parts are designed to simply fit together and the clock will start working. However, there are hundreds of different printer designs with different tolerances that make each part slightly different. Some adjustment to get the parts to fit properly is expected.

This section of the manual will help guide you through some additional debug steps if your clock does not start working right away.

The pre-check summary is repeated to emphasize the importance of these steps. They are all related to reducing friction. Going through this list again will give your clock a good head start.

1) Visually inspect the gears for defects like elephant foot or excess stringing
2) All gears spin on their arbors
3) All arbors spin in the frame arbor holes
4) Gear 6 fits through the front dial and spins easily
5) Gear 7b spins on gear 7a and the ratchet is working
6) Pendulum bearing free swing test runs for at least 5 minutes, preferably 10-20 minutes
7) The gear 4 assembly and gear 6 have some end shake inside the frame

A few additional checks can be added after the clock is assembled. It is important to notice how the clock is stopping to decide where to focus your debug efforts.

8) Is the clock hanging properly to minimize frame sag?
   The first thing to check is if the clock is hanging properly. If the clock is simply hung on a nail, the main support beam will tilt downwards from the weight on the front of the clock. This will cause the thin sections of the frame to bend so the entire frame becomes a parallelogram and the gears can go out of alignment. They could become pinched by the frame. Or the gears could tilt so the sidewalls interfere. The hanging screw depth needs to be properly adjusted and it needs to be strong enough so it will not pull away from the wall.

9) Is the clock in beat? Move the pendulum slowly from side to side to observe.
   A clock that is in beat will have a balanced tick tock sound as the pendulum moves back and forth. This clock should be close to being in beat with the frame vertical. The only adjustment is to tilt the frame left or right. Only a small amount of adjustment should be necessary. It is a good idea to check the beat after each winding since the frame might have shifted. A clock that was previously working great but stops running within 30 minutes of winding is often an indication that the beat was changed while winding.

10) Does the escapement rotate quickly when the pallet arms clear the escapement teeth?
   This clock has a Graham deadbeat escapement that allows the pendulum to swing freely to its natural amplitude without pushing the escapement backwards. The escapement needs to rotate quickly when it changes from the “dead” portion to the active portion where the angled teeth engage and the escapement pushes on the pendulum. If the escapement is really sluggish, it will not impart any energy into the pendulum and the clock will quickly stop.

If the escapement starts spinning slowly, it might barely touch the pallet arms before the pallet moves past. Some energy is transferred, but not the full amount. The clock may run, but the pendulum amplitude will be weak. The problem could be friction in the gear train or too small of a drive weight. The friction pre-checks may help. You could also try a small bit of grease on the pinion teeth. PLA seems perfectly tolerant of most lubricants. Adding extra drive weight may also help.

11) Does the pendulum slowly loose amplitude and eventually stop?
    This could either be too much pendulum support bearing friction or not enough drive weight. Some builders mention that they get less than a minute on the pendulum free-swing test. I have not found a 623 bearing that runs for less that 5 minutes unless the bearing felt like it was dropped in sand. I have ordered hundreds of bearings and never see more than 1-2% that are bad. And I buy the cheapest bearings I can find. The bearings usually come in sets of 5 or 10. Try different bearings.
    Another thing to check is if the bearings are really tight in the frame, they might be skewed and adding a side load which will cause extra friction. Enlarge the hole slightly so the bearings are loose but not sloppy in the frame.
    If all the pre-check friction tests are working, then try adding a weight shell extension.

12) Does the clock stop in less than a minute?
    If the pendulum free-swing test runs for 10 minutes, then the clock should run for several minutes unless the escapement is getting in the way of the pallet. You may see the escapement jump from the pallet arms hitting it. This may be caused by friction in the gear train not allowing the escapement to rotate quickly. Repeat the pre-check tests looking for where the excess friction is coming from.

13) What is the pendulum amplitude?
    The minimum pendulum amplitude for the clock to run is one degree in each direction, however a clock with only one degree of swing will stop from the slightest disturbance. Two degrees in each direction will be much more stable. Try reducing friction or adding more weight to get closer to the two degree target.

14) Does the clock appear to run, but the time does not change?
    This is usually a simple fix to reduce friction in the hour hand gears or increase pressure on the friction clutch spring. If gear 6 is binding where it passes through the frame, then the friction clutch will slip and the time will not change. Sand the gear 6 shaft or the frame opening where gear 6 passes through. Or it could be caused by a lack of end shake on the central arbor. Reduce the height of one of the gears in the stack or the spacers making up the friction clutch. Another option is to stretch the spring so it applies more pressure. The good news is that the primary gear train is working so the clock is almost completely functional.

15) Look at the clock from the side. Are any gear side walls touching?
   The clock is designed with a reasonable amount of clearance between gears that are not supposed to touch. It is a balance between just enough clearance to make a compact clock or a lot of clearance making a really large clock. Possible causes include frame sag, warped gears, or too much end shake allowing extra sideways movement. Frame sag is usually fixed by following the clock hanging procedure. Warped gears may need to be re-printed. Excess end shake can be solved by adding spacers to limit the sideways movement.

16) If all else fails, test gear pairs looking for excess friction.
   Most of the pre-check tests focus on individual components or small modules. Sometimes, the extra friction occurs when gears don't mesh properly. Try testing gear pairs and spin them by hand. For example, put just gears 3 and 4 into the clock. Do they spin easily? You may need the spacers or other gears above gears 3 and 4 so you can add the front frame to hold the arbors straight. Try again with gears 2 and 3. Keep going through the gear train testing pairs.

17) Test the entire gear train without the pallet.
   After testing all the gear pairs, try the entire set of gears without the pallet. Hang the clock on the wall. Add the weight shell. All the gears and the escapement should spin. It may take an hour for the weight to reach the floor. This is also a great way to break in the clock.
   It the gears stop, look for friction where they stop. Touch each gear. If it starts spinning, see if you can find anything near that gear causing friction. Start and stop the escapement. It should start spinning quickly each time.

These are the most common reasons why your clock might not be working right away. A mechanical clock is a complex piece of engineering, so there may be other reasons. There are a lot of moving parts. I try to design using loose tolerances, but there can still be things that need adjustment for your clock to function properly.

Once the clock is working properly, it should continue to work for many years. I have been running mine for a few months so far and it has been working flawlessly. My other clocks with similar construction techniques have been running for years.

I am available to answer questions and help you complete the last few debug steps to get your clock working. You can ask questions on MyMiniFactory, YouTube, or the forum on my web site at https://www.stevesclocks.com/forum Try to provide as much information as possible. If there are different runtime options, mention which option you are using and how much weight you are using. The pendulum free-swing time for your clock may also be useful information.

You can post pictures of your clock on any of the web sites. The forum allows any type of clock related questions and comments, even related to clock designs from other designers.

Final Comments

Clock design has been a hobby of mine for many years. It really expanded about five years ago when I got my first 3D printer. The ability to quickly go from prototype to working clock is so easy with a 3D printer. I usually have several works in progress at any time. Some are grand plans that may take years to complete. Others are minor revisions.

The motivation to design these clocks has been building for a long time. My early designs are good solid designs, but when I look at them now, they appear a bit crude. My newer clocks are all easier to build. This progression started with my "Easy Build" clocks SP4 and SP5. Everything afterwards included features that simplify construction while making the clocks even more reliable. My first clock, SP1, was completely overhauled and released as SP13. I just finished some of the development for the "Perfect Print Gears" and had enough free time to make the improvements to SP2 and SP3.

The addition of the perfect print gears should make these clocks my most reliable weight driven clocks so far. My plans are to migrate the perfect print gears to some of my other clocks, starting with the easy build clocks SP4 and SP5.

Feel free to check out my other clocks. They are easy to find by searching for "Steve Peterson clocks". You can find additional information on my web site at https://www.stevesclocks.com

Parts kits for all the non-printed parts except the weights are available on my Etsy store. Check the main description where the model was purchased for a link.

One of my future goals is to start making wooden gear clocks. There have been a few small steps in that direction, but I keep finding more 3D printed clock projects to keep me busy. Migrating the perfect print gears to other clocks may keep me busy for a few months. It is possible that I will start working on a real wooden gear clock sometime in 2025. Stay tuned for more information.

Good luck with your clock build.

Steve

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

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

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

I recently had all of my clocks on display at the 2023 Bay Area Maker Faire. It was a great experience. Most of the people attending seemed to be interested in the large robots, but I still had a nearly constant stream of visitors for six days. It was refreshing to see so many young people asking how to design a clock. Here are all of the wall mounted clocks.

Sorry about the bad quality images. The lighting was horrible and there was only a few minutes between setup and a line of people in the booth. Here are the desktop clocks.