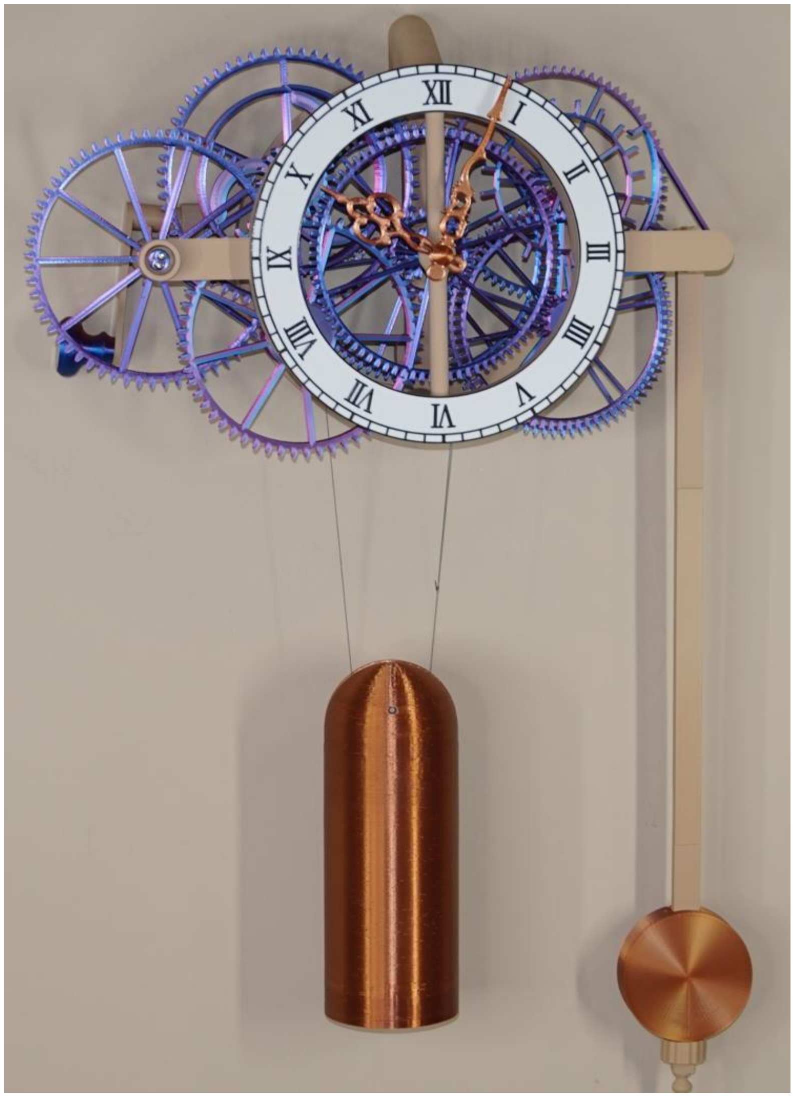


LARGE EASY BUILD CLOCK

SP4B Assembly Notes

Instructions for building a large 3D printed clock
with simple construction and runtimes up to 23 days
Major improvements were made to improve reliability

Steve Peterson
15-Feb-2025

Contents

Revision History

06-Mar-2021	Original SP4 release.
10-Apr-2022	Added helical gears to push gear3 away from escapement.
02-Sep-2023	Rev 2 update adds set screws to completely isolate gear 3 from escapement.
15-Feb-2025	Major refresh as SP4B. New gear profile to improve reliability. Updated frame design.

Introduction

This clock was originally released in 2021 as "SP4: Large Easy Build Clock with 21 Day Runtime". It is one of my first clocks designed specifically with the intention of being easy to build. Parts fit together without any complex assembly. Runtimes could be as long as 21 days per winding, although the clock would be much more reliable when configured for shorter runtimes. I have recently been developing a more efficient gear tooth profile that makes longer runtimes possible again with high reliability.

The updated clock is being re-released as SP4B in the same location on MyMiniFactory as the original SP4 release. If you purchased SP4 and can still log into MyMiniFactory, you can download SP4B to get the new design. The original (outdated) design will still be included in the zip file if you need access to any of the older parts. If this is your first clock, then I highly recommend building the new design.

Retrofitting an old design with a couple of new parts is not possible. You need to re-print all the gears and a new frame, so you basically have to re-print most of an entire clock.

The dial has a diameter of 8" (203.2mm), so the minimum size printer needs to have a print area of at least 205x205mm. This makes it possible to print on most normal sized printers such as an Ender 3, Prusa MK3/MK4, BambuLab A1/P1S, etc. Smaller printers like the Prusa Mini or BambuLab A1 Mini are not large enough to print this clock, but they can be used to print the smaller SP5 design.

The bill of materials is reduced compared to my other clocks. 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.

The design of this clock has several options to customize the look and performance. Runtime options can be selected for 8, 11, 17, or 23 days. The dial can be changed between classic Roman numerals or simple numbers. Two different hand styles are available. Of course, you can select any color you like. My personal favorite is dual color blue/red silk PLA for the gears.

This document describes the steps required to 3D print and assemble your own clock. It is one of my easiest to build clocks and also a very useful timepiece. The primary goal of all my designs is to create a functional clock that is also visually impressive. This clock is 15.2 inches wide with an 8 inch dial and fully exposed gears. Accuracy is within a few minutes per week. A clock that only needs winding once a week is a very functional clock. Once every two weeks is even better.

Note: Many diagrams in this manual show the smaller SP5B clock. This is only done when both designs have similar features. New diagrams specific to SP4B are added when there are important differences. For example, this clock uses a gear labeled as gear9_60, while SP5B uses gear9_54. Both look similar and I try to change all references to gear9_54 to say either gear9_60 or possibly just gear 9. A few typos might still slip through.

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 22 and follow the cut list on page 25. A parts kit is available on my Etsy store if you want to save time ordering parts. This step is listed first to allow additional lead time for shipping if needed.
2) Print the frame components listed on page 16 and miscellaneous parts on page 17 using 0.2mm layer height, 4 perimeters, and 25% infill.
3) Select a runtime option. If this is your first clock, I suggest something conservative like 11 days.
4) Print the gears listed on page 16 using 0.15mm layer heights, classic slicer, and 4 perimeters.
5) Refer to the gear and spacer cross reference diagrams on pages 19-21.
6) Follow the pre-assembly cleanup steps shown on pages 26-28.
7) Assemble the frame as shown on pages 29-30.
8) Component pre-assembly steps are on pages 31-36.
9) Additional pre-assembly checks are on pages 37-40.
10) The step-by-step process of adding the gears is on pages 41-46.
11) Weight shell information is on page 18 after determining how much your clock needs.
12) Hang and test the clock following the instructions on pages 47-48.
13) Additional debug steps are on pages 49-51 if needed.

Updates from SP4 to SP4B

SP4B is the enhanced version of SP4. Both designs look very similar. The update started with just a few minor edits to the frame and gears. It ended up as a nearly complete redesign. The following updates were made:

1) The gears were updated to a more efficient tooth profile. It is a modified cycloid design that has been optimized for 3D printing. I call them "Perfect Print Gears". They appear to be significantly less likely to stick compared to the modified involute gears in the original design.
2) The escapement was reduced in size and weight to make it more efficient.
3) Alignment tabs were added to the frame components for more precise positioning.
4) The winding key was updated to use metal pins instead of the printed tabs that were prone to breaking off.
5) Additional bearings were added to the ratchet and behind the central arbor. These may be considered optional and can be replaced with printed bushings if desired.
6) Slightly different gear ratios were used for the different runtime options. Some gears now have different names because the number of teeth is encoded in the names.
7) The screw holding one end of the winding cord was replaced with a printed hook that is less likely to break.
8) The two screws securing the front frame have a steeper angle that is less likely to split when assembling the clock.
9) A larger pulley was added to the weight shell, although the old design with a small pulley will still work.

By the time all these updates were made, only the pallet and pendulum were left unchanged from SP4.

Details

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

The original design started with the goal of reducing the number and types of non-printed components. It used one size 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 pennies for the pendulum bob. Everything else is 3D printed. The upgrade follows similar design goals with additional reliability from the new gear profile.

This clock uses two gear tooth sizes. The gears near the winding drum use around 11.36 diametral pitch (11.36DP or MOD 2.235) which gives a 60 tooth gear a pitch circle of 5.28 inches. The lighter gears near the escapement have smaller 15.0DP (mod 1.693) teeth giving a 60 tooth gear a pitch circle of 4.0".

Gear Design

The gear tooth profile is a modified cycloid shape that has been optimized for 3D printing. Clockmakers have had an ongoing debate about the best gear style for clocks. Come say cycloid gears are more efficient. Others say it doesn't matter and both types get the job done. It is a bit like the "Ford vs Chevy" debate amongst car enthusiasts. I have an opinion that it may not matter for traditional brass gears with steel pinions, but modified cycloid gears are better for 3D printing. This section describes the process that went into developing the gear tooth profile used in this clock. Over time, I hope to update several of my other clocks to use this new gear tooth style.

Clocks have a unique gear structure where the weight turns the slowest gear and all other gears turn at higher speeds. Most gears have large tooth counts turning low tooth count pinions. The escapement starts and stops the gears with each tick. If there is any tendency for the gears to stick or jam, it will show up in the escapement that suddenly loses energy and the clock stops.

The oldest clocks used hand cut brass gears with steel pinions. The profile seems to be able to handle slight tolerance errors due to hand filing. Brass meshing with steel is somewhat self-lubricating so the gears last a long time. Many clocks built hundreds of years ago are still running today.

The industrial age introduced involute gears that were more easily mass produced by automated gear cutting machines. Most modern clocks use involute gears. The original version of this clock used an involute tooth profile optimized for 3D printing. It appeared to work efficiently and the clock was designed with runtimes as long as 21 days. However, the clock had a tendency to run great for a while, then suddenly the escapement would slow down and the clock could stall. Greasing the pinions seemed to help, but only for a short time. I needed to find a better solution.

The first failure analysis of a stalled clock showed that the escapement could halt if there was any side load applied to it. This design is unique with multiple gears stacked on the arbors near the escapement. Any side thrust applied to the escapement would take away most of the energy and the clock would stop. Adding helical gears to push gear 3 away from the escapement was the first improvement, but did not completely stop the clock from randomly stopping. My prototype clock was reverted to a short runtime instead of the desired 21 day mode.

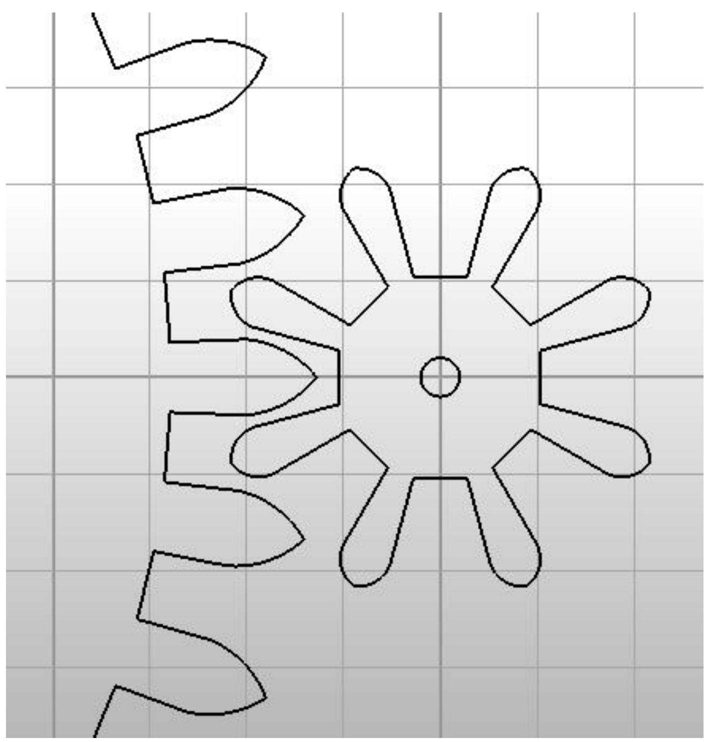
The Rev 2 update added set screws to isolate the escapement from the gear behind it. This was a big improvement in reliability. There is no longer any way for gear 3 to push against the escapement. The clock ran significantly better, but would still occasionally stall. There was still something taking energy away from the escapement. There is no longer any risk of side pressure. Could the gears themselves be adding extra friction? It turned out that the first two fixes only solved one problem.

The final improvement added to this clock is a switch from involute to a modified cycloidal gear tooth profile. I believe this will solve the gear sticking issue. Involute gears appear to have more engagement friction where the pinion pushes into the larger gear as the teeth start to engage. This is especially noticeable with small tooth count pinions. Cycloidal gears have more contact after the line of centers where the teeth are pushing away instead of pushing into each other. Switching this clock to a cycloidal gear tooth profile appears to have made a significant improvement in the escapement reliability. The overall drive weight needed to run the new clock appears to be about 20% lower than the original design.

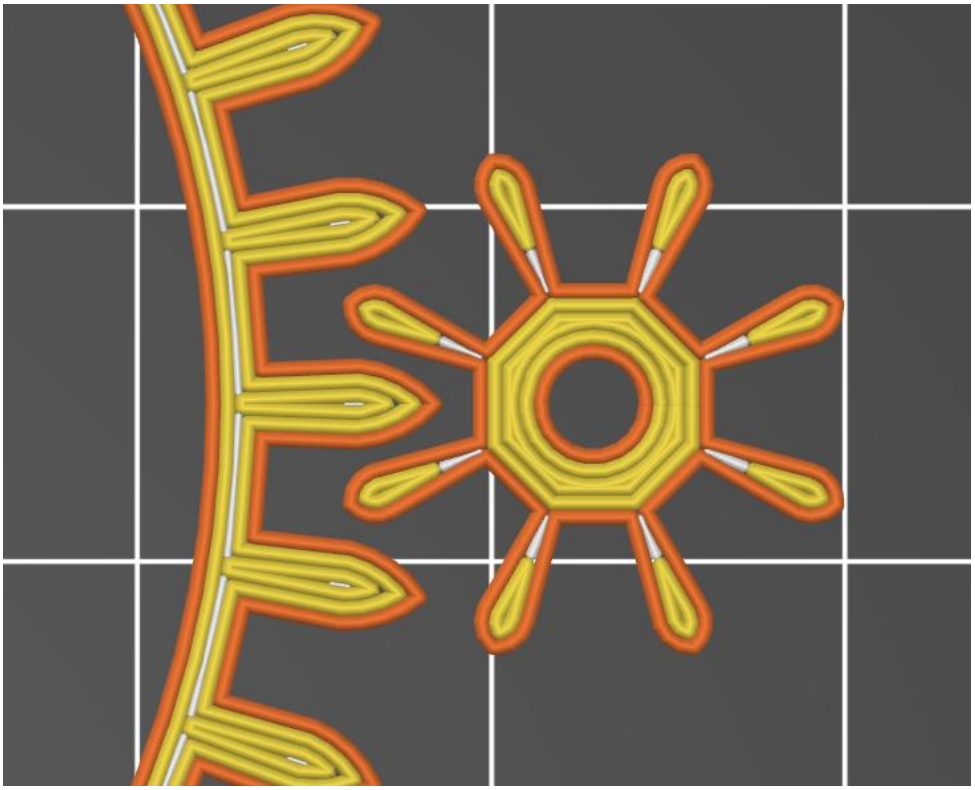
Perfect Print Gears

I call the gear tooth profile used in this update "Perfect Print Gears" with optimizations specifically for 3D printing. The new profile appears to have low overall friction, and most importantly, it appears to reduce the engaging friction that was robbing the escapement energy. Here is a description about how this gear tooth profile evolved.

The oldest known clocks used hand cut variations of cycloid gears. This style works great with brass gears and steel pinions. This 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 soft brass gear teeth. Brass against steel is somewhat self-lubricating so these gears can last for centuries when used in a clock.



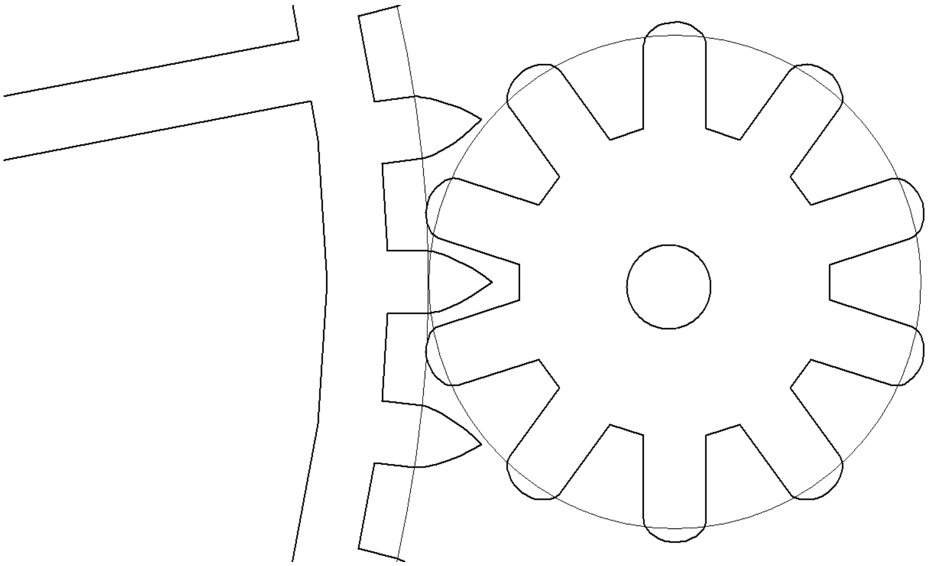
Cycloid gears work great with brass gears and steel pinions. Unfortunately, the results are not so great when 3D printed. The slicer output of an unmodified cycloid gear pair is shown below. The large gear is acceptable, but the pinion is a mess. The pinion teeth are way too delicate and would wear out or break if made from the same material as the large gear.



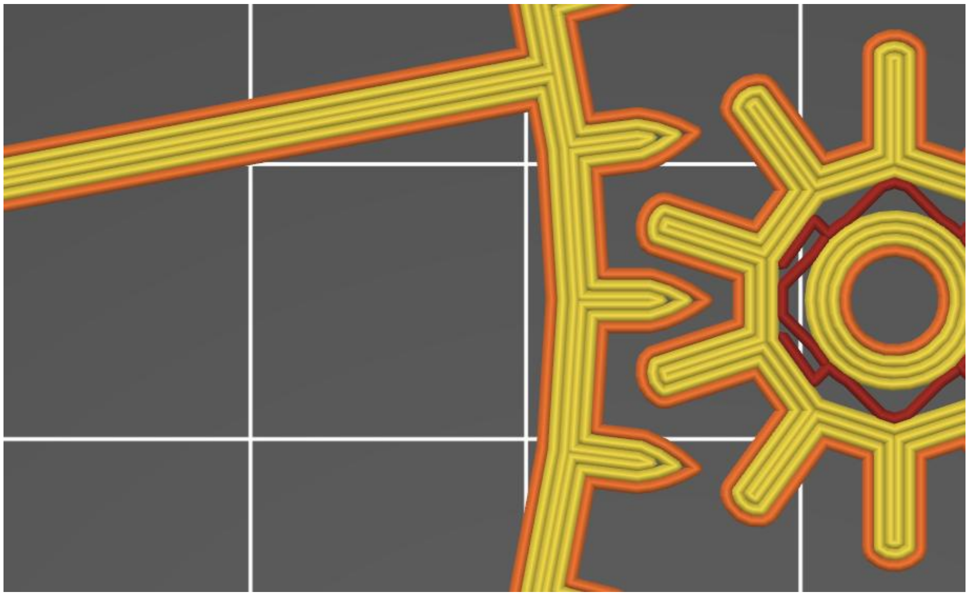
The pinion needed to be made thicker to give it some strength. The main gear was made slightly narrower to give extra space for the pinion. The result is better, but not perfect. The gears need additional improvements to reduce retraction so printing can finish with minimal stringing.

The modifications for 3D printing were based on two primary criteria. The gears must have constant angular velocity and low friction. Constant angular 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 angular 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 developed for this clock has uniform width side walls that print cleanly and a tooth tip that provides constant velocity. The result is shown below. Most of the tooth engagement takes place with the primary tooth touching the pinion after the line of centers, so friction is minimized.

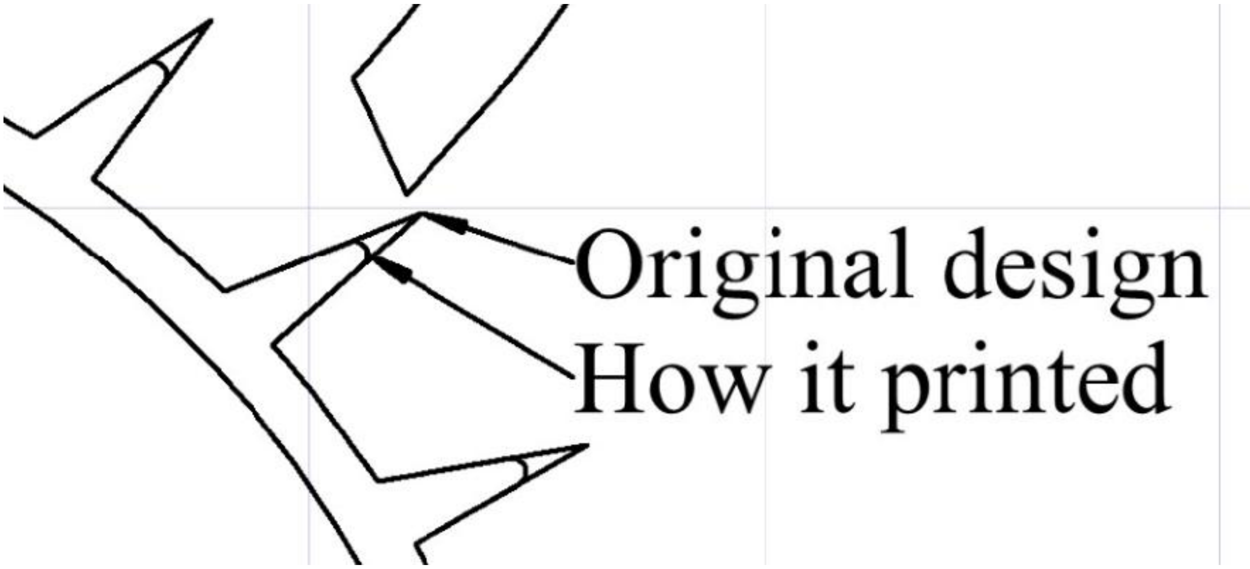


These are the resulting gears in the slicer. Notice the clean the filament paths with minimal retractions.

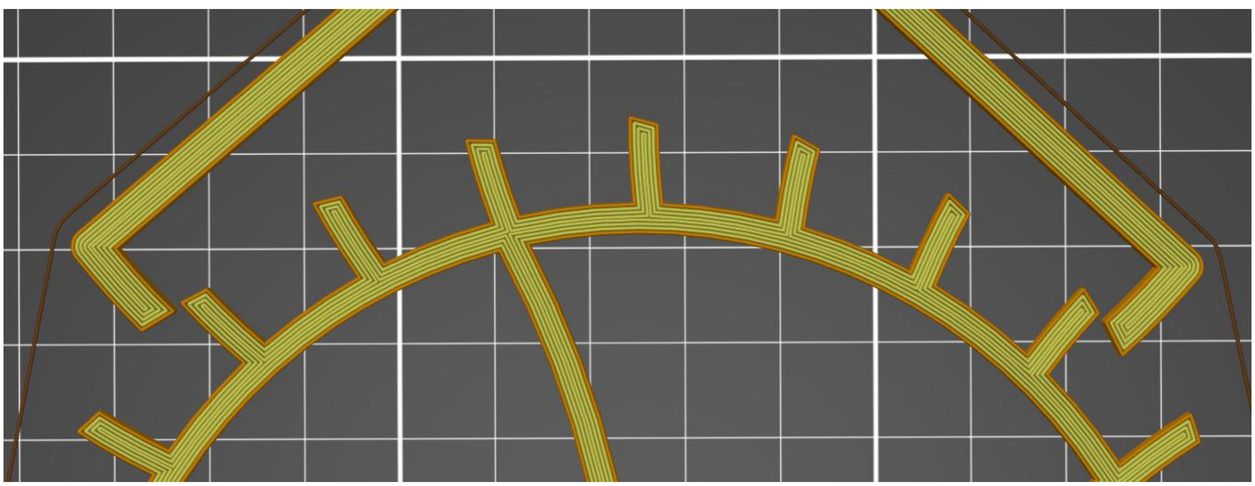


The new gear tooth profile appears to work significantly better than the original design, especially with the longer runtime options. The original design needed 11 pounds in 21 day mode, and I eventually reverted to either 8 or 12 day mode with around 8 pounds of drive weight to keep the clock running reliably. Running the clock with lower weight would work for a while, but eventually would suffer what I used to call “sticky gears”. The escapement would suddenly lose power and the clock would stop. The new design will run in 23 day mode with 9 pounds of weight. The clock has not stopped once, although the pendulum amplitude is the minimum to keep the clock running. It is quite robust with 11 pounds. I believe that these new gear tooth profiles are a significant reason for the increased reliability.

The escapement had similar optimizations for better 3D printing. The escapement and pallet are among the most important components in a clock. A traditional design has sharp escapement teeth that become rounded off when 3D printed, resulting in the escapement releasing way too early.



The escapement teeth could be lengthened to compensate, but different printers would need different optimizations. The solution used in all my clocks is to widen the tips of the escapement and extend a consistent width to the rim and spokes. The pallet width was reduced to provide the proper clearance. It may look different than a traditional design, but the active surfaces are similar. The predictable length of the escapement teeth makes it very reliable in a 3D printed design. The consistent width allows everything to print cleanly like the new gear tooth profiles.



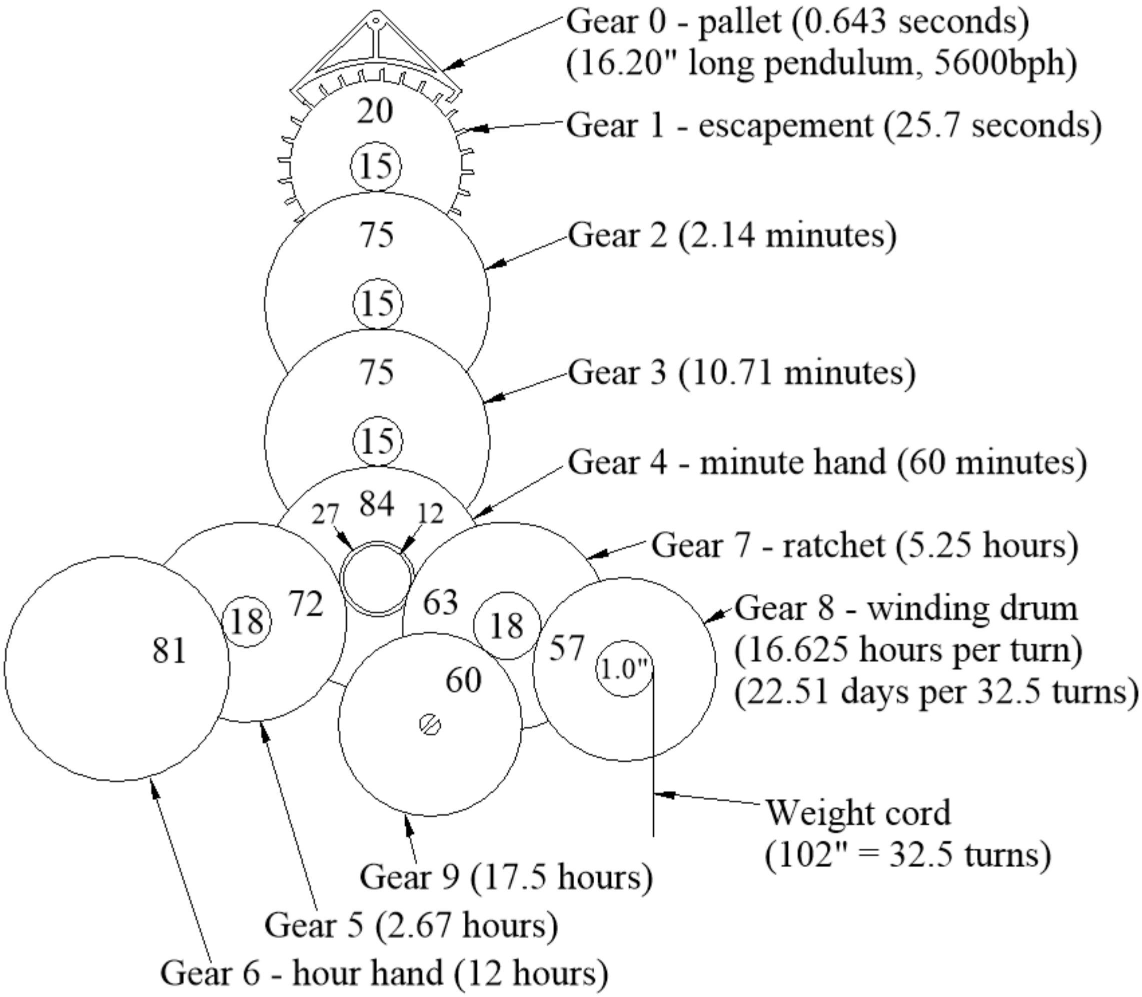
Gear Ratios

The 23 day option uses the following gear layout. Power is provided by gear 8 in the lower right corner of the diagram and transferred to the escapement near the top. The escapement pushes on the pallet arms which in turn pushes the pendulum.

The escapement and gears in the top of the diagram were chosen to allow a pendulum length that is proportional to the size of the clock. The 20 tooth escapement works with the 16.20” long pendulum.

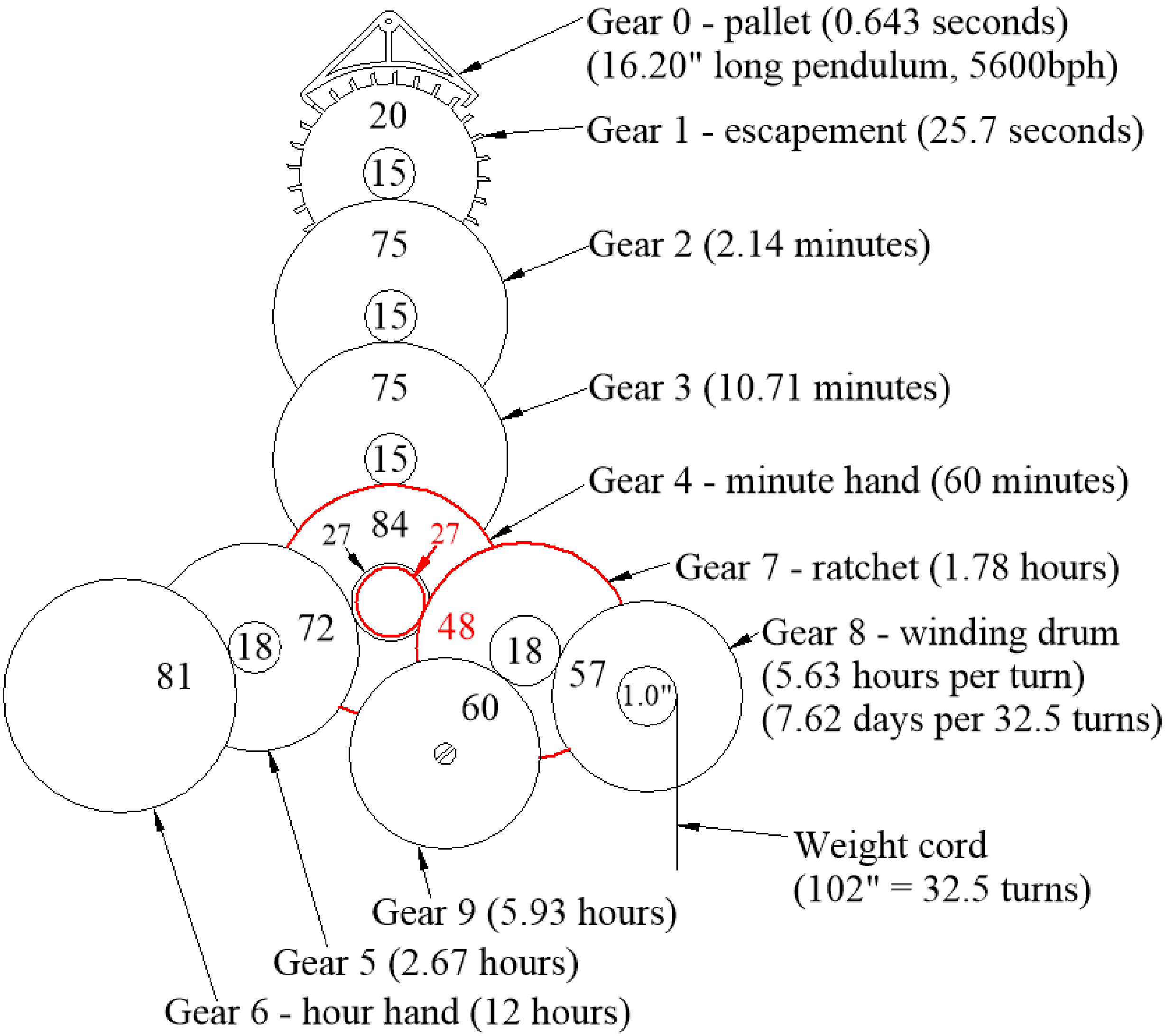
A friction clutch between gear 4a and gear 4b provides a loose connection to the minute and hour hands. This allows changing the time without disturbing the gears providing power to the escapement.

This clock is different than most of my other clocks by having a separate gear 9 to wind the clock. The only reason for this is to minimize the number of bearing sizes used. Gear 8 uses the same small bearing as the pendulum. Gear 9 adds a convenient method to pass a large connection through the front frame to securely connect the winding crank. Gear 9 is unloaded so friction is minimized.



SP4B Clock Gear Ratios 23 Day

Changes for the 8 day mode are highlighted below in red. Gears 4 and 7 get have different ratios. This provides more power to the clock with the same drive weight, or they will allow the clock to run with a smaller weight.



SP4B Clock Gear Ratios 8 Day

The clock can be configured with runtime options of 8, 11, 17, and 23 days by using the following gear 4 and 7 ratios. Here are the configurations supported.

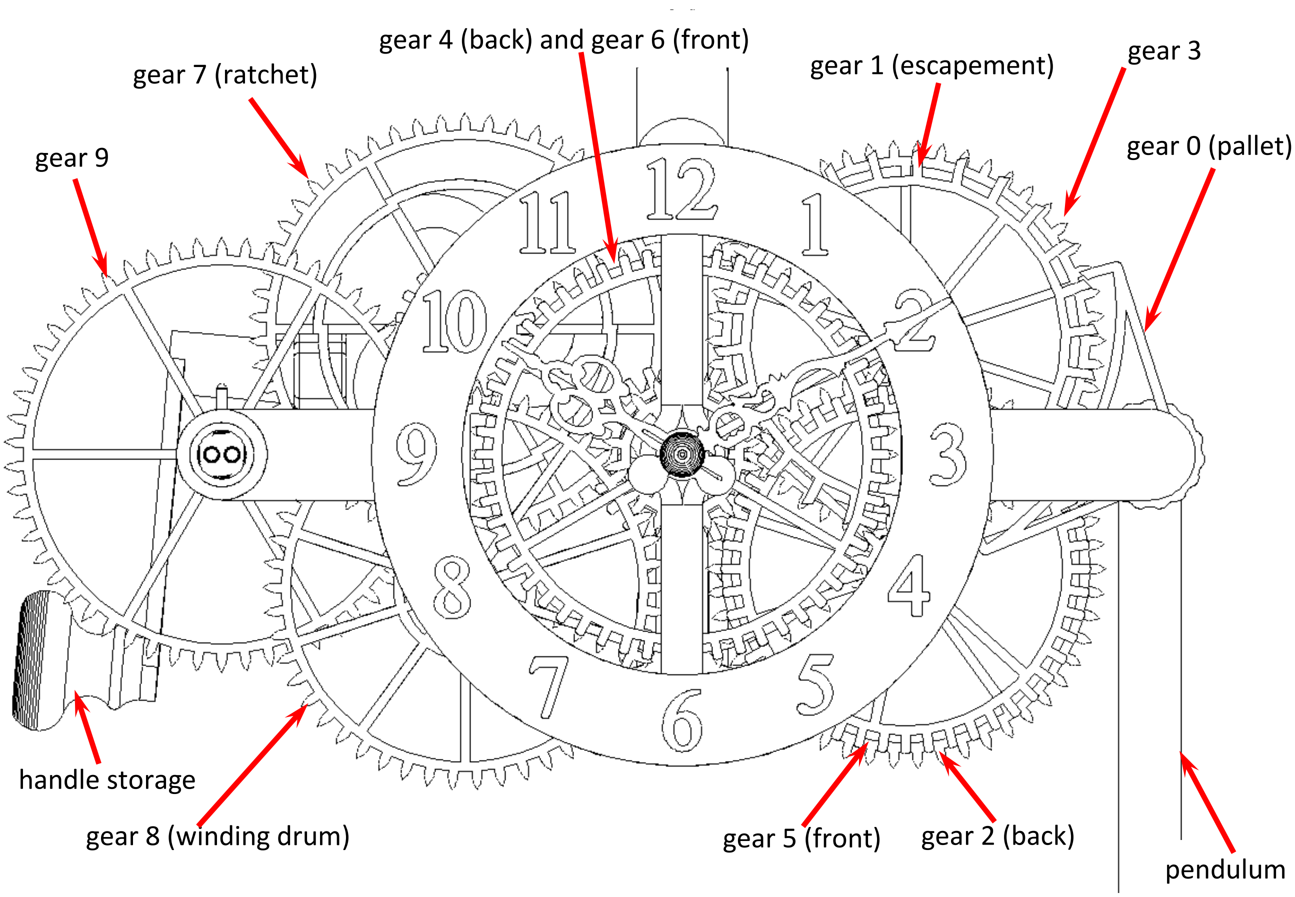
Option	Gear 7:4	Gear 8:7	Gear 8 Size	Gear 8 Time	Runtime
8 Days	48:27	57:18	1.00”	5.63 hours	7.62 days
11 Days	54:21	57:18	1.00”	8.14 hours	11.03 days
17 Days	60:15	57:18	1.00”	12.67 hours	17.15 days
23 Days	63:12	57:18	1.00”	16.63 hours	22.51 days

Gear Diagrams

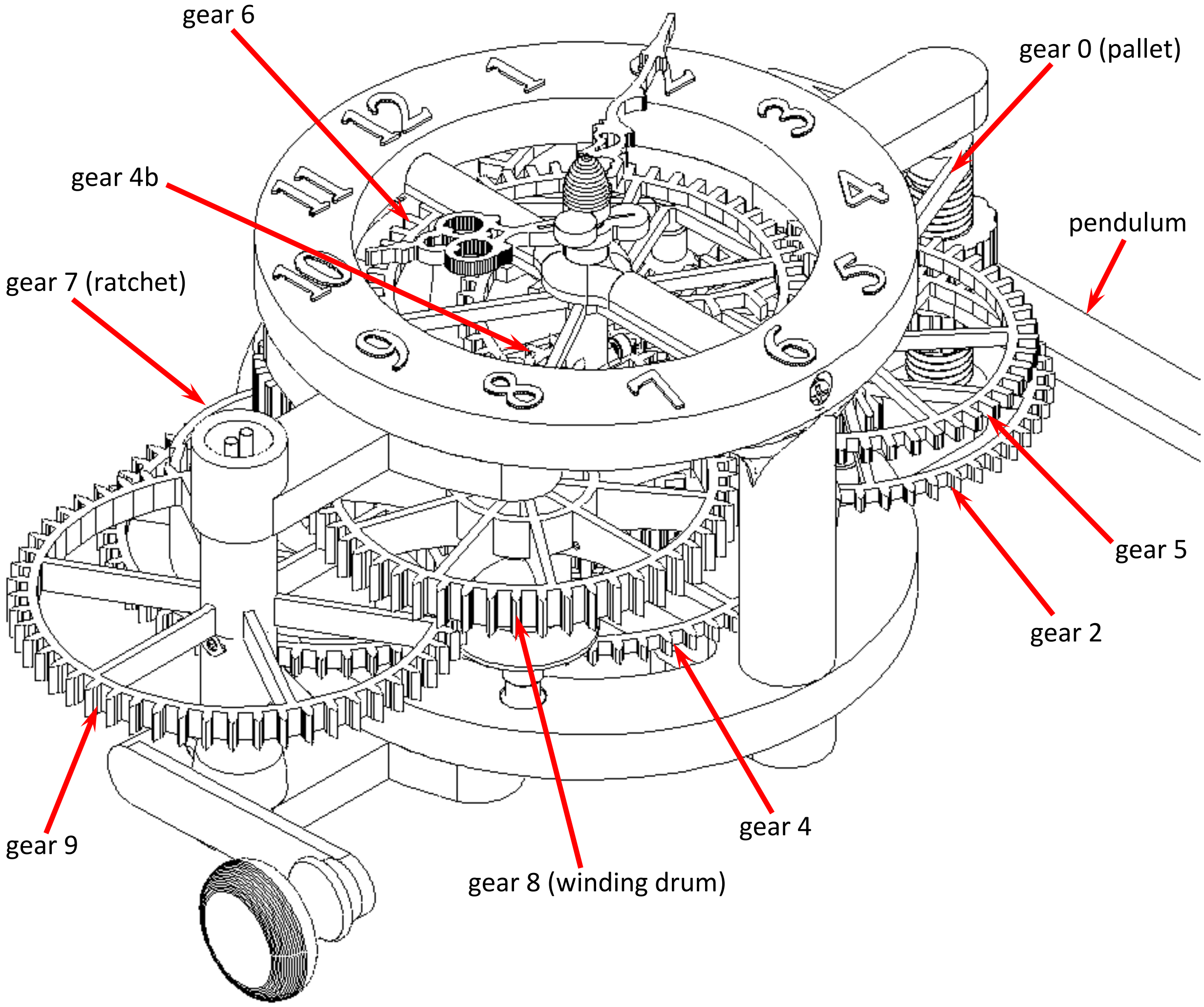
A significant change in the overall design of this clock was a shift to a horizontal orientation. This allows the pendulum to attach directly to the pallet shaft. Friction is reduced by spreading the load equally between the bearings and the connection to the pallet is very solid. Runtime is improved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

The following diagrams show multiple orientations of the clock with the gears labeled as much as possible. The topology is very similar to the original SP4 design, but a few gears have different tooth counts. These diagrams might help to determine gear positions when building the clock.

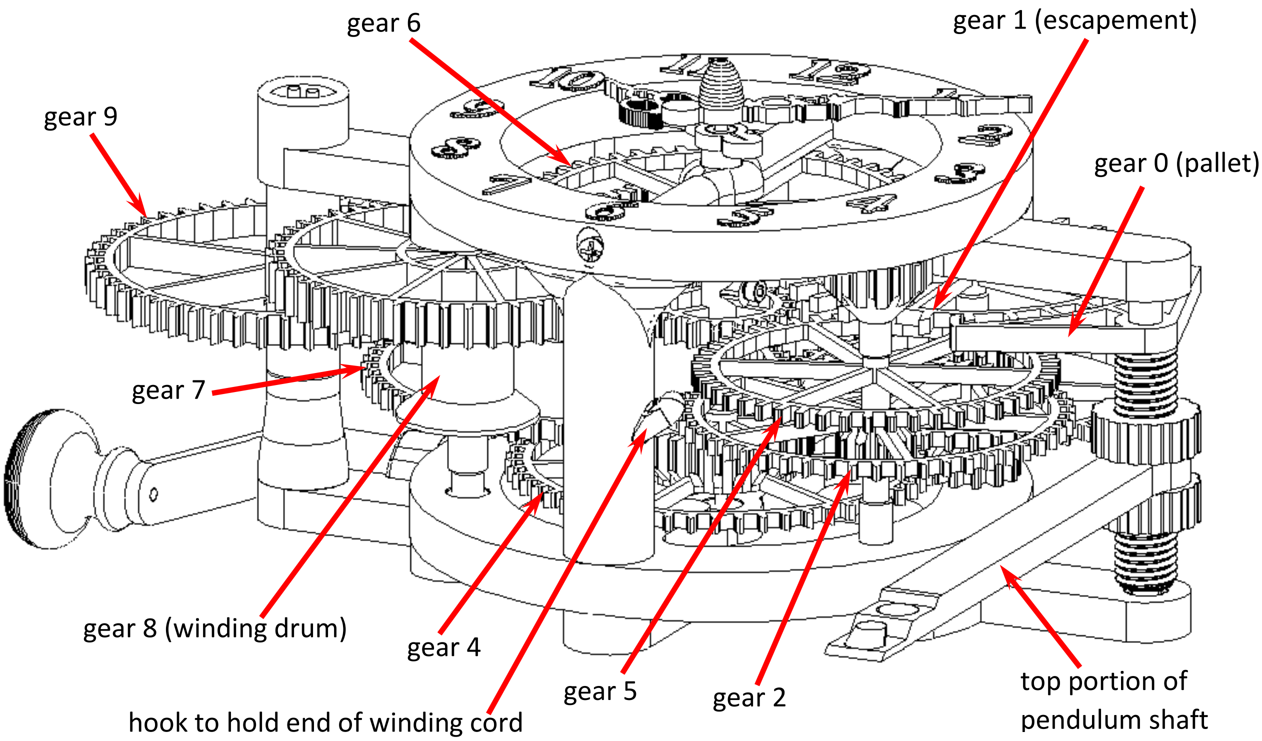
Front View (SP5B is shown, all gears are similar):



Another view from the lower left side:



And the view from the lower right side:



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 original_reference_design if you want to print the original design, although I highly recommend printing the new and improved design.

Both the gears and the frame have been updated for this release. Unfortunately, very few of the parts are interchangeable between versions. If you want the new gear update, you have to print the entire set of gears and a new frame to go with them.

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 (gears use 0.15mm STRUCTURAL)
Layer height	0.2mm for most parts (gears should use 0.15mm layers)
Perimeters	4 for most parts (some slicers call this “Wall Loops”)
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 first layer 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 your 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. PrusaSlicer has a preset for SPEED that is about 20% faster than STRUCTURAL, but I recommend STRUCTURAL for higher accuracy.

I print my clocks on Prusa machines. The largest component is 203.2x203.2mm, so any medium size or larger printer can print these clocks. I use two printers working together to make everything go faster. One printer does the frame while the other printer does 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. The final weight depends on the runtime option selected and friction in your clock.

Below is the lists of parts to print. The colors listed were used to print the clock 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. Strength is important for these parts, so I always use 4 perimeters with 25% infill. 0.2mm layer heights are fine.

Part Name	Color	Print	Notes
frame_back_bottom	tan	1	
frame_back_center	tan	1	
frame_back_left	tan	1	
frame_back_right	tan	1	
frame_back_top	tan	1	
frame_dial_numbers	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_left	tan	1	
frame_front_right	tan	1	

Gears

Select a runtime option for your clock before printing the gears. If this is your first clock, it may be best to start with something conservative like 11 days. The shorter runtimes are easier to keep running reliably. Match the runtime options for gears 4a, 7a, and 8. Print one of everything else.

Print the gears using 4 perimeters, 0.15mm layer heights, and the **CLASSIC slicing algorithm**. I typically use 0.25mm elephant foot compensation. Look at the first layer in the slicer to see what works best. 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_esc20_12	purple	1	
gear2_75_15	purple	1	
gear3_75_15	purple	1	
gear4a_84_27_8day	purple	select 1 to print	8 day runtime option
gear4a_84_21_11day			11 day runtime option
gear4a_84_15_17day			17 day runtime option
gear4a_84_12_23day			23 day runtime option
gear4b_27	purple	1	
gear5_72_18	purple	1	
gear6_81	purple		
gear7a_48_ratchet_8day	purple	select 1 to print	8 day runtime option
gear7a_54_ratchet_11day			11 day runtime option
gear7a_60_ratchet_17day			17 day runtime option
gear7a_63_ratchet_23day			23 day runtime option
gear7b_18	purple	1	
gear7c_clicks	purple	1	
gear8_57_1p0	purple	1	
gear9_60	purple	1	

Miscellaneous Parts

The “misc” directory includes all the remaining parts except the weight shell. Select a hand style and print the minute and hour hands. The spade style hands should have a color change to add some highlights.

Part Name	Color	Print	Notes
dummy_bearing	any	0	Can be used instead of a bearing in a few select locations. See note 1
hand_gothic_hour_?????	copper	1	Select the style you like and print one that fits properly onto the hour hand arbor. See note 2
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, See note 2
hand_spade_minute_?????	white, purple		
pallet_nuts_0p40	tan	1	0.4” thick nuts to secure pendulum on pallet
pendulum_arm_lower	tan	1	
pendulum_arm_mid	tan	1	See note 3
pendulum_arm_upper	tan	1	
pendulum_bob_back	copper	1	
pendulum_bob_front	copper	1	
pendulum_nuts_0p25	tan	1	0.5” thick nuts for adjusting pendulum length
swing_gauge	black, white	1	Optional gauge to measure pendulum swing
winding_key_arm	tan	1	
winding_key_knob	purple	1	

Notes:

1) This design update adds bearings to both ends of the ratchet and behind gear 4. These additional bearings may be considered optional. They can be replaced with a 3D printed dummy_bearing (bushing) to save a tiny bit of cost. Friction will be slightly lower using bearings and the clock should last longer, but the clock should run fine with the bushings. The original SP5 design ran using printed holes in these locations. The parts kit available on my Etsy store will include the additional bearings.

2) There are two hand styles included in the design, with four different degrees of fit on the arbors. Select a style and print the one that fits best. Start with “normal”, and switch to one of the other fits if needed. They print fast enough that you could just print the entire set.

3) This middle pendulum arm segment should be the proper length to allow adjusting the proper rate. This assumes that your pendulum arm and bob have approximately the same density as mine so the effective length is similar to mine. Longer and shorter middle pendulum sections are included in the “backup_pendulum_shafts” subdirectory, although it is unlikely that you will need them.

Weight Shell

The weight shell parts are listed below, 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 specific clock.

There are five different diameters of weight shells included with the design. They go together as a set depending on diameter. If you print the 2.8” (2p8) shell, then it will need to be paired with the 2.8” bottom plate and 2.8” extension if needed. The extensions can be stacked any number of times to increase the total weight. All sizes use the same weight_shell_pulley.

The weight_shell_short files are only needed if your printer has a limited print height. Adding one extension makes it approximately the same size as the normal height weight shell.

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. Additional information about the weight shell is later in this document.

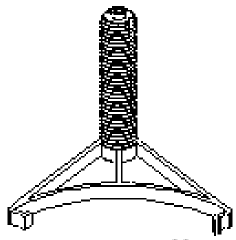
File Name	Color	Print	Notes
weight_shell_bottom_2p4	Copper	0	2.4” diameter weight shell
weight_shell_top_2p4	Copper	0	
weight_shell_short_2p4	Copper	0	
weight_shell_extension_2p4	Copper	0	
weight_shell_bottom_2p6	Copper	0	2.6” diameter weight shell
weight_shell_top_2p6	Copper	0	
weight_shell_short_2p6	Copper	0	
weight_shell_extension_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_extension_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_extension_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_extension_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.

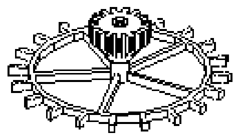
Weight Shell Diameter	Lead Shot Normal Height	Lead Shot with One Extension	Normal Height Filled with BBs	One Extension Filled with BBs
2.4”	5.3lb (2.4kg)	6.4lb (2.9kg)	4.3lb (2.0kg)	5.2lb (2.4kg)
2.6”	6.5lb (3.0kg)	8.0lb (3.6kg)	5.3lb (2.4kg)	6.4lb (2.9kg)
2.8”	7.9lb (3.6kg)	9.7lb (4.4kg)	6.3lb (2.9kg)	**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)

Gear Summary

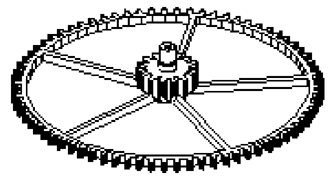
Here is a summary of the gears used in the clock. The names for each gear include the arbor number and gear tooth counts to help identify them. Some gears look similar with different length arbors or other small changes. The runtime options have small labels to help identify them.



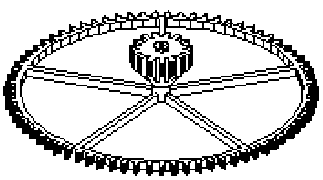
gear0_pallet



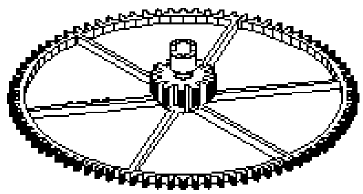
gear1_esc20_12



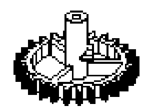
gear2_75_15



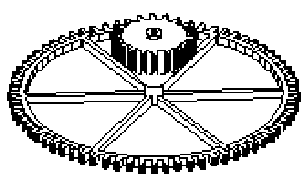
gear3_75_15



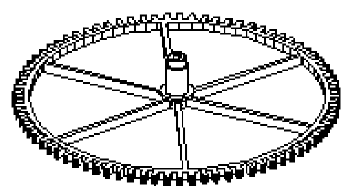
gear4a_84_12_23day



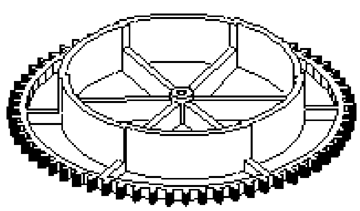
gear4b_27



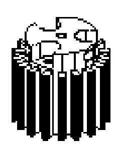
gear5_72_18



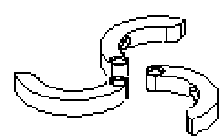
gear6_81



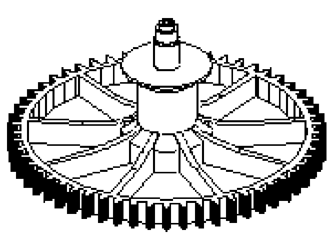
gear7a_63_ratchet_23day



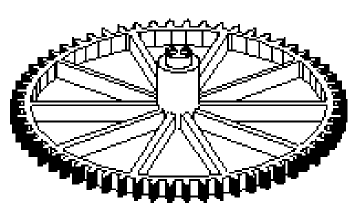
gear7b_18



gear7c_clicks

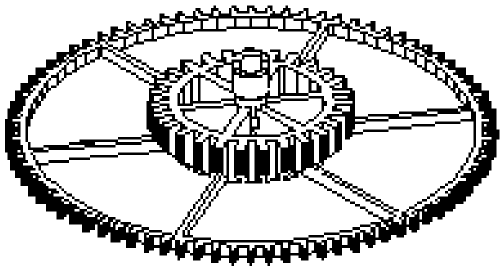


gear8_57_1p0

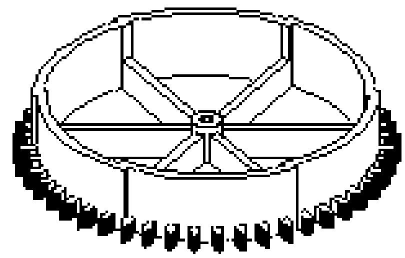


gear9_60

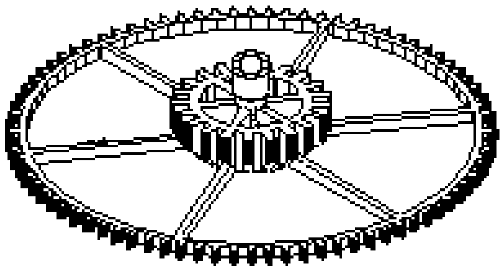
Gear 4a and gear 7a have four different options to support different runtimes. They go together in pairs as shown below.



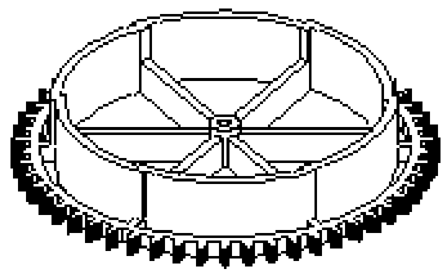
gear4a_84_27_8day



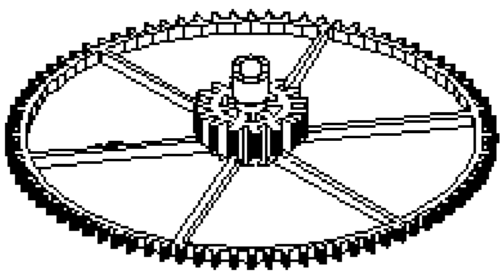
gear7a_48_ratchet_8day



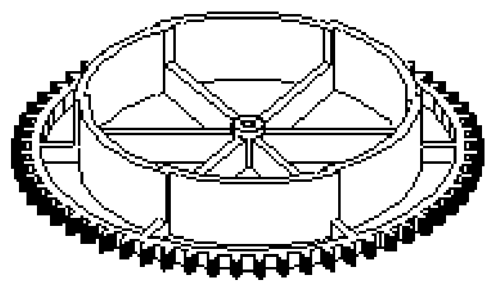
gear4a_84_21_11day



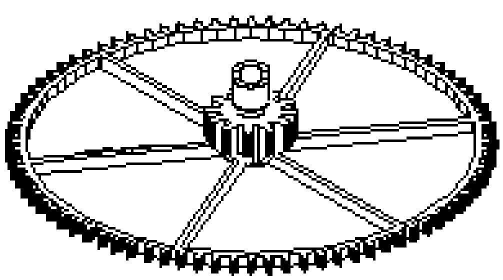
gear7a_54_ratchet_11day



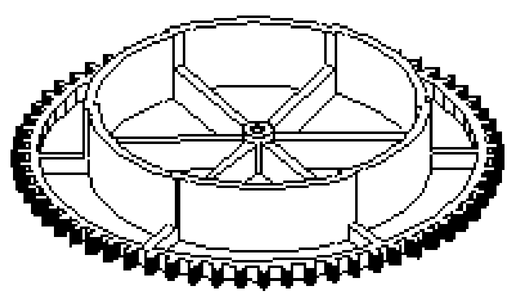
gear4a_84_15_17day



gear7a_60_ratchet_17day

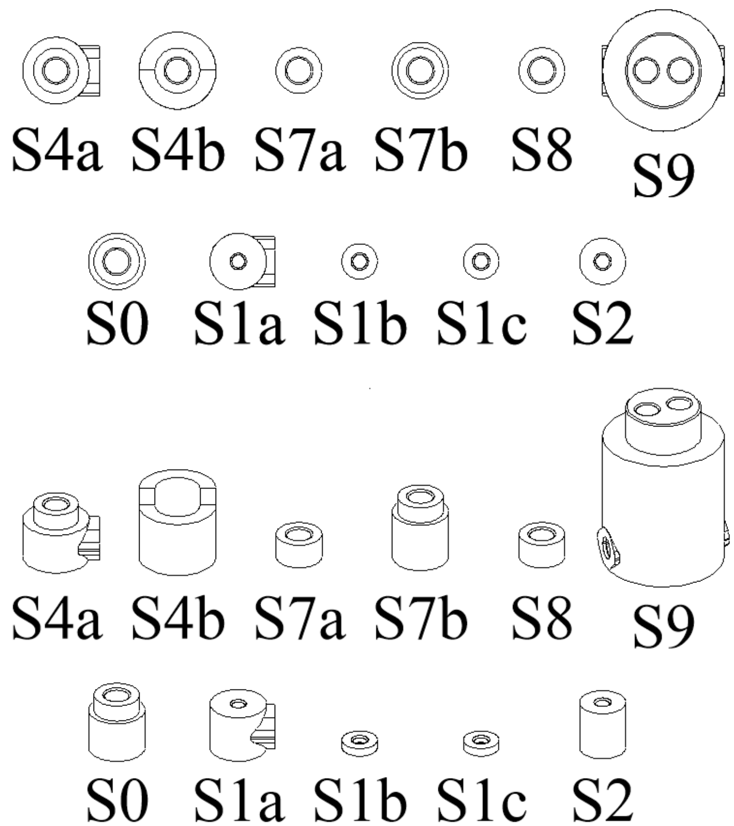


gear4a_84_12_23day



gear7a_63_ratchet_23day

All of the spacers used in the clock are included in a single file. They are shown below with labels according to the gear they are associated with. Two orientations are shown, top view, and isometric projection. Some, like S1b and S1c, or S7a and S8 are identical. Others, like S0 and S7b are slightly different. They may be referred later in this document as spacer 0, spacer 1a, etc.



Decision Summary

There are a few decisions to make based on the files described in the previous section. Many are cosmetic, such as colors, dial type, and hand styles. There are no right or wrong decisions here. Any choice will run just as well as any other. The clock will look different, but it will run the same.

The options that really matter are the runtime selection and the weight shell size. The first choice is for the runtime length. Most builders seem to want to go for the most aggressive option, in this case, the 23 day option. This may be a good choice if you have built other clocks and have experience debugging to get the clocks running. ANY excess friction can make the 23 day clock stop running.

If this is your first clock, I recommend choosing something less aggressive, such as 11 or 17 day modes. It is a much more enjoyable experience to have a working clock right away, and the runtime is still great. The shorter runtime options will be much easier to get running and keep running.

The final choice is the drive weight. The required value is proportional to the runtime option and can be selected later during the final tuning.

Additional Components

This clock 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 different line items.

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 very short run times. Look at other 3D printed clocks on the internet and you will find many with runtimes of only a few hours. A real clock needs to run for at least 24 hours and an "easy to live with" clock needs to run for several days or longer. Ball bearings and metal arbors are required to give this clock runtimes of up to 23 days.

Metal arbors are 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 other sources like Amazon or eBay. Many parts can be substituted with the closest metric or imperial size. For example, the small 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. The 3mm arbors must be 3mm to fit through the center of the bearings.

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
~24	#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
6	M3x8mm socket head screws	91292A112	M3x10mm may also work
22" (56cm)	3mm stainless rod	1272T33	Brass or plain steel rod should be OK. See cut list
6" (15cm)	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. Many other brands of braided line should work.
5-8	623RS bearing (3x10x4mm)		Used to support the pendulum and several places with heavy loads. Some may be optional. See notes
4	click pen springs		Used for ratchet and friction clutch
8-10 lb. (4-5kg)	lead shot or steel BBs		BBs are safer than lead shot and only need a slightly larger weight shell
~44	pennies, washers, or BBs		Used to fill the pendulum bob

Notes:

The clock uses small 623RS ball bearings anywhere a load needs to be supported. The five bearings on the pendulum, gear 8 winding drum, and weight shell pulley are required to support the heavy loads. Three additional bearings around the gear 7 ratchet and behind gear 4 are recommended, but optional. Printed dummy_bearings (bushings) can be used instead of real bearings to save a few dollars. The bearings are often sold in sets of 10, so one set will be enough for all the bearing locations. The optional bearing loads are smaller than the gear 8 winding drum and the clock will still work with the bushings. Also, the bushings are replaceable if they do wear out.

Low friction bearings used to support the pendulum are critical to reduce friction on this fast moving part. I find that cheap 623RS bearings available for around US$8 for 10 work the best. More expensive bearings may have tighter tolerances with higher friction in the mode we are using them. I have never heard of anyone debugging their clock that was able to fix their issue by using expensive ceramic bearings. The solution is usually something else, so stick with the cheaper bearings.

Bearings with rubber seals can easily be removed using a sharp pin. Soak the bearings in 90+% alcohol to remove most of the thick factory grease. A blast of compressed air can be used to remove the rest of the grease, or spin the alcohol soaked bearings by hand a few times to loosen the embedded grease. Then let the bearings soak in clean alcohol again. A coat of Teflon dry lube can be added to help lubricate and prevent rust. I use Teflon lube designed for bicycle chains. The bearings should spin freely after cleaning. Select the ones that appear to spin the best for the pendulum. Any of the remaining bearings can be used for the slow moving weight shell areas of the clock.

These are the non-printed components used in the clock, plus the 3mm and 1.5mm rod shown later:


~25X #6x3/4” (M3x20mm or M3.5x20mm) wood screws


1-2X #8x1-1/2” (M4x40mm) pan head screws or nails


4X pen springs


5-8X 623RS (3x10x4mm) bearings


~44X pennies or small coins

12' (3.5m) 65lb microfilament fishing line


8-10lbs (4-5kg) lead shot, steel shot, or copper plated BBs

The weight shell needs to be filled with a dense material. Typical fill material includes lead shot, steel shot, or copper plated steel BBs. Many other dense materials such as pennies, washers, rusty nails, or scrap steel might also be acceptable. Sand, plastic airsoft BBs, or rice are NOT dense enough to make reasonable size weight shells.

This is my new favorite weight shell fill material. It is less toxic than lead shot and only about 20% less dense. A 50lb bag is only around US$70 on Amazon. There is enough material for several clocks.

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

If you only plan on building one clock, then BBs may be a cheaper alternative. A large bottle of 6000 weighs around 4.5lb. You may need two bottles. Make sure to get copper plated steel BBs and not plastic airsoft BBs.

Roll over image to zoom in

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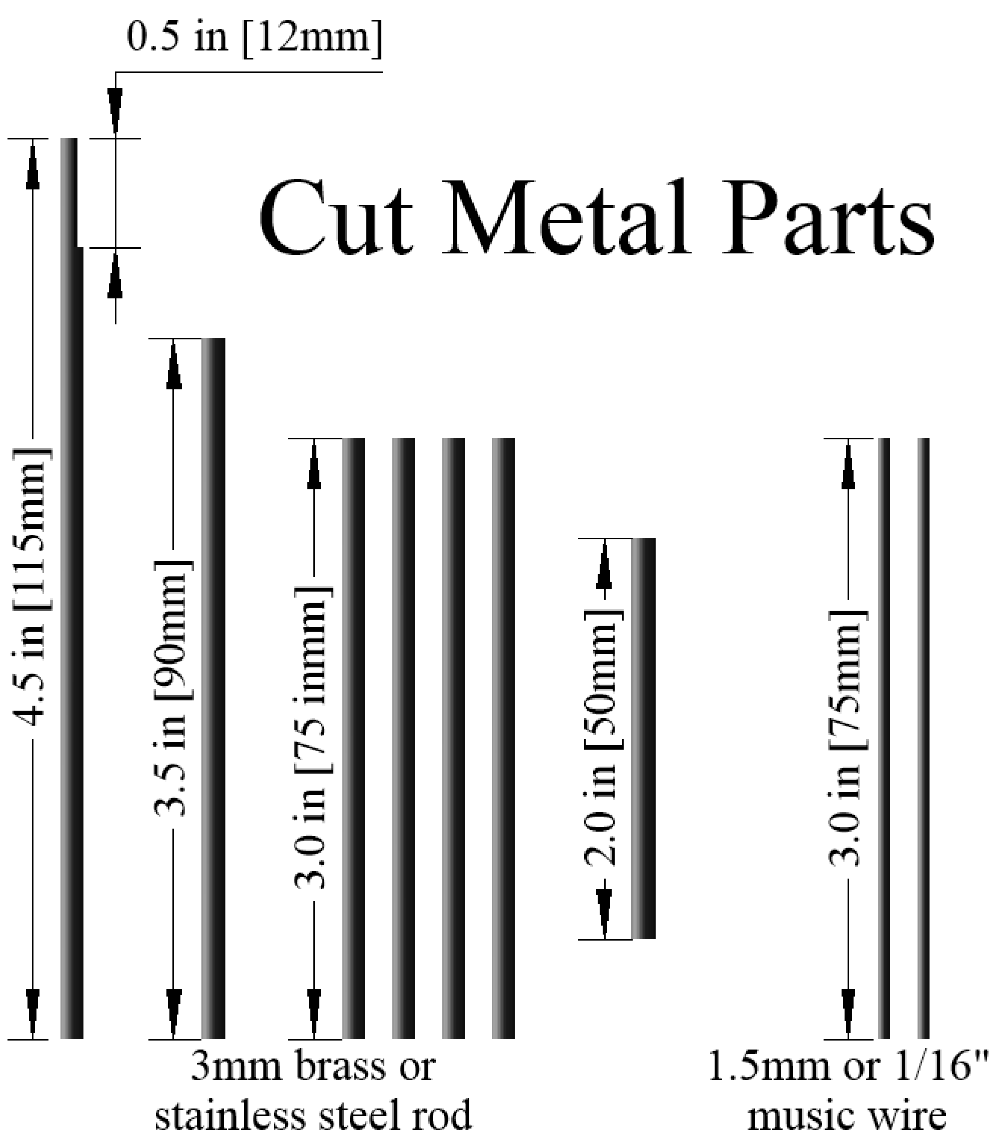
Metal Cut List

This clock uses metal arbors to reduce friction. This is the best reliable way to get long runtimes. Most of the arbors in the clock use 3mm rods. The strength requirements are fairly small, so nearly any type of metal should be acceptable. I use stainless steel rod. Brass rod should also work just as well. Aluminum might work as long as it is not too soft. The diameter must be 3mm to fit into the bearings, although you may be able to use 1/8" arbors if you reduce the ends to fit.

Two arbors on the right side use 1.5mm or 1/16" music wire. Either size is acceptable. These are the fastest moving gears in the clock so small diameters were chosen to reduce friction. Music wire needs to be cut with a hardened cutter. An abrasive Dremel cut-off disk also works.

The following diagram can be used to cut the metal parts. Debur and slightly chamfer the ends. The longest arbor needs a flat notch filed to fit into the minute hand.



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 guide 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:

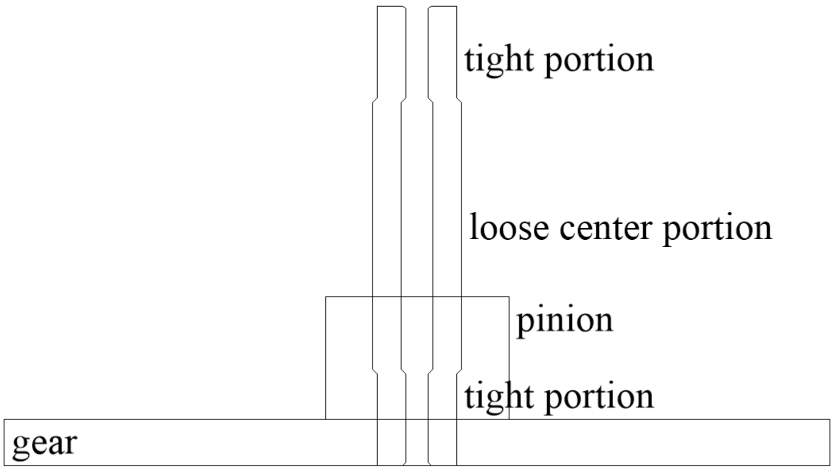
- Sandpaper or small hand files

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 into the frame.

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.

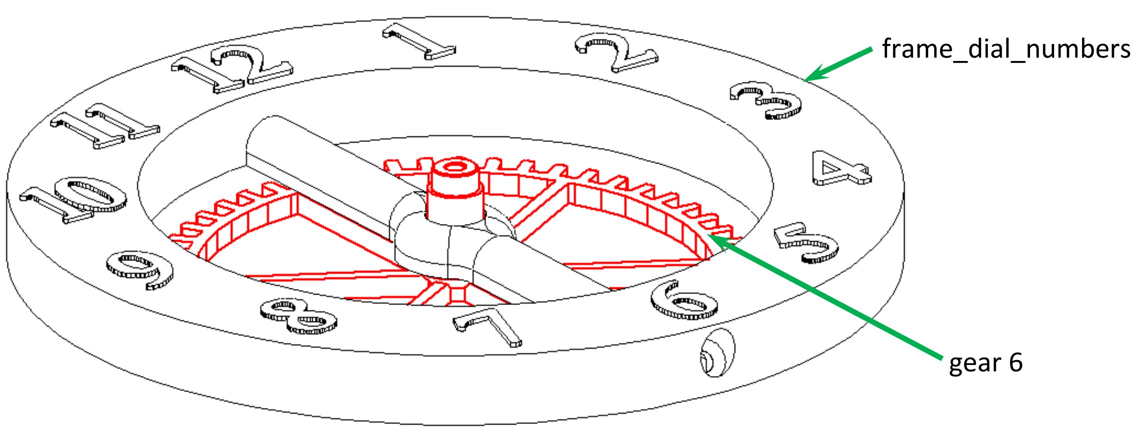


Drill both ends and blow through the hole to clean out the swarf. Test each gear by spinning it on an arbor. Gears with properly sized holes should spin for 10-20 seconds. If it slows quickly, then drill it again. It will be obvious when the hole is the perfect fit and friction is low.

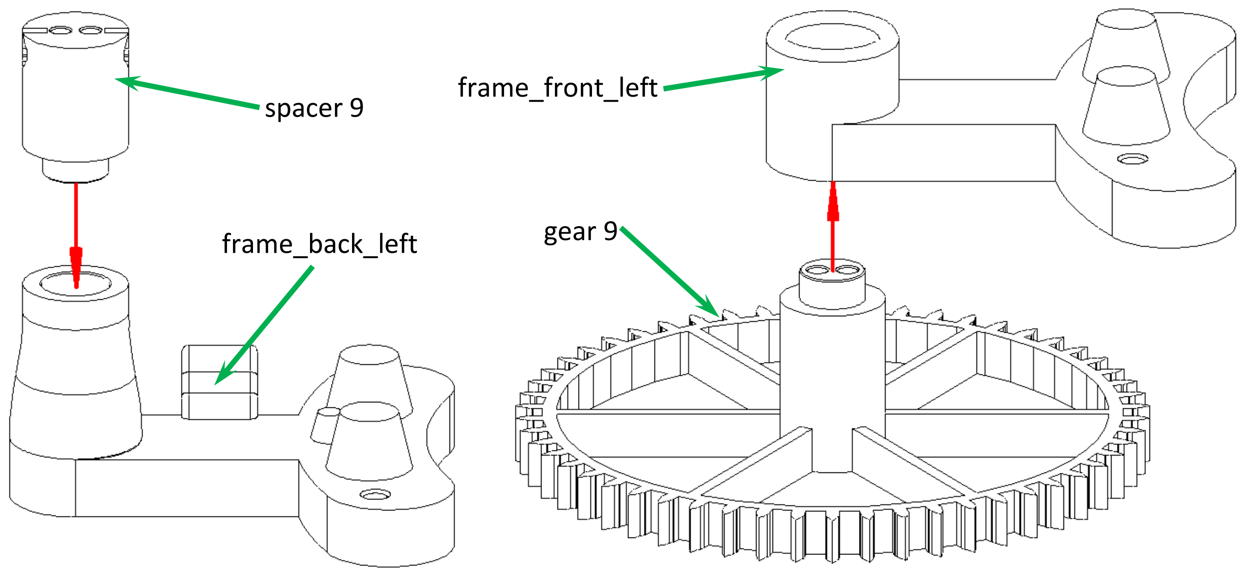
There are a few 3D printed parts that need to move inside other printed parts when the clock is running. They need to be checked for the proper fit and adjusted if needed. Use hand files or sandpaper to adjust the sizes of either component until the parts rotate smoothly. These parts involve PLA rubbing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

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.



Make sure spacer 9 fits into frame_back_left and gear 9 fits into frame_front_left. All parts should spin easily.



Notes on Friction

It is worth stating how important it is to reduce friction in a mechanical clock. These clocks can run for up to 23 days using a few ounces of weight per day to provide power. The pendulum ticks over 3 million times in 23 days. The pendulum needs to tick nearly 60,000 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. **The most important component pre-check is to ensure that every gear spins freely on its arbor and every arbor spins freely in the frame.** Another 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 usually runs 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.

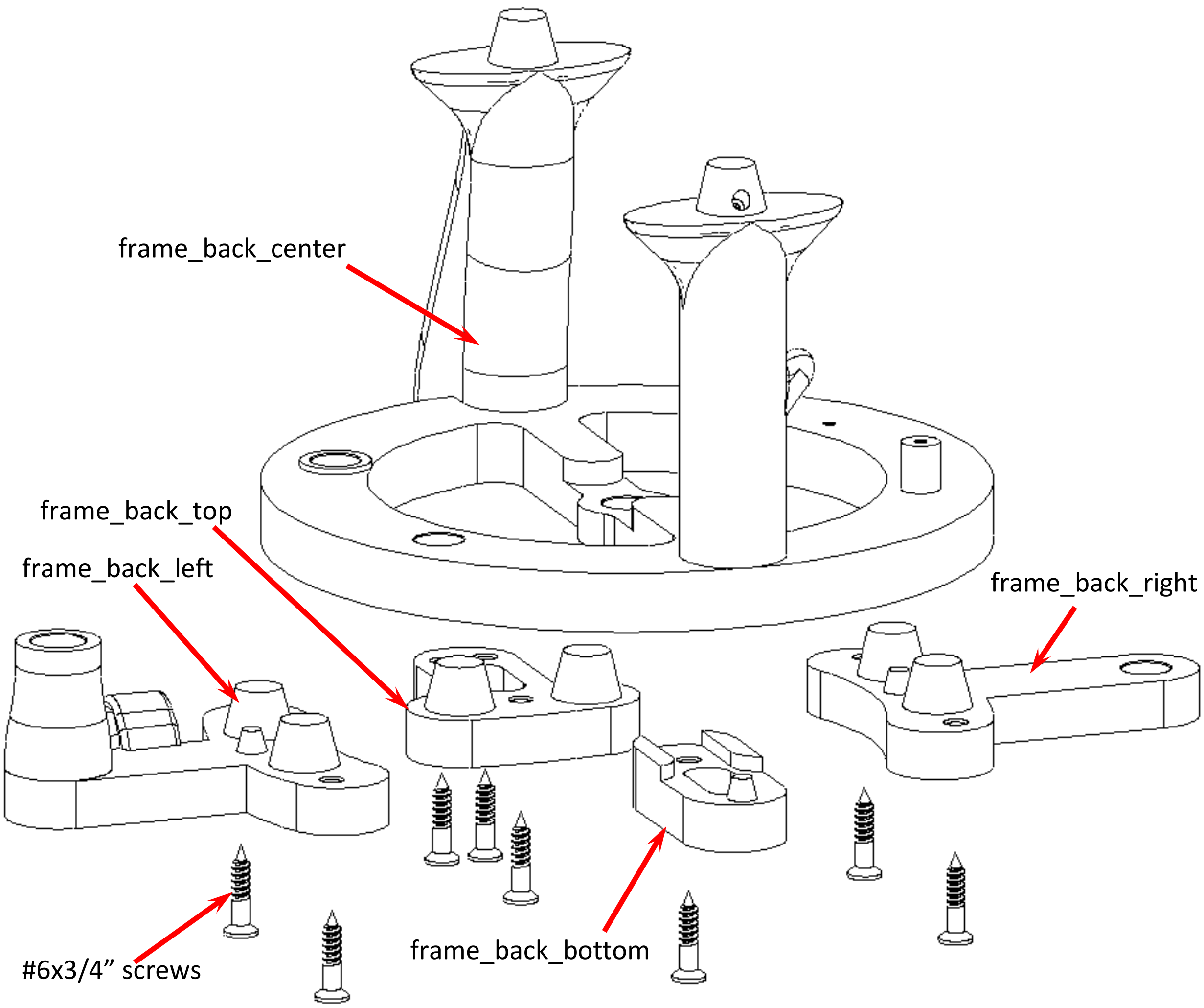
The small 623 bearings used to support the pendulum work best with the thick factory grease removed to minimize friction. Remove the rubber seals using a needle and wash the grease using solvent (paint thinner, mineral spirits, acetone, 90%+ alcohol, etc.). 91% isopropyl alcohol used for cleaning the 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

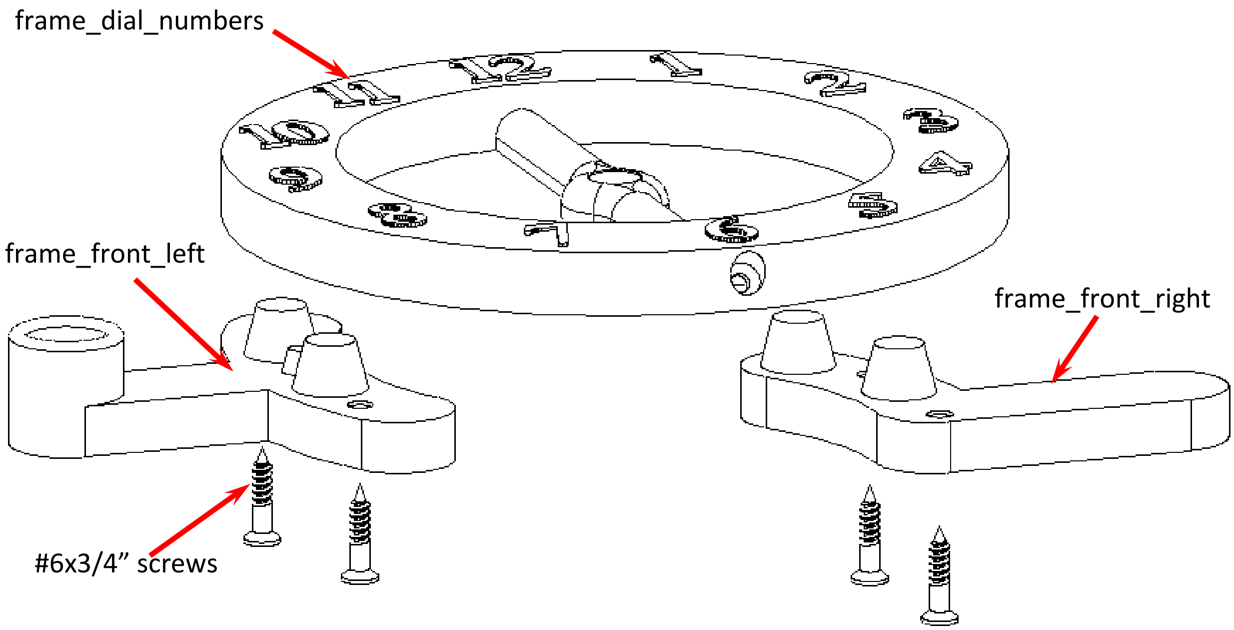
The frame is designed to fit together easily using tapered alignment pegs and screws to hold parts together. The alignment pegs do most of the work. Assemble the components shown below using #6x3/4” (M3.5x20mm or M3x20mm) flat headed wood or sheet metal screws.

The upper three screws holding frame_back_top in place do most of the work to keep the clock on the wall. The remaining screws are just holding parts in position.

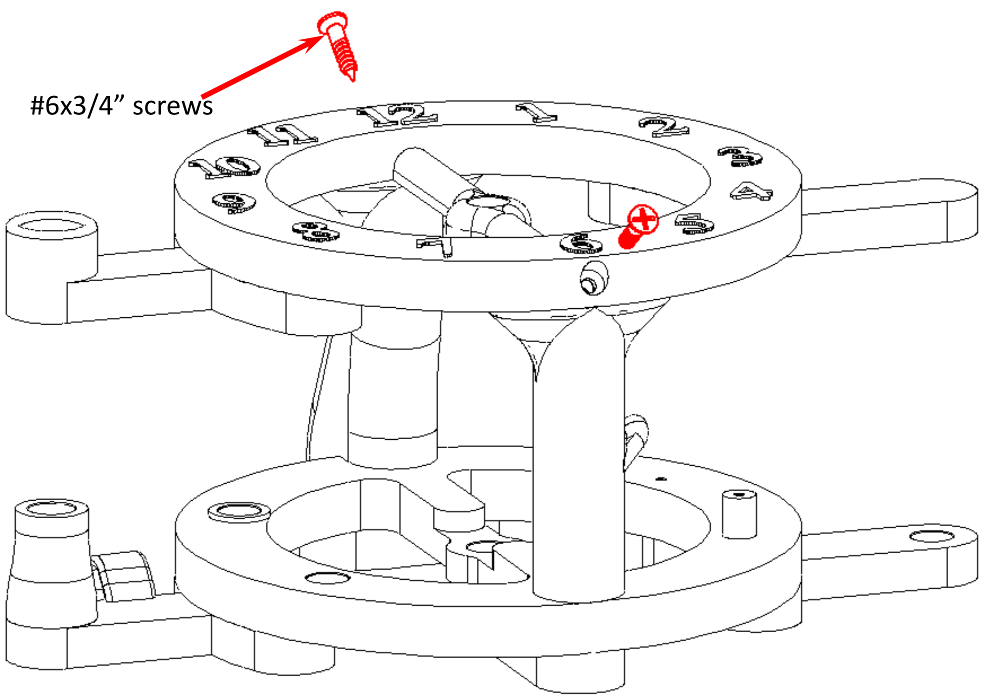
The clock is held to the wall using a pan head screw or nail set into a wall stud. The top hanger supports most of the weight. There is an additional hanger in frame_back_bottom for a second screw if you need help keeping the clock level when winding. I usually never use it, but it is there if you need it.



The front frame is even simpler, just three components and a few screws. There are two dial styles to select, classic Roman numerals, or simple numbers.



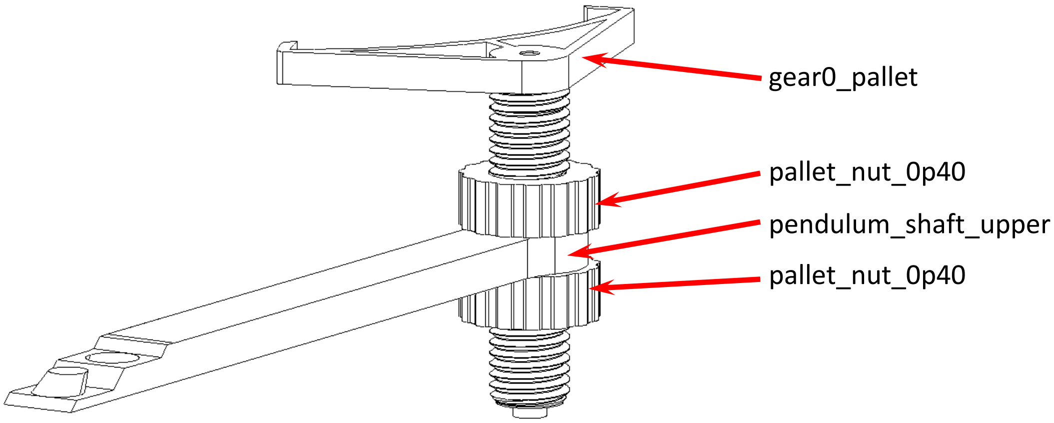
The two frame assemblies join together using two #6x3/4" wood screws (highlighted red). The screws are angled to spread out the forces on the tapered pegs to help prevent splitting. These screws do not need to be very tight, just enough to keep the dial from falling off. Check that the frame halves go together. The front frame will need to be removed to add the gears.



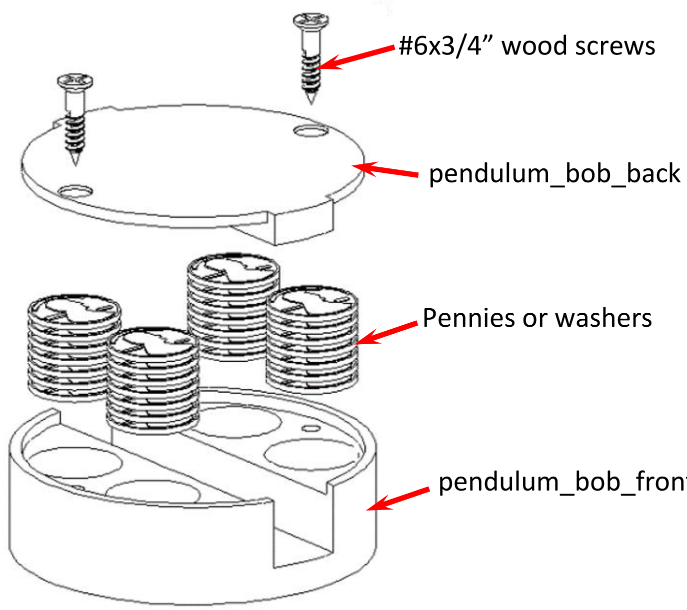
Component Pre-Assembly

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

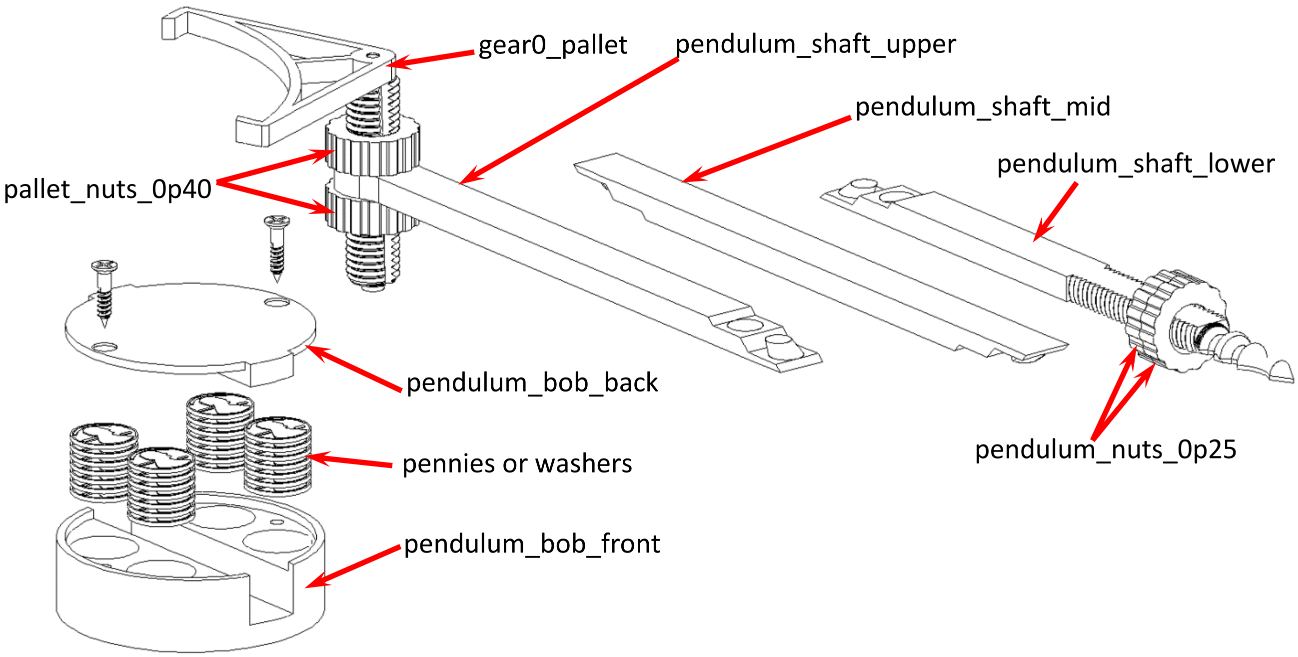
The top portion of the pendulum should be added to the pallet with two 0.4” thick pallet nuts. A spiral groove is used to adjust the pendulum and pallet angle relative to the clock frame. Start with the pendulum shaft near the center of the adjustment range.



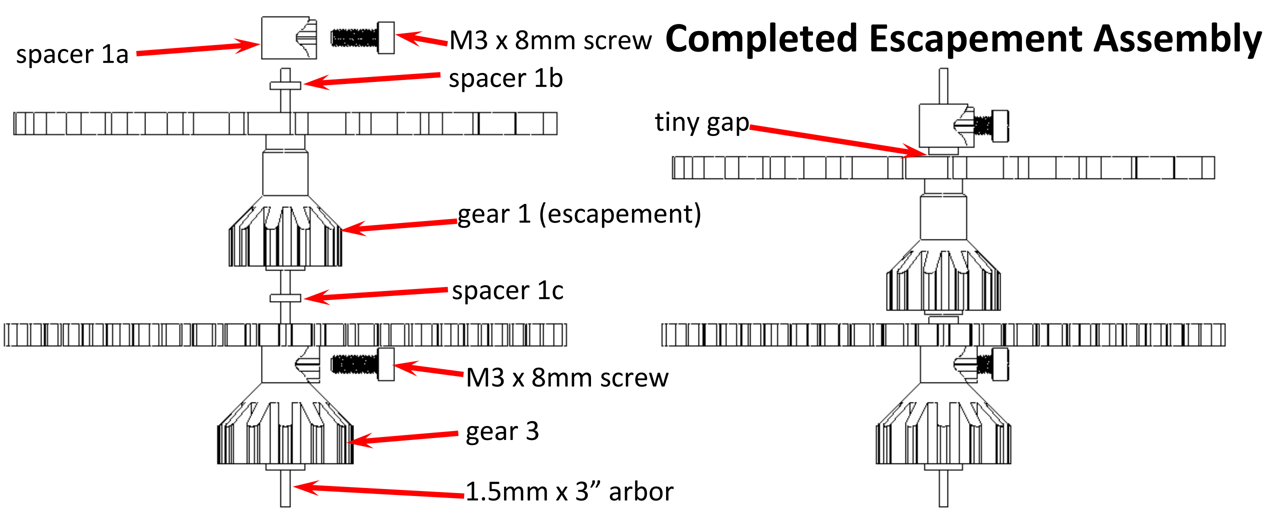
The pendulum bob is a two-piece shell filled with pennies or washers for weights. The actual weight is not a significant factor in regulating the time. A heavy bob and a light weight bob will both swing at approximately the same rate. It only needs enough momentum to continue swinging during minor disturbances and not be so heavy that it creates excess friction at the pivot point. The bob could be filled with pennies, washers, or anything dense. 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 completed pendulum assembly contains the components shown below. The pendulum shaft components drop in place and stay secure without glue. This allows easy pendulum removal when moving the clock. Two printed nuts are used to adjust the length of the pendulum to set the rate. Start with the nuts positioned just below the center of the available threads.



The escapement assembly adds set screws to both ends of the arbor to reduce any side thrust on the escapement. Add the components shown below to one of the 1.5mm x 3" (75mm) arbors. M3 x 8mm set screws hold the end components in place. Adjust so the components are centered on the arbor and there is a very small amount of end shake in the escapement. Check that the escapement spins freely on the arbor.

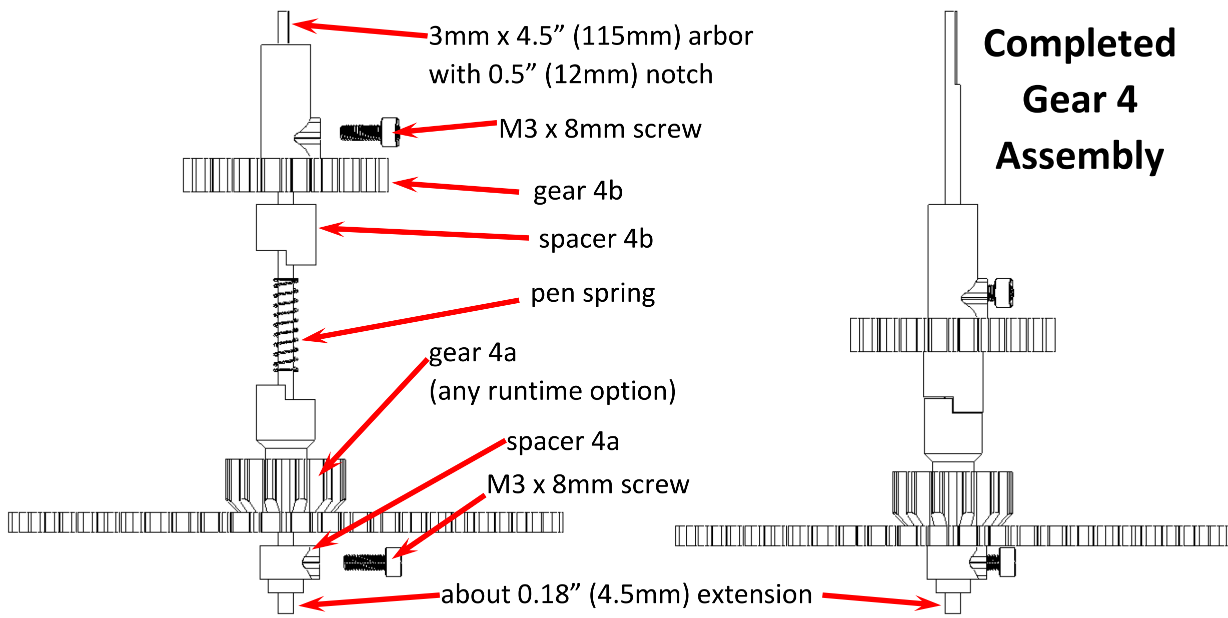


The gear 4 assembly contains the friction clutch used to allow changing the time while the clock is running. Start with spacer 4a near the bottom of the 3mmx4.5” arbor. Secure it with a M3x8mm screw. The arbor should extend out the bottom enough to pass through a 323 bearing (about 0.18” or 4.5mm). Add gear 4a with the desired runtime option. Place a pen spring and spacer 4b onto the arbor. Add gear 4b and secure it with a M3x8mm screw. The screws only need to be tight enough to keep the spring from pushing the components apart.

The friction clutch is one of the components that gets a reasonable number of questions. I tried to simplify it as much as possible in this design. The components can only go together one way if you follow the diagram. When it is completed, the pen spring will be compressed and gear 4a should be able to rotate with a slight resistance.

The spring pushes gear 4a against spacer 4a, allowing all components to rotate together during normal operation of the clock. The weight shell turns gear 4a which in turn provides power to the escapement. The friction clutch pressure causes the arbor to also rotate, which moves the minute hand. This is the primary mode of the friction clutch.

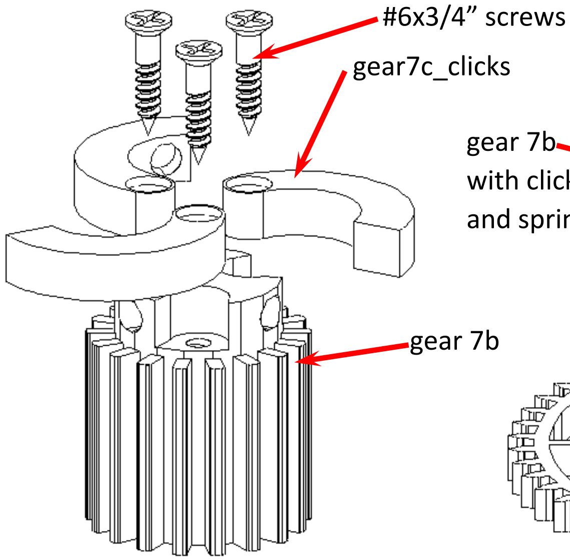
The secondary mode of the friction clutch is to allow slippage when changing the time. Manually turning the minute hand causes the arbor to rotate relative to gear 4a. Gear 4b rotates with the arbor to change the hour hand along with the minute hand. Gear 4a continues providing power to the escapement.

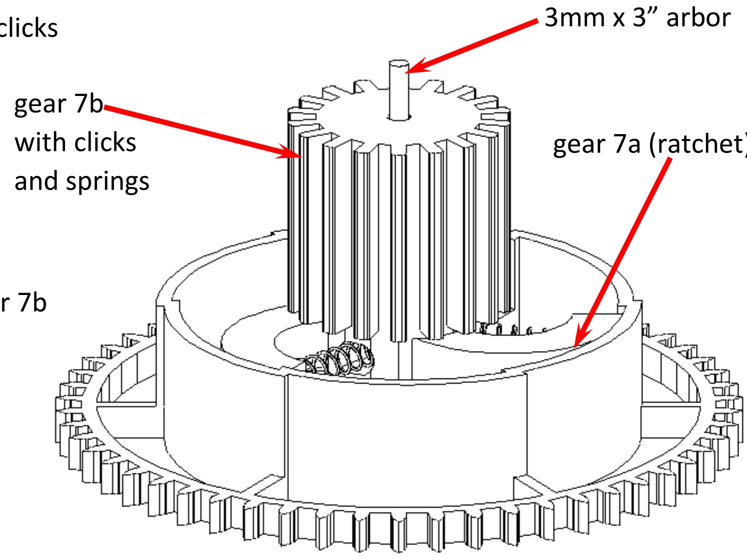


There are two common errors that can occur with the friction clutch. The spring can be too weak or it can be too tight to fit the arbor. Most common click pen springs should work. Springs with a natural length of around 1” (25mm) are perfect. If your spring is significantly shorter than 1”, then stretch it to have a relaxed length of around 1”. If one end is tight on the arbor, then there are two options. Cut the tight end off the spring and stretch the length to around 1”. Or place the tight end of the spring closest to spacer 4b, so gear 4a will see the full pressure of the spring.

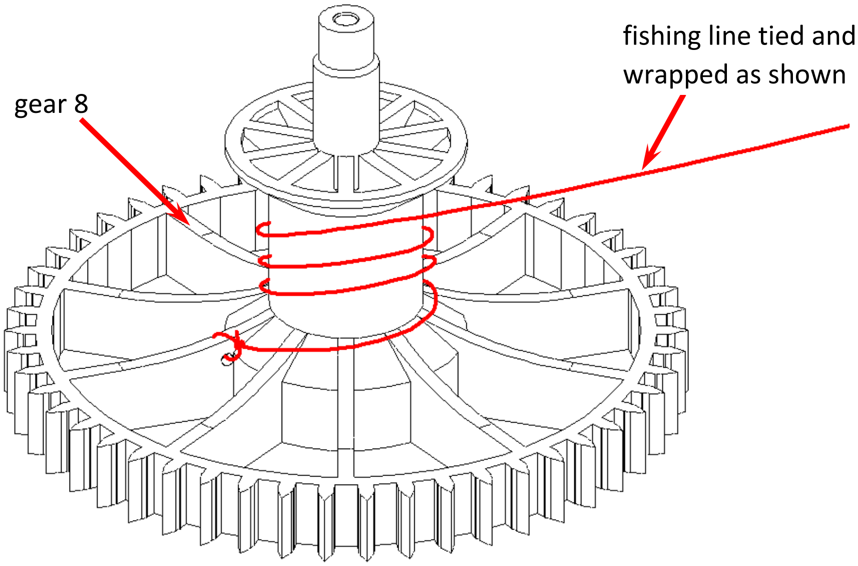
The ratchet assembly starts by adding the three clicks onto gear 7b using #6x3/4" wood screws. The clicks need to spin freely on the screws. Enlarge the holes in the clicks if needed so they move freely.

Add the clicks to gear 7b 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 and place it on the 3mm x 3" arbor and 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.

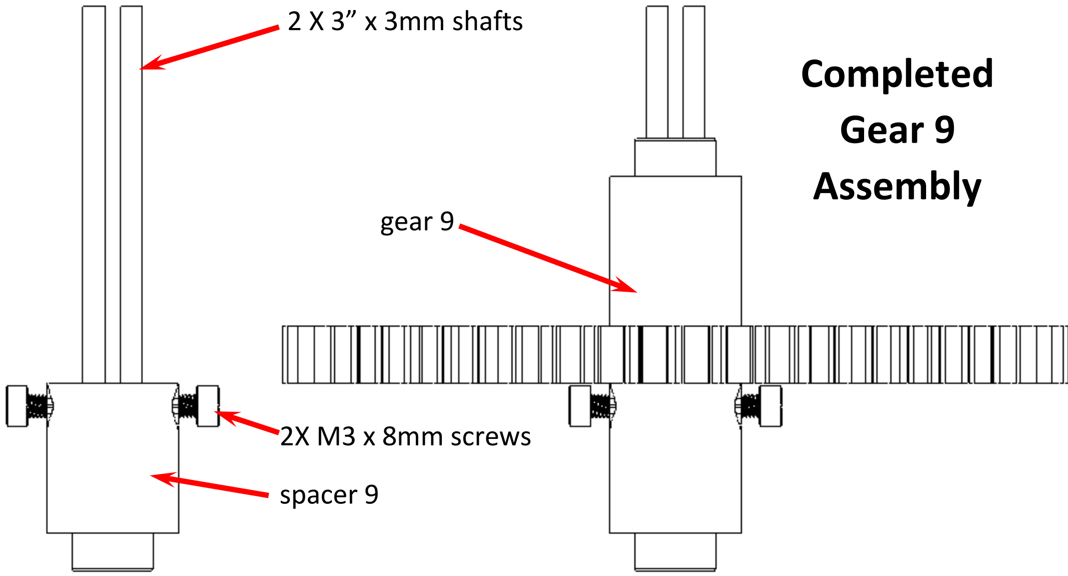




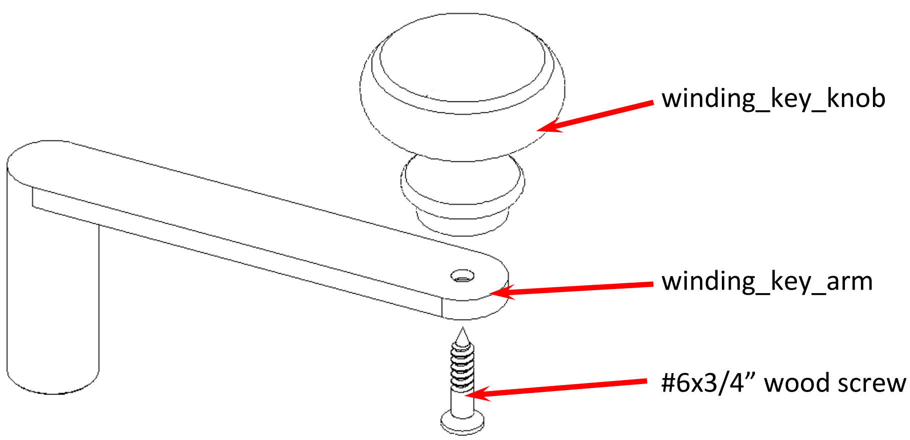
Tie one end of the monofilament fishing line around the hole in gear 8. Wrap the line around the drum in the direction shown. Tie a loop on the far end of the line to hang on the back frame hook.



Add two M3 x 3" (75mm) arbors into spacer 9 and secure them using two M3x8mm screws. The arbors should extend all the way to the bottom of spacer 9. Gear 9 should fit over the arbors to look like the diagram on the right.



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.



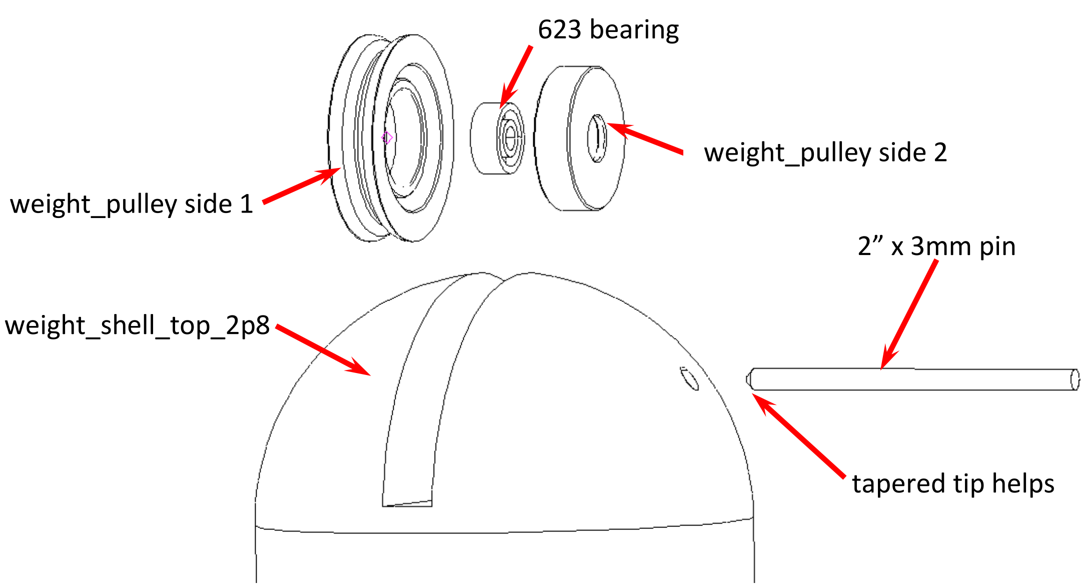
Weight Shell

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 size of weight shell required depends on the runtime option selected and fill material used. Longer runtime options will need more weight. My clock runs in 23 day mode with a shallow pendulum amplitude using a 9 pound weight and a strong pendulum amplitude with an 11 pound weight.

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

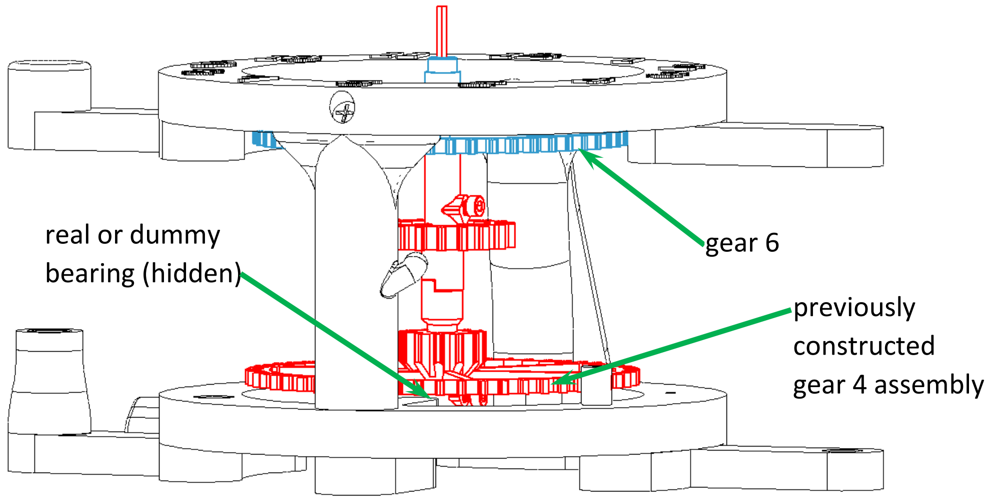


Turn over the weight shell and fill it with BBs (or lead shot). Take appropriate safety precautions if using lead. Assembly should be obvious when you see the parts. Each weight shell extension uses four #6x3/4" wood screws. Multiple extensions can be used if needed. Fill the weight shell and add the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

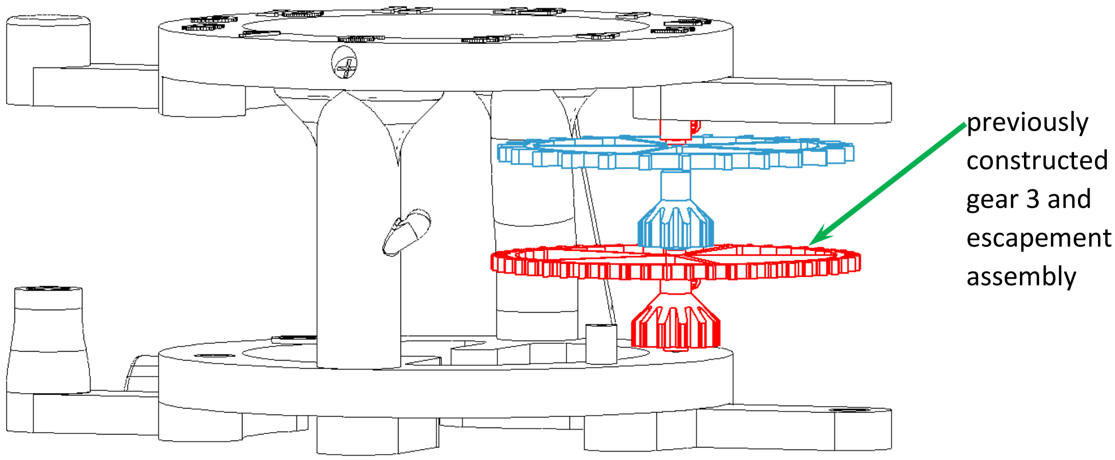
Pre-Assembly Checks

It is a good idea to test a few things before assembling the entire clock. 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 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 gear 6 into the frame including the front frame. 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 gear 4a and spacer 4b to make the stack thinner. Test that gear 6 spins independently from the gear 4 assembly.



The other critical gear stack to check is the escapement arbor. Add the previously constructed gear 3 and escapement assembly into the frame. Secure the front frame with both screws. The escapement should spin freely on the arbor. Gear 3 also needs to spin freely in the frame. Gear 3 has a set screw attaching it to the arbor, so the arbor spins with gear 3. Make sure the arbor holes in the frame were drilled out. Remove some thickness from one of the spacers if the stack is pinched by the frame.



Pendulum Free-Swing Test

One very important pre-assembly check is the pendulum free-swing test. This clock uses small ball bearings to support the pendulum. I consider this to be the most reliable pendulum support that is easy for a non-horologist to build. 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 with no signs of wear. The pendulum amplitude is still as strong as it was 5 years ago.

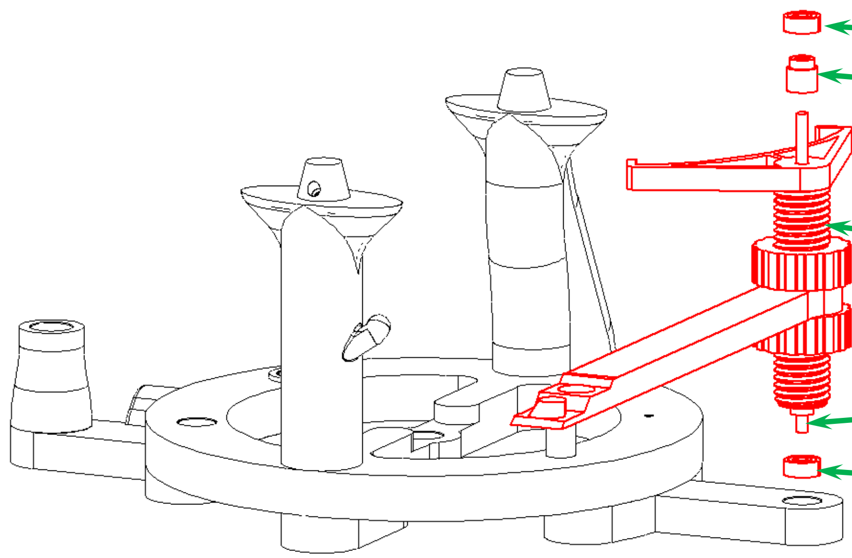
The traditional pendulum support method would be a pendulum support spring. These are only available at clock maker supply stores. They are also very delicate. Properly cleaned ball bearings are nearly as good and significantly more robust. None of the other methods I have tested come close to the performance of small ball bearings. A simple knife edge would be easy to build, but the friction of a 3D printed version was so high that it would only work with a 1-2 day runtime. I will continue to design clocks using ball bearing pendulum supports unless I find something better.

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. This assumes that the rubber seals have been removed and the thick factory grease has been cleaned out. I usually purchase the cheapest bearings from Amazon, eBay, or AliExpress. They all work great as pendulum support bearings. Very few 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 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 loosen the grease. A blast of compressed air is a fast but messy way to remove the remaining grease. An alternative is to slowly spin the alcohol soaked bearing to bring the grease to the surface where it can be cleaned with a toothpick. Soak the bearings again in clean alcohol to remove the rest. 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. Complete the assembly by adding the front frame with two retaining screws.

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.



It is OK for the frame to tilt from an unbalanced weight distribution during this test. Move the pendulum to one side and release it. There is a swing_gauge that can be used to measure the amplitude up to 5 degrees in each direction.

Start with a swing of +/-5 degrees and measure the amount of time it takes for the amplitude to degrade to a negligible amount. It should be at least 5 minutes and preferably 10-20 minutes before the amplitude degrades. If the time is less than 5 minutes, then the bearings have too much friction for the pendulum support. Clean the bearings again or swap them for different bearings. The bearings typically come in sets of 10 and there may be some slight variations among them. Select the best of the batch for the pendulum support and use the remaining bearings closer to the slow moving weight shell.

Pre-Check Summary

Don’t start assembling the clock until all of the previously listed pre-checks have been completed. They are repeated here to stress how important these steps are.

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
4) Gear 6 fits through the front dial and spins easily
5) Gear 9 and spacer 9 spin easily in the frame
6) Gear 7b spins on gear 7a and the ratchet is working, grease may be needed on the clicks
7) The gear 4 assembly and gear 6 has some end shake inside the frame
8) The gear 3 and escapement assembly has some end shake inside the frame
9) Pendulum bearing free swing test runs for at least 5 minutes, preferably 10-20 minutes

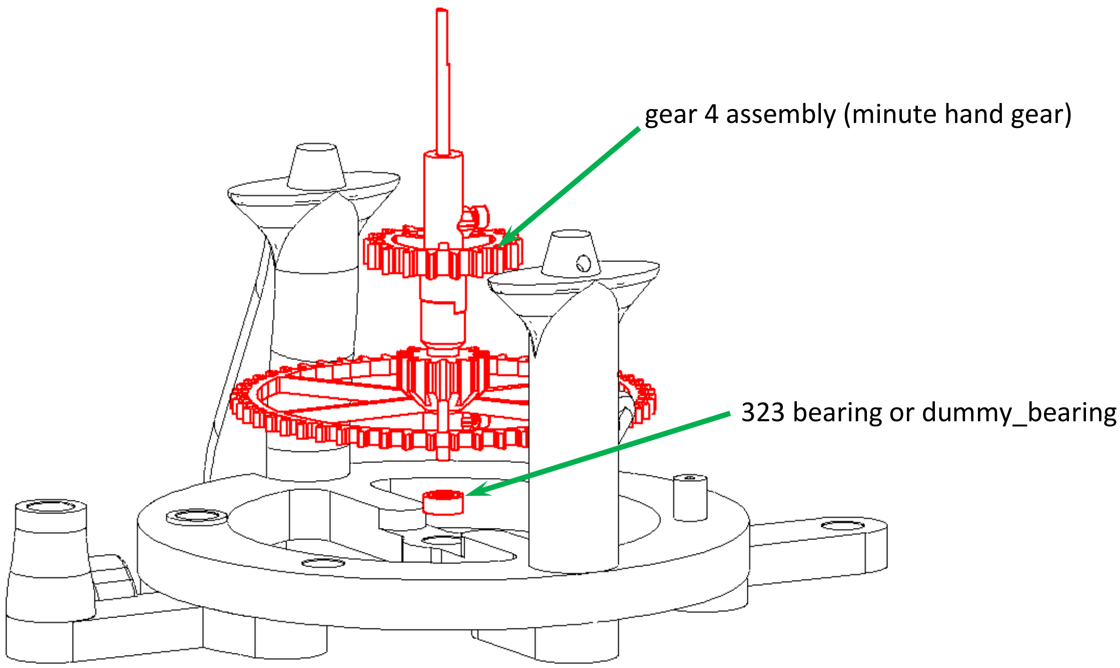
If all of these pre-checks are good, then it should be OK to start the final clock assembly. The most common issues that might cause the clock to be non-functional are the bearing free-swing test, excess friction on arbors, or lack of end shake.

Final Assembly

The rest of the clock can now be assembled. Assembly videos for the original SP5 release can be found at https://youtu.be/gM1UZuv43u4 and https://youtu.be/SawrNzYoE2A The SP4B assembly is similar enough that you should be able to follow along for most steps.

The following pages show the step by step assembly instructions. The diagrams show the components added at the current step highlighted in red. Assembly starts with the back frame sitting flat on a table. The gears are added from the bottom working up towards the top.

The first component can either be a real 323 bearing or a printed dummy_bearing. This is a fairly small friction point, so either a real or dummy bearing can be used. I did all my prototype testing using a real bearing, although the original design runs just fine with a printed hole in the frame. Add the previously constructed gear 4 assembly into the bearing.

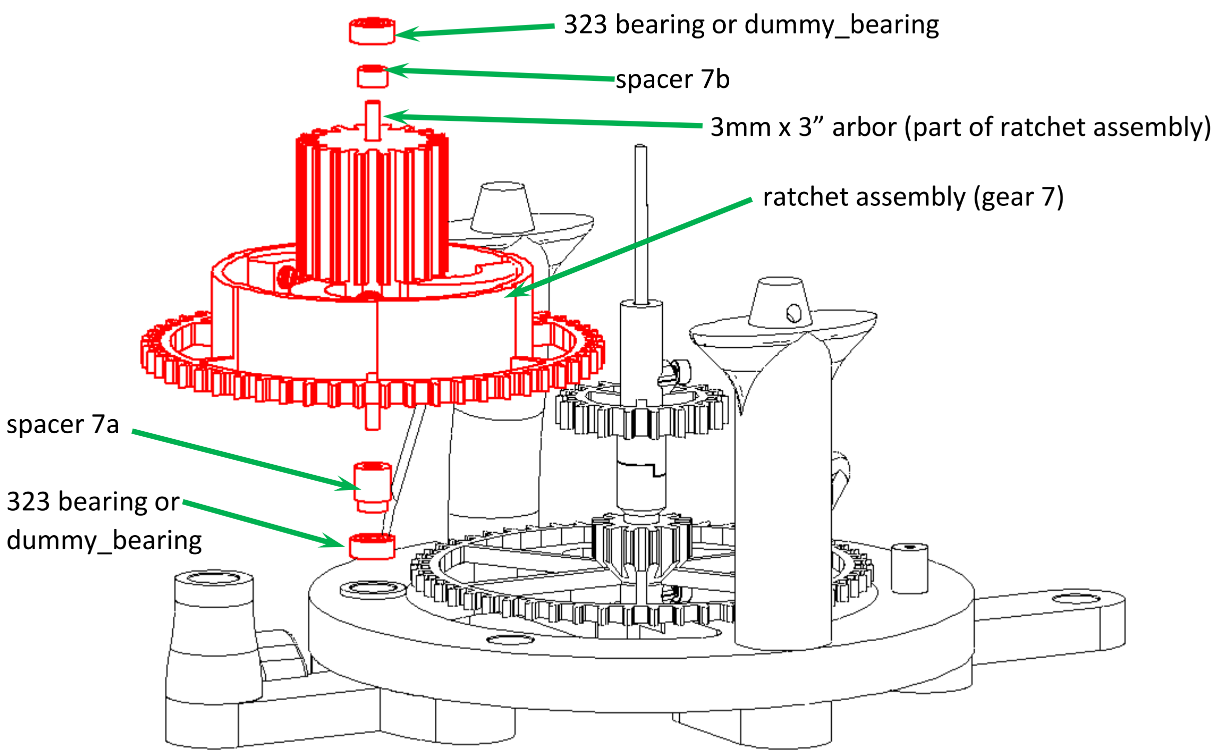


Power Train

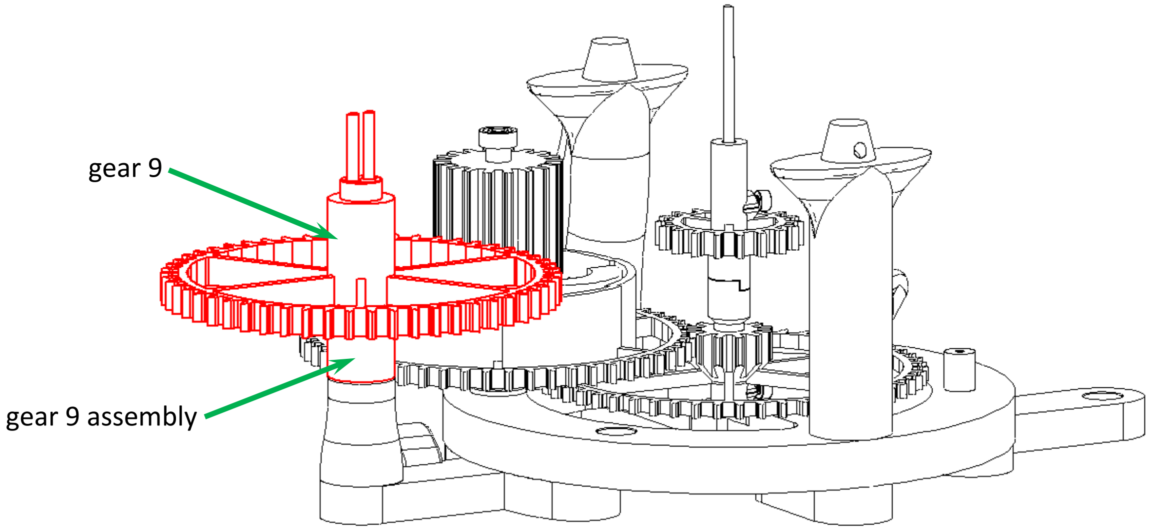
The left and right sides of the clock do not interfere with each other so either side can be assembled first. Let's start with the power train on the left side of the clock. Add a real or dummy bearing into the upper left frame hole. The friction load here is larger than the gear 4 assembly, so real bearings are recommended, but the original design runs fine with printed holes. The choice is yours.

Add spacer 7a onto the ratchet assembly with the narrow end facing the bearing. Place the ratchet assembly into the bearing. Gear 7 should mesh properly with the gear 4 pinion. If they do not mesh, double check that the proper runtime options are being used. For example, if gear 4a has the 23 day option, gear 7 must also have the 23 day option.

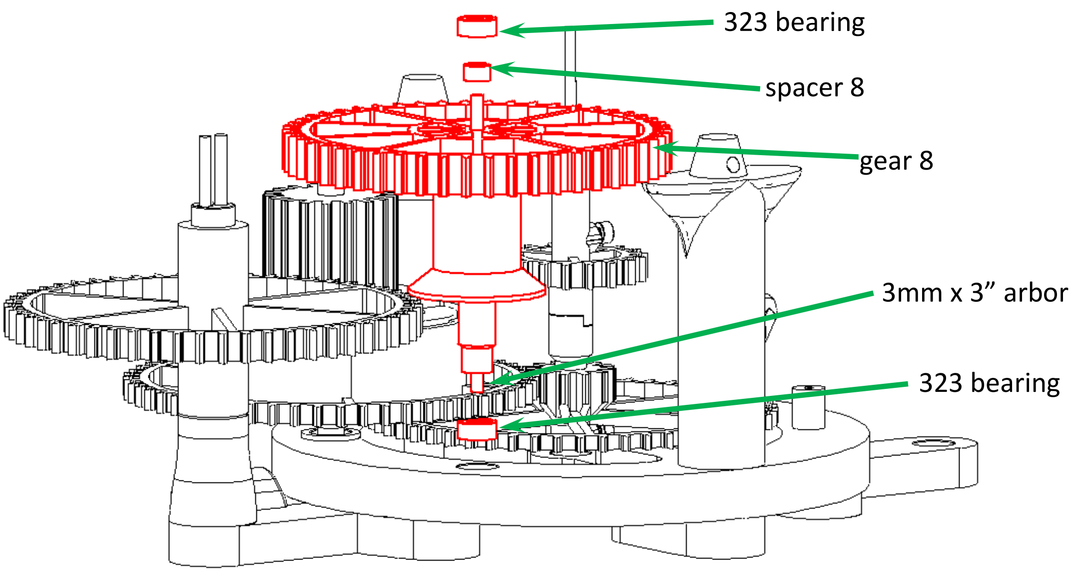
Add spacer 7b and another real or dummy bearing onto the arbor.



Add the gear 9 assembly into the left hole. Add gear 9 if it is not already part of the assembly.



Gear 8 is the final component on the left side. This gear supports the entire weight shell so real bearings are required. Add a 323 bearing into the lower left hole. Add an 3mm x 3” (75mm) arbor and gear 8 with the string attached. Add spacer 8 and another 323 bearing onto the arbor. Gear 8 should also mesh with the tall pinion on the ratchet.

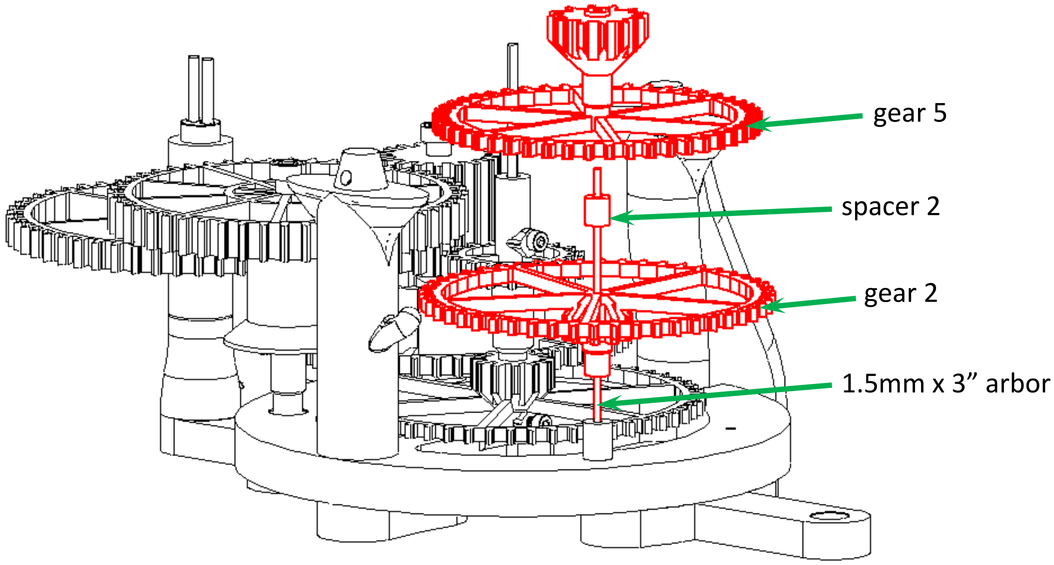


Motion Works

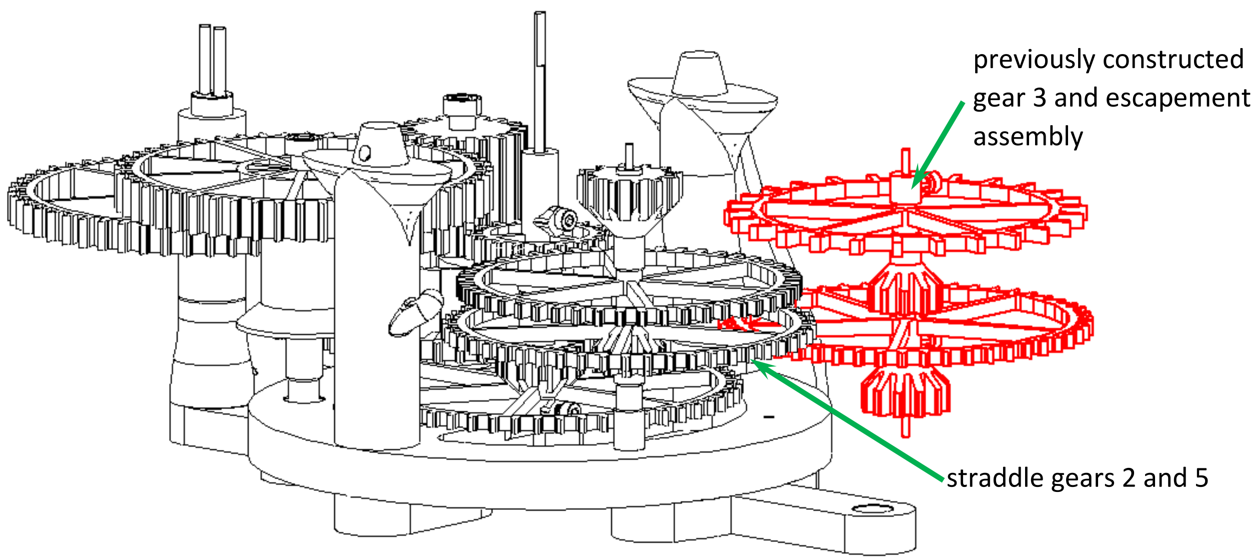
We can now add in the gears between the minute hand and the escapement, also known as the motion works. The following diagrams are shown from the perspective of the lower right corner.

Adding gears on the right side is tricky since the escapement is already assembled into a module so the gears cannot be added from the bottom up. One assembly method that works is shown.

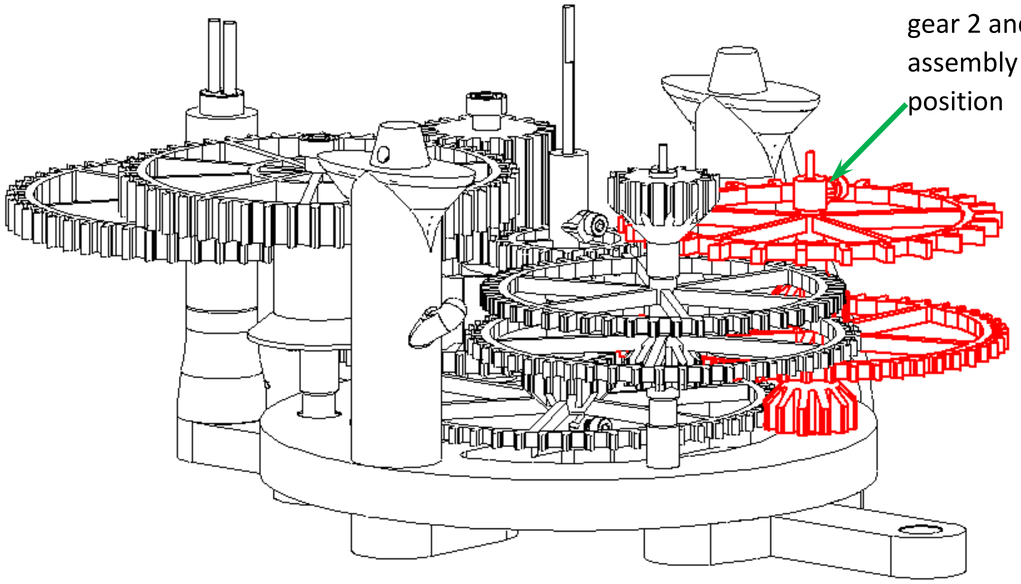
Place a 1.5mm x 3" (75mm) arbor into the lower right hole. Add gear 2, spacer 2, and gear 5 in the orientations shown.



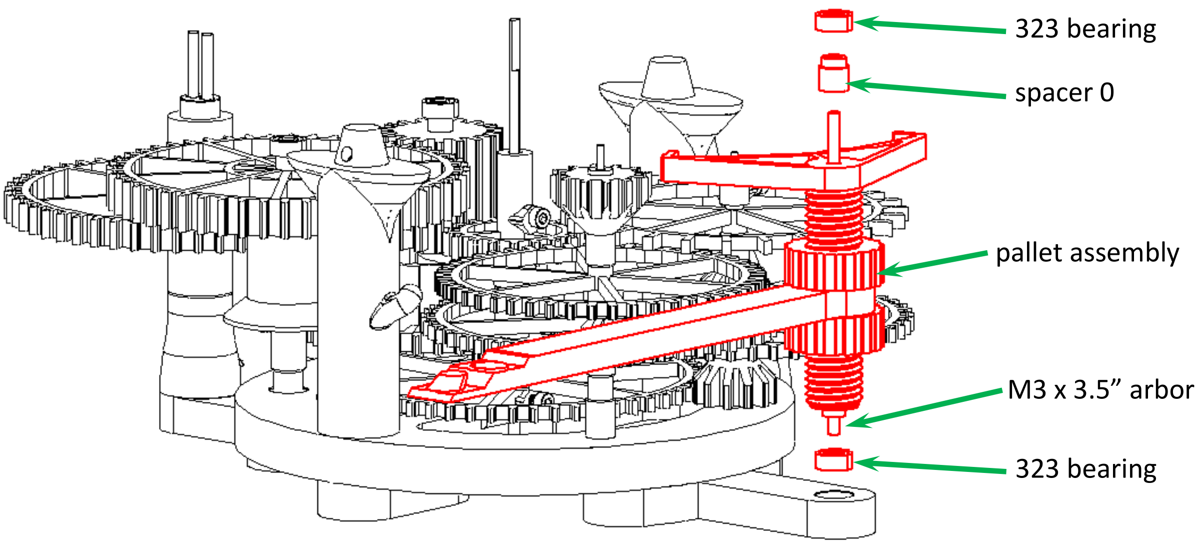
The escapement assembly has already been constructed as a module. It needs to be slid in from the side so gear 3 and the escapement surround the two gears that were just placed.



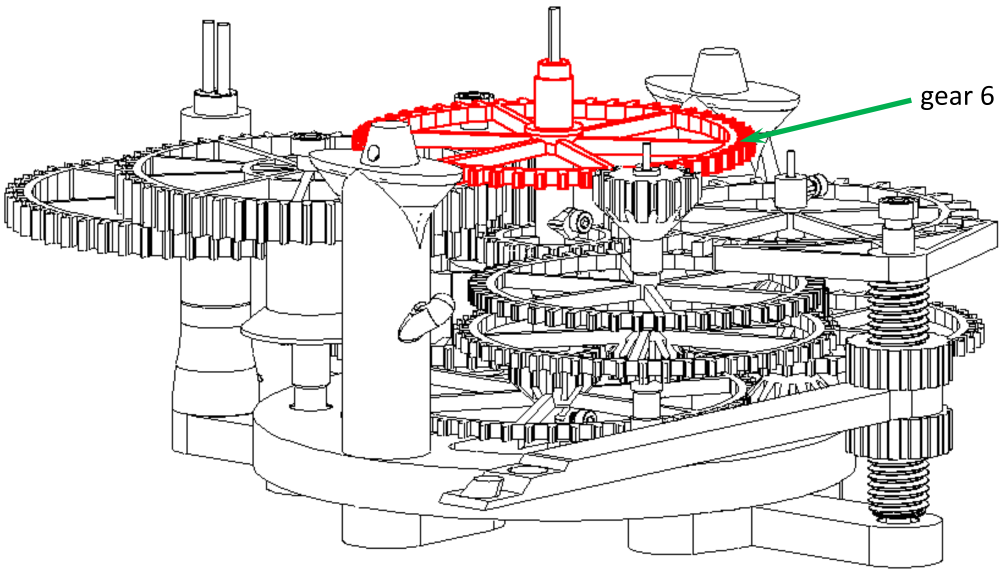
Slide the escapement assembly into position so the arbor can drop into the upper right hole. You may need to lift the lower left gear stack slightly. The final position is shown.



The pallet is the final component on the right side. Real bearings are required here. Start with a 323 bearing in the right side hole. Add a 3mm x 3.5” (90mm) arbor, the pallet assembly, spacer 0, and another 323 bearing.

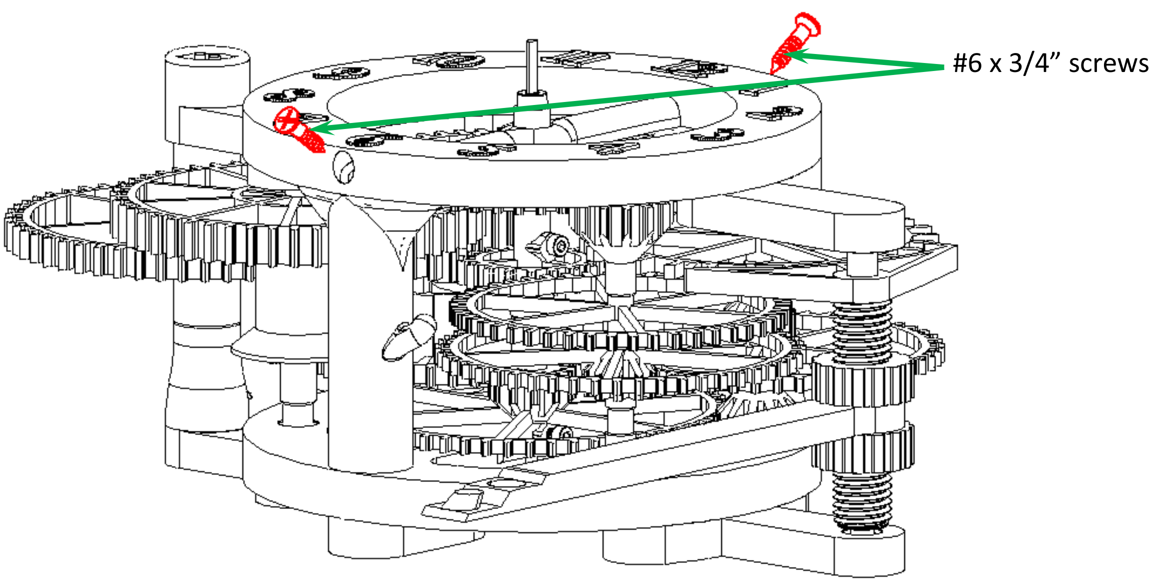


The only gear left is gear 6 that goes onto the gear 4 central arbor.



Add the front frame to complete the clock. It can be a bit tricky to line up all the arbors so the frame can drop into position. Start by positioning the left hole over gear 9 and the dial over the central arbor. The tapered alignment posts should be lined up. Look from the side and wiggle the arbors one by one so the front frame can drop slightly. It is easiest to start on the left side. Eventually, the pallet bearing will be the last component and the entire frame will drop into position.

Secure the front frame with two wood #6x3/4" or M3x20mm wood screws. These screws insert at a steep angle to reduce the risk of splitting the support posts when tightening the screws.



Testing the Clock

The hands can be added to the clock at this point. The hands come with two different styles and several different levels of levels of tightness on the shaft. The tightness level built into the names should be obvious such as loose, normal, tight, and tightest. Select one, or just print them all since they are small files that print fast.

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

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

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

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

The first test is to determine how much weight will be required. Tie a loop in the end of the winding cord and hang a small weight on the end. A plastic water jug is useful for adding or removing weight as required. If you hang the weight directly on the cord, the drive power is effectively doubled compared to what it will be with the pulley. Start with around 2 pounds (1kg) for the shorter runtime options and 4 pounds for the longer runtimes.

Setting the Beat

Move the pendulum slowly to the left and right until the clock ticks. Hold the clock level during the first single line test since the weight is not balanced yet. The escapement should move quickly with each tick and tock. If the escapement is sluggish or doesn't move at all, then add additional weight or look for excess friction somewhere. Repeat the assembly pre-checks if needed.

After the escapement is moving quickly, release the pendulum swing and see if the clock runs. Tilt the frame angle so the clock ticks evenly on each side. This is called setting the beat. You want the clock to make the sound of "tick…..tock…..tick…..tock….." instead of "tick.tock………tick.tock………". The swing gauge helps to determine if the clock is in beat. Each tall line on the swing gauge corresponds to 1 degree of pendulum motion and the short lines are 0.2 degrees. The clock should tick at around 1.5 degrees to the left and 1.5 degrees to the right of the mid-point.

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 this weight to account for the pulley and add a 30-50% safety margin. This should be the target weight for your clock. My test clock would just barely run using 4 pounds directly on the cord in the 23 day configuration. Doubling this to 8 pounds and adding a safety margin would imply a final weight target between 10 and 12 pounds. I use 11 pounds. Shorter runtimes should work with proportionally smaller drive weights. Theoretically, my clock should run in the 8 day mode with around 3.7 pounds. Your clock might need a different amount of weight depending on the overall friction in your gear train.

Print a weight shell large enough to handle your target weight. Refer to the table in a previous section. Pass the cord under the weight shell pulley and hang the end on the hook on the side of the lower support column. The original design of this clock used a screw to hang the end of the winding cord. I never experienced it, but saw a picture of a user that said his frame broke at the screw location after a period of time. The printed hook should reduce this possibility.

Adding the weight shell with the pulley allows better weight distribution so the clock should naturally hang level on the wall. This may upset the beat. It can be adjusted back to beat by moving the pallet nuts backwards or forwards so the pendulum shifts on the spiral groove in the pallet. Tighten the pallet nuts around the pendulum when you find a position that keeps the clock in beat.

The pendulum needs about 1.5 degree of swing in each direction for the escapement to be functional. A bit of extra movement is desirable to keep the clock from stopping from a slight breeze. I like at least 2 degrees of swing in each direction. Adding extra weight would increase the swing and the clock should be a bit more reliable, although it gets slightly louder.

Set the time by rotating the minute hand.

Congratulations, you have completed your clock!!!

Adjusting the Rate

The clock should be reasonably accurate with the pendulum length around the middle of the adjustment range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. The lower adjustment nuts are relatively coarse at around 12 threads per inch. One complete rotation of the adjustment nut will add or subtract around 4 minutes per day. Partial turns of the nut allow the time to be accurate within a few seconds per day.

The clock rate may change during the first week or two as the components settle into position. Then it should stabilize to a consistent rate. Wait to get past this break-in period before attempting the final timing adjustment. My clock is usually accurate to a minute or two per week. I consider this to be pretty amazing.

Winding

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

Wind the clock by placing the key in the winding hole and rotate counter-clockwise. The ratchet should click as the cord is wound. I usually steady the frame when winding the clock to prevent it from shifting and changing the beat. I quickly check the beat after each winding.

There is a spot on the frame behind gear 9 to hang the winding key.

Debugging

This clock was designed with the intention of being easy to assemble. Parts are designed to simply fit together and the clock should 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 may be needed.

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
4) Gear 6 fits through the front dial and spins easily
5) Gear 9 and spacer 9 spin easily on the frame
6) Gear 7b spins on gear 7a and the ratchet is working, grease may be needed on the clicks
7) The gear 4 assembly and gear 6 has some end shake inside the frame
8) The gear 3 and escapement assembly has some end shake inside the frame
9) Pendulum bearing free swing test runs for at least 5 minutes, preferably 10-20 minutes

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.

10) 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 easiest adjustment is to tilt the frame left or right. Additional adjustment can be achieved by moving the pendulum arm along the spiral groove on the pallet shaft. 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 within 30 minutes of winding is often an indication that the beat was accidentally changed while winding. Tilt the frame to get the clock back into beat.

11) 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 sluggish, it will not impart much energy to 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 not enough 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.

12) Does the pendulum slowly loose amplitude and eventually stop?
    This could either be too much pendulum support bearing friction, not enough drive weight, or excess friction somewhere in the gear train. 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 than 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 10. Try swapping the bearings with others in the set if needed. 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.

13) 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.

14) 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.

15) 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.

16) Look at the clock from the side. Are any gear side walls touching?
    The clock is designed with a reasonable amount of side 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 warped gears or too much end shake allowing extra sideways movement. Warped gears may need to be re-printed. Excess end shake can be solved by adding spacers to limit the sideways movement.

17) 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.

18) Test the entire gear train without the pallet.
    After testing all the gear pairs, try the entire set of gears without the pallet. The pallet is easy to remove on this clock by taking out the screws on frame_back_right. 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.

19) Double check the winding cord.
    The winding cord can sometimes fall off the back of the drum and wrap around the arbor. This is usually only a risk after moving the clock. The escapement may move slightly, but it will be very weak. The solution is obvious, fix the winding cord.

20) Double check the escapement is not pinched.
    The Easy Build clocks have set screws on both sides of the escapement. These set screws can get pushed together and pinch the escapement if the frame is squeezed while the clock is getting set up. The solution for this is also obvious, re-align the set screws on the escapement arbor.

21) Reduce the runtime option if needed.
    This clock has a large range of runtime options ranging from an easy to build 8 days to an aggressive 23 days. The longer runtimes take proportionately larger drive weights and will be more sensitive to excess friction anywhere in the gear train. A good option is to re-print gears 4a and 7a to something less aggressive. A running 8 or 11 day clock is a lot more fun to watch than a non-functional 23 day clock. Winding once a week is still an easy to live with clock.

22) Repeat the first 9 checks.
    Seriously, the most common issues affecting this clock can be solved by double checking that all gears spin on the arbors and all gears have a small amount of end shake.

These are some 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 design using loose tolerances, but many components need to work together for your clock to function.

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.

If You Still Need Help

I am always willing to answer questions to help you get your clock running. The most common questions have been answered in this assembly guide, but there could be other reasons. You can ask questions on MyMiniFactory, YouTube, or the forum on my web site at https://www.stevesclocks.com/forum

Provide as much information as possible. Mention which runtime option you are using and how much weight you are using. The pendulum free-swing time for your clock is also useful. It is much easier get help if you provide this information instead of asking “My clock doesn’t work, what do I do?”.

There is an old debug video for SP5 that is very similar to this clock at https://youtu.be/uQcfjhecORE
I will try to update the video with information specific to this updated clock.

Final Comments

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

The smaller SP5 iteration of this clock amazed me with the ability to run for 32 days per winding. However, the initial excitement wore off as the clock started getting finicky and randomly stopping after a few months. Three updates later and SP5B is now a reliable 32 day clock. This clock is more impressive, but the larger heavier gears take additional energy. It is completely reliable in 23 day mode using reasonable size drive weights.

The final update that improved reliability considerably was the introduction of what I call “Perfect Print Gears”. They are a modified cycloid gear with optimizations for 3D printing. I am still fine tuning the algorithm, but it appears close to optimum in this clock. Running for 23 days with around 11 pounds (5kg) using these gears is a good test case.

This clock is the larger iteration of my most popular 32 day clock. This update makes it significantly more reliable. I hope you enjoy building the clock as much as I enjoyed designing it.

Future plans may include porting some of my clock designs to use wooden gears.

Please feel free to support me by purchasing any of my other clocks at MyMiniFactory. I have a Patreon page at https://www.patreon.com/user?u=30981480 (Steve’s Clocks) with a small amount of clock design information. I hope to add more content regarding clock design in the near future. I have a YouTube channel with clock design information at https://www.youtube.com/@stevesclocks and also a website at https://www.stevesclocks.com and a forum at https://www.stevesclocks.com/forum where you can ask questions or post pictures of your build.

Good luck with your clock build.

Steve

Here is the clock that started it all. It is posted to https://www.thingiverse.com/thing:3524448 and https://www.myminifactory.com/object/3d-print-32-day-clock-easy-build-156759

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 is a display of all the latest clocks.

The top row includes all the classic style weight driven pendulum clocks. The bottom row are desktop clocks. Some are motorized with an accuracy of a minute per year. Others have electromagnetic pendulums of motor driven rewind mechanisms.

All of these clocks are available at https://www.myminifactory.com/users/StevePeterson

A video describing the clocks is at https://www.youtube.com/watch?v=uGHhY59GpHM