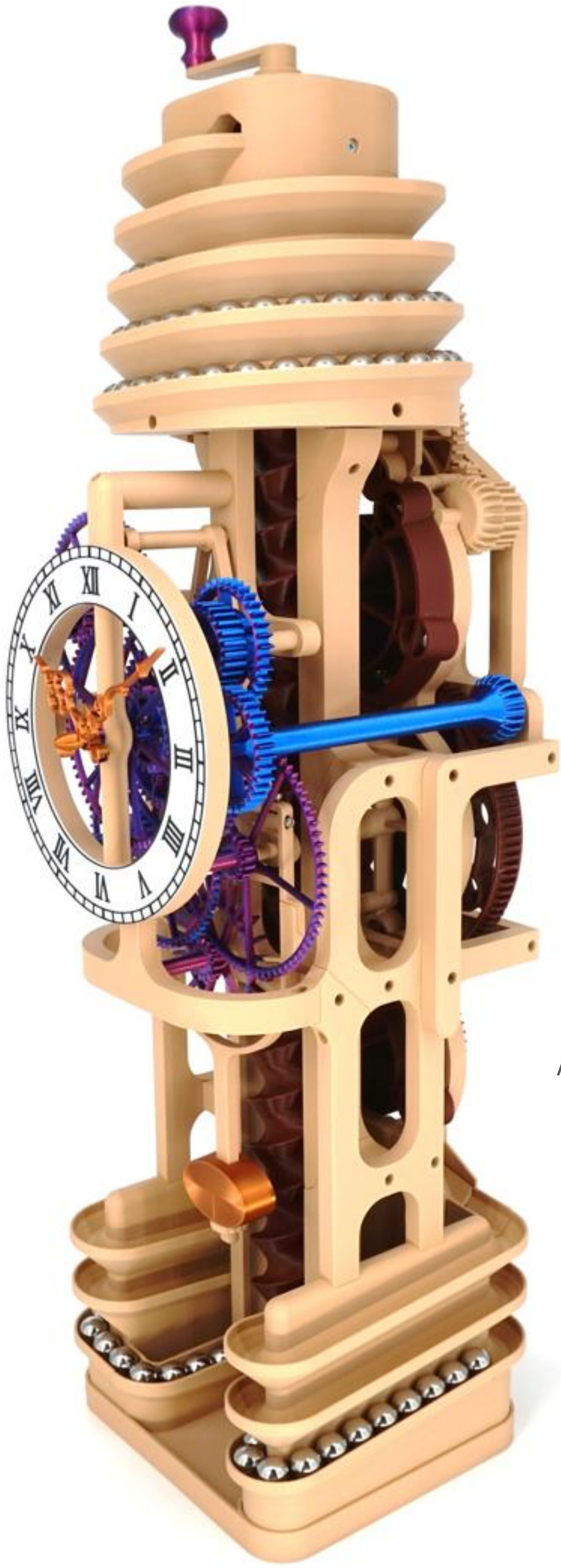


ROLLING BALL CLOCK

SP17 Build Notes

Assembly notes for a large rolling ball clock powered using 3/4" steel balls

Steve Peterson
10-Sep-2026

Contents

Tables

Revision History

10-Jul-2026	Original version.
13-Jul-2026	Updated spiral lifter to support tube sizes from 15-20mm. Changed pages 10, 11, 15.
25-Jul-2026	Added bug fix addendum and minor changes in the main text.
30-Jul-2026	Added frame_405x405 subdirectory for very large printers.
10-Sep-2026	Added gate to limit balls feeding into upper ball drop.

Most of the revisions to this assembly guide are minor or cosmetic enhancements. The 10-Sep update fixed a reliability bug that was reported by several builders. Balls were apparently getting stuck in the upper ball drop and causing the clock to stop. My prototype clock didn't show the issue, making it hard to debug. However, my second clock showed the symptoms and would stop every few days. I added a gate valve to feed balls one by one into the ball drop. It is worth adding this update to your design if you are an early customer. There are only four new and three replacement components required to make your clock significantly more reliable. If you downloaded the stl files along with this assembly guide, then you already have the latest updates.

Description

This is my largest and most exciting clock. It has great symmetry with the prominent dial flanked by rolling ball tracks above and below. A waterwheel style ball drop powers the clock using 3/4" (19mm) steel balls. It is sure to attract a lot of attention. There are no other 3D printed clocks like it.

The overall size is 9.15" (23cm) wide, 10.75" (27cm) deep, and 33.5" (85cm) tall.

This clock breaks a lot of records for me:

1) It is my heaviest clock requiring around 5.3kg of PLA filament. Despite its size, it can be printed on most standard size printers including the Prusa MK4 (250x210mm) or the Ender 3 (220x220mm). Larger BambuLab printers (256x256mm) or the SnapMaker U1 (270x270mm) are even better. Total print time is around 120 hours on a modern printer with input shaping.
2) The design effort was the most intense of all my clocks so far. The ball drops and spiral lifter needed to be engineered from scratch. Many new mechanisms needed to be designed to load and distribute the balls efficiently. There are very few reference designs to use as inspiration.
3) This is my loudest clock. Each time a ball drops, there is a loud clunk as the balls roll or bump together. It becomes enjoyable after a few days, but is still loud. The clock is likely only suitable for locations where you can tolerate the sound.
4) Despite its size, it is easy to build. The bill of materials is small. This assembly guide walks you through the process of putting everything together.
5) This is my new favorite clock. The Moon Phase Wall Clocks and Crazy Gear Desk Clocks have some interesting characteristics. This clock blows them away with all the new features. If you already have several clocks, this one will likely be the one drawing most of the attention.

The design requirements for this clock are:

1) The clock must be accurate. This clock typically maintains an accuracy of 1-2 minutes per week.
2) The clock must be reliable. The deadbeat escapement used in this design has proven itself to be very robust. The clock often starts ticking as soon as the balls are loaded. The balls provide a consistent source of power and maintain power while winding.
3) The clock must have a runtime of at least a day. My wall mounted clocks can run for eight days or more. They run on pounds of weight falling over 48”. This clock has a smaller weight with only 16” of drop. Runtime is up to 2.4 days with 125 balls loaded.
4) The clock must look good. This clock has great symmetry in all directions. The dial is balanced between the ball drops. From the side, the clock module and waterwheel style ball drop are mirrored beside the spiral lifter. It is very ergonomically balanced. I think the simple gear layout looks great. Hopefully, you like the way it looks as well.
5) The clock should be easy to assemble. The list of non-printed materials is quite small. This guide shows the step by step assembly process.

Quick Start

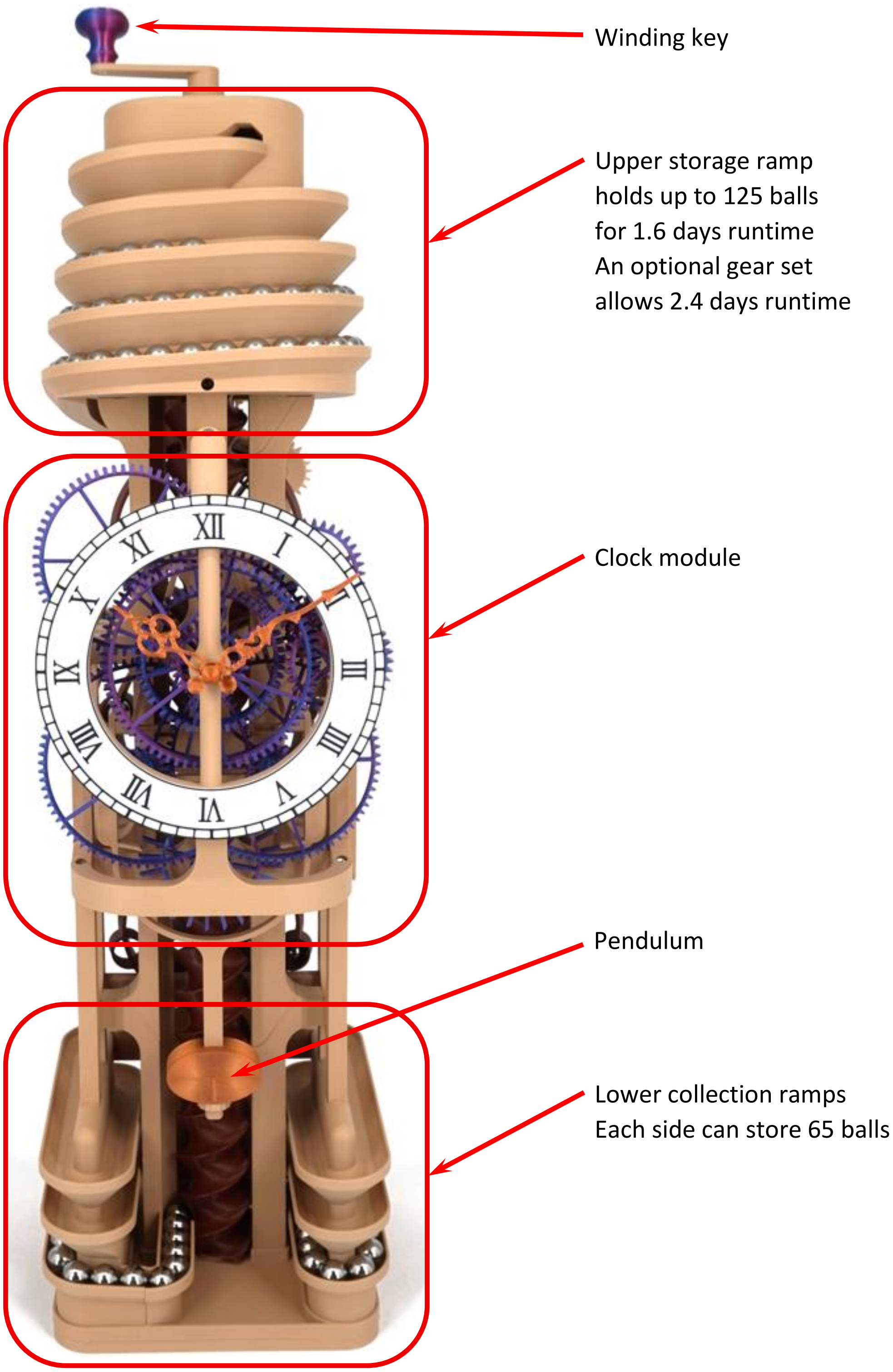
This clock is designed to be easy to print and assemble. This manual will walk you through the process. Here are the most important steps if you want to get started right away.

1) Order the non-printed components listed on page 10.
2) Follow the metal cut lists on pages 12-13.
3) Print the ball track components listed on page 15 using 0.2mm layer heights and 4 perimeters.
4) Print the frame components listed on page 16 using 0.2mm layer heights and 4 perimeters.
5) Assemble frame sub-components as shown on pages 18-20.
6) The frame module cross reference chart is on page 17.
7) Print the gears listed on page 21 using 0.15mm layer heights and 4 perimeters.
8) Refer to the gear cross reference chart on page 22.
9) Refer to the gear topology diagram on page 23.
10) Follow the pre-assembly cleanup steps shown on pages 24-26.
11) Component pre-assembly construction steps are on pages 27-33.
12) The frame assembly is shown on pages 34-41.
13) The step-by-step process of adding the gears is on pages 42-51.
14) Load balls into clock as shown on page 52.
15) Additional debug steps are on pages 52-55.

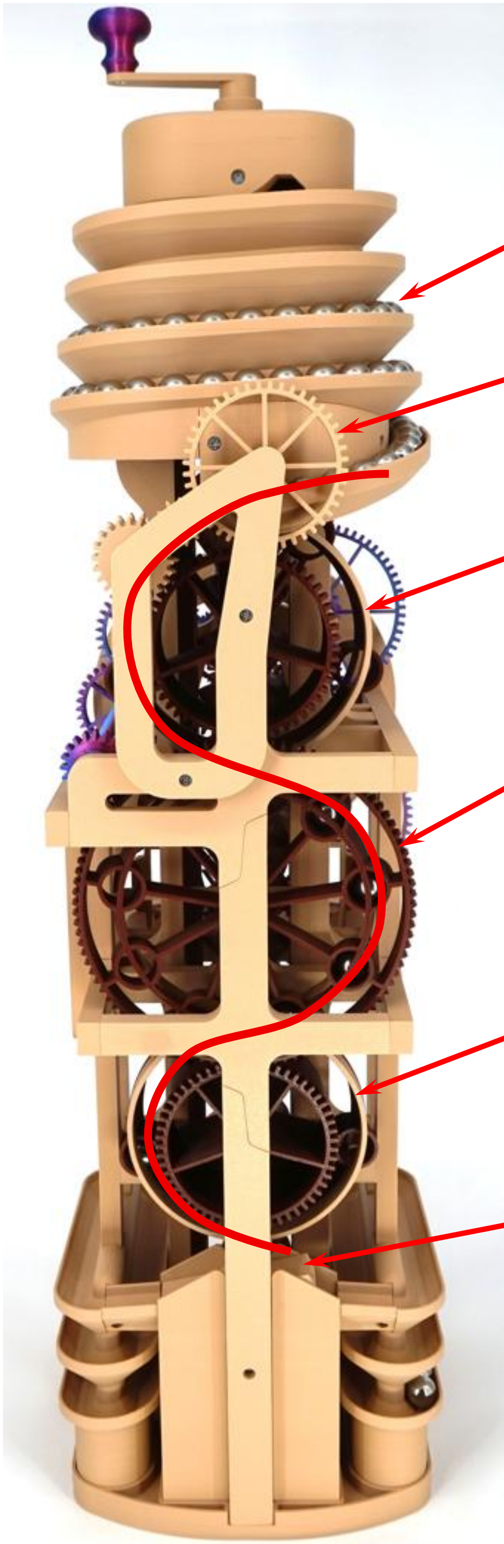
Clock Overview

There are a lot of components in this clock. Here is a brief overview of the major blocks:

The front view can be broken into three zones. The upper and lower zones have ball delivery and storage ramps. The center portion contains the actual clock mechanism.



The back view shows the waterwheel style ball drop. Balls feed from the upper storage ramp through three connected ball drops.



Balls enter the ball drop from the upper storage ramp and follow the path shown

Ball limiter to feed balls one at a time into the ball drops

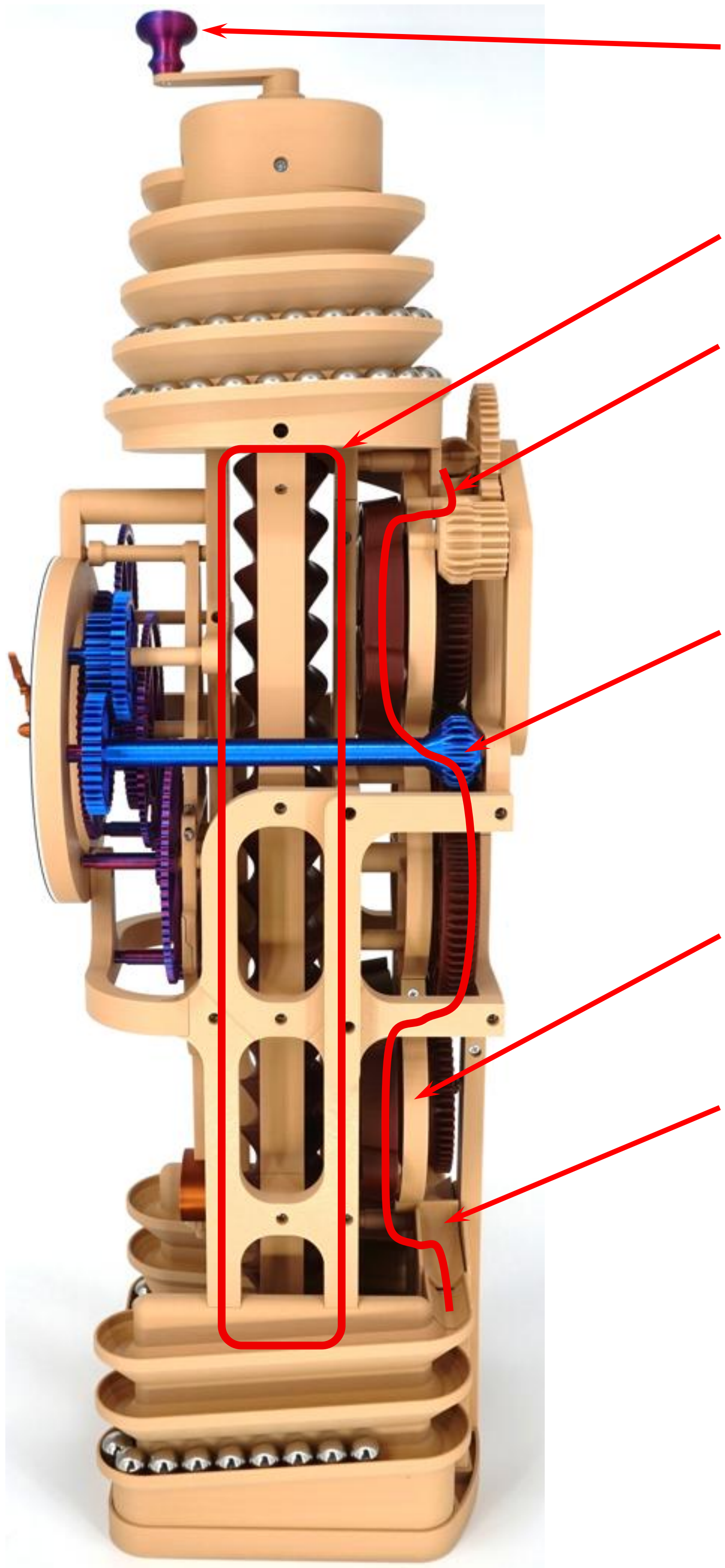
Upper ball drop with 5 pockets

Center ball drop with 9 pockets

Lower ball drop with 5 pockets

Toggle gate to equally distribute balls between the lower collection ramps

The side profile shows the connections between the front and back of the clock.



Design Considerations

Designing this clock was huge challenge. There are very few reference designs. Many concepts needed to be invented. Here are a few of the clocks that may have provided some inspiration.

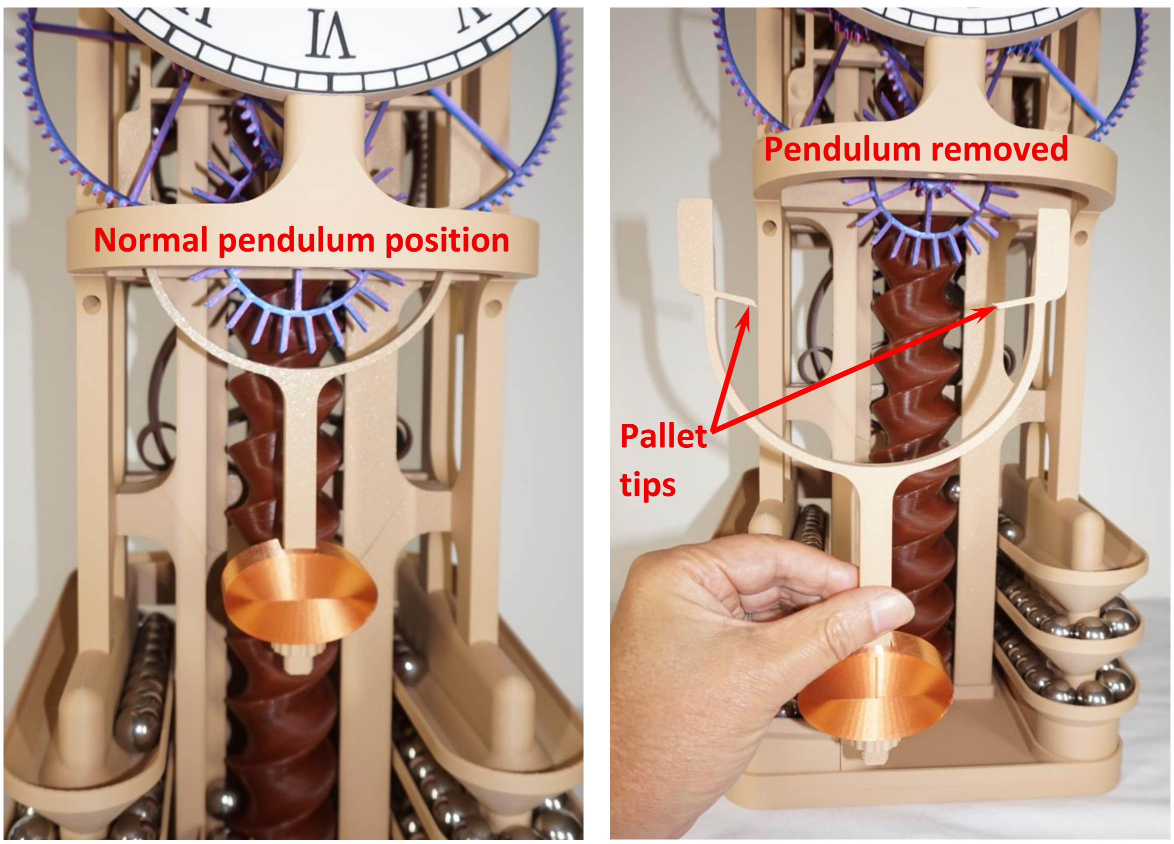
Idle Tyme uses balls to display the time in minutes, 5 minutes, and hour increments. The balls count the time, but do not actually drive the clock. The balls determine the time on the Congreve clock shown on the right, but power is provided by a spring.

The clocks below are closer to the effect I was looking for. They are usually found as 19th century or early 20th century novelty clocks in antique auctions. Some may be modern replicas. The first clock below is listed as a “French style mystery water wheel rolling ball clock”. It appears that the balls do actually power the clock as they drop back down. The second clock is a Thwaites and Reed falling ball clock. It drops one large ball per hour to power the clock. This is the closest reference design to the clock I wanted to build.

I wanted steel balls to be the focus and primary power source for the clock. Prototypes for some of the design was completed many years ago. Finishing the rest of clock was a long process. I knew what I wanted to achieve and could approximate some component positions. The waterwheel style power source would take up the center portion. Ball ramps would sit above and below. The frame holding everything together would be huge. The tallest vertical columns are over 30" tall, so they were split to be printed on standard size printers.

One tricky design challenge was defining a way to load balls when starting the clock. The balls can only enter serially from the top ball ramp. During normal operation, the clock loads one ball every 20-30 minutes. This would take hours to fully load the ball drop while the pendulum is swinging. The trick is to remove the pendulum, or rather the pallet, so the escapement can spin at a much faster rate. This allows loading a new ball every few seconds and the clock can be initialized in minutes.

The pallet is moved to the bottom of the pendulum to create the removable lower section. Theoretically, only the pallet tips need to be removed. It was easier to remove everything below the pallet including the pendulum bob. Here is how it works.



That is enough theory for now. The final section in this guide shows additional detail if you are interested. Let's start building the clock.

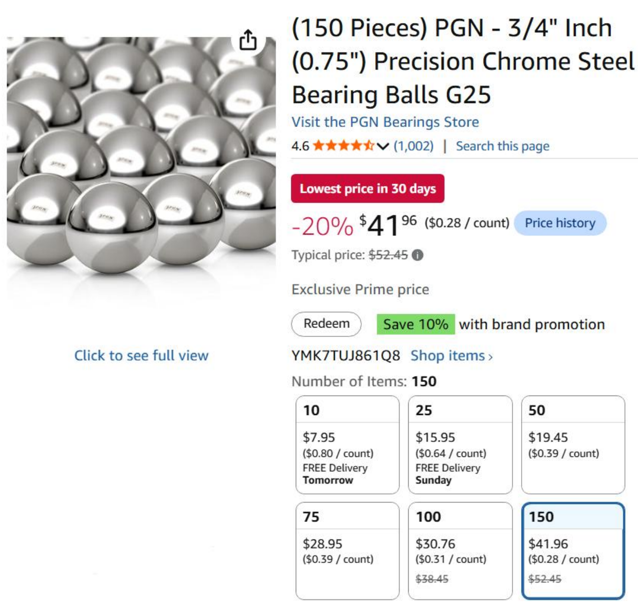
Bill of Materials

This clock runs using the weight of 3/4” (19.05mm) steel balls. Make sure you can find a bulk source of steel balls before starting the clock build. Most other non-printed components are easy to find. Many are the same components used in my other clocks. McMasterCarr part numbers are listed if possible.

Qty	Component	McMC Part No.	Notes
100-125	3/4” (19.05mm) chrome steel balls		Chrome steel balls are best. 3/4” or 19mm balls will work
28” (71cm)	1/2” EMT conduit or other metal tubing with an outer diameter of 15-20mm	1829T1	Adds strength inside spiral lifting auger. Cut to 28” (71cm) long. See notes on next page
94-99	#6x3/4” flat head wood screws	90048A151	Metric equivalent is M3.5x20mm
7	M3x8mm socket head screws	91292A112	8mm or 10mm lengths will work
48" (120cm)	3mm stainless rod	1274T42	Stainless steel is best. Brass or plain steel rod should be OK. See cut list
20" (50cm)	1/16” or 1.5mm music wire or spring steel	89085K85	1/16” or 1.5mm diameters can be used. See cut list
24	pennies or washers		Used in pendulum bob. Can also use two 3/4” steel balls
1	608 bearing (8x22x7mm)		Generic skateboard bearing used under the spiral lifting auger
2	623RS bearing (3x10x4mm)		Used to support the pendulum

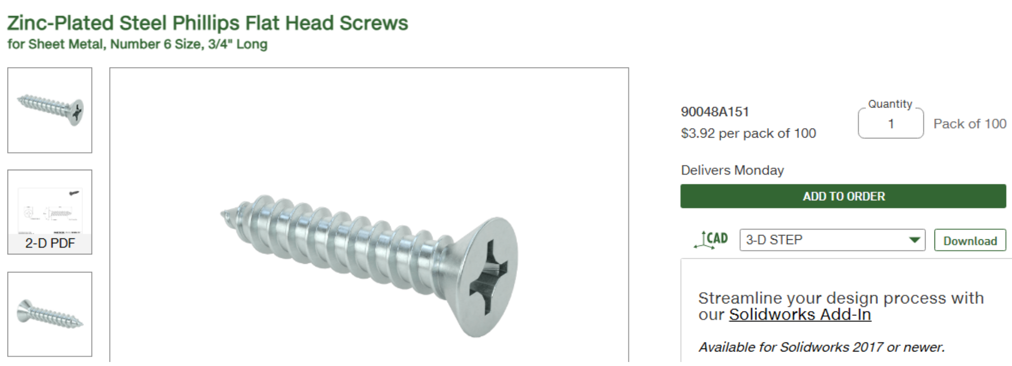
Table 1: Non-printed parts

The 3/4” (19.05m) steel balls are the first component to find. Amazon in the US is a good source at a reasonable price. I have used plain steel bearings in a low humidity area, but chrome steel is probably better. 19mm bearings will also work. I don’t know if 18mm or 20mm balls will work. The clock will run for 30 hours using 100 balls or 38 hours using 125 balls. The 2.4 day runtime option increases this to 45 hours with 100 balls or 57 hours with 125 balls.

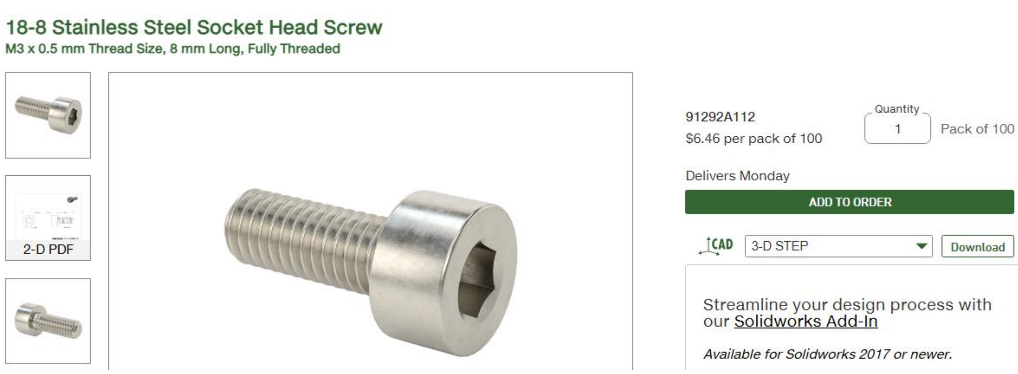


The spiral lifting auger in the center of the clock uses a 28" (71cm) length of rigid tubing for strength. 1/2" EMT is the best choice in the US. It has an outside diameter of 0.706" (17.9mm), so it will use the spiral_lift files with an 18mm hole. Any other tubing sizes between 15mm and 20mm can also be used. Find something within the size range and print the files with the closest size center hole. The files can be sized slightly for a perfect fit. EMT is a good choice in the US. Other types of metal tubing can also be used. Solid rod might work, but it will be heavier and more expensive. Straight grain hardwood dowels might also be an option.

This clock uses a lot of #6x3/4" wood screws to hold the frame together. I counted 94 screws for 250x250mm printers and 98 for the others. I may have missed a few, so get at least 100. My favorites are fully threaded "Sheet Metal" screws at McMasterCarr that have consistently good quality. Partially threaded wood screws will also work. The closest metric size would be M3.5x19mm. M3.5x18mm, or M3.5x20mm. M3x20mm should also work. Flat or oval heads are best.



M3 socket head screws are used in a few places to secure gears to arbors. The optimal length is 8mm. M3x10mm will also work. Socket head is preferred.



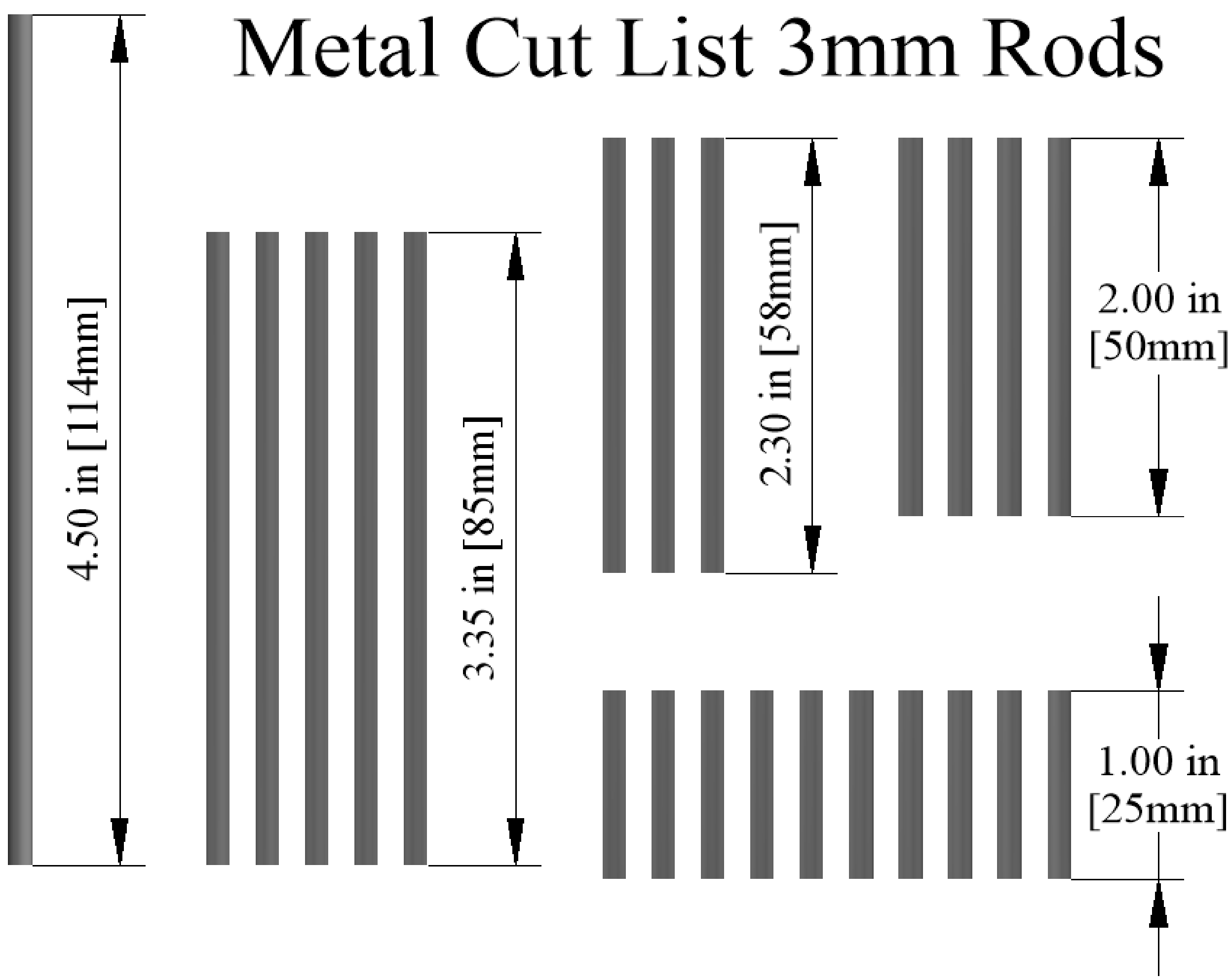
3mm Metal Cut List

3mm rods are used in any arbor position supporting a load. Stainless steel is preferred. Brass or plain steel rods would also be acceptable. 1/8" rods can also be used in most locations if the holes are drilled larger. One of the 3.35" rods needs to fit into bearings with 3mm center holes. Reduce the diameter of this rod to fit the bearings if needed. All of the other rods have looser tolerances and can use 1/8" rod if it is easier to find.

Cut the rod to length using a hacksaw or bandsaw with a metal cutting blade. Slightly undersized lengths are preferred instead of too long. Smooth the ends and remove any burrs using a file or bench grinder.

The reliability update made on 10-Sep-2026 added the three M3x2.3" arbors.

The short 1" lengths can often be found as M3x25 dowel pins to avoid having to cut and deburr so many small pieces.



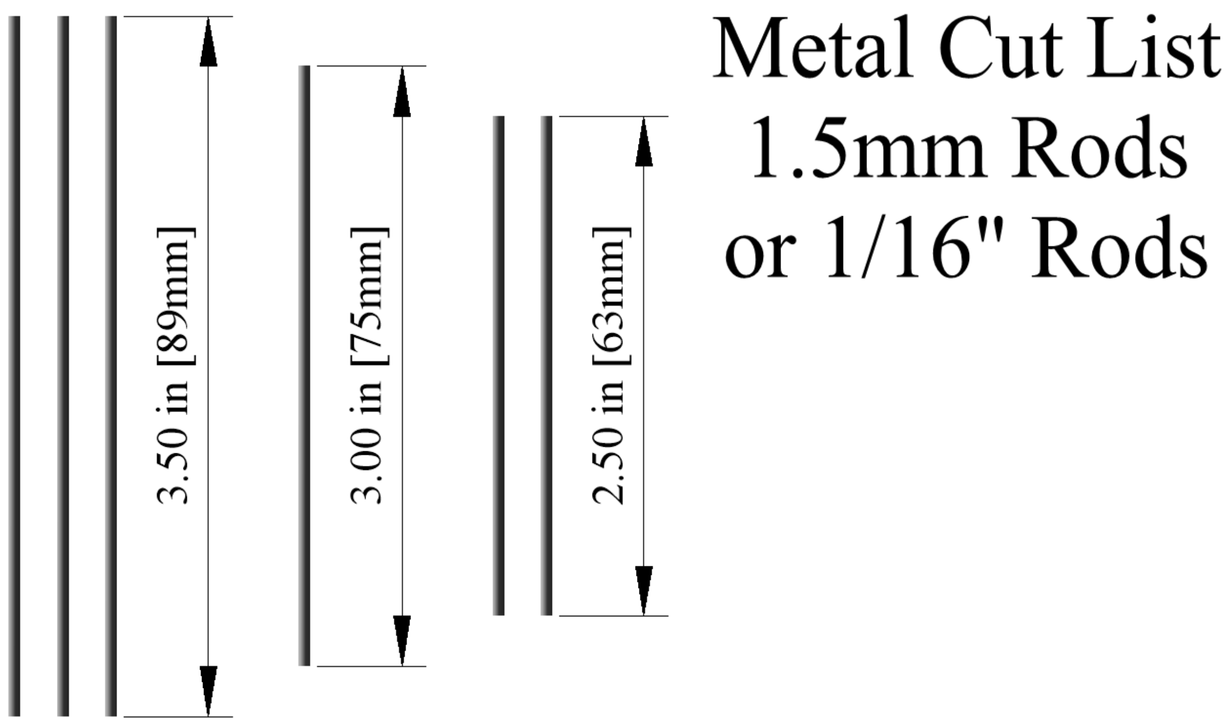
1.5mm Metal Cut List

The fast moving gears and the escapement use 1.5mm or 1/16” music wire rods. Either diameter is acceptable. Music wire is also known as spring steel or piano wire. It is a hardened steel rod with a lot of strength even with a small diameter. This small diameter is needed to reduce friction in the escapement.

Music wire is available in the US at Ace Hardware and RC hobby shops that sell small metal parts. Make sure to buy straight rods, not coiled wire unless you want to spend hours trying to make straight segments.

The 2.5” pieces create a friction clutch to allow changing the time while the clock is running. This needs the stiffness of the hardened music wire to apply the proper pressure.

Music wire needs to be cut using a hardened steel cutter or a Dremel tool with a cutoff. Cheap wire cutters may be damaged if you try to use them. Bolt cutters will also work. They may leave a sharp point that needs to be removed. Smooth the ends and remove any burrs using a file or bench grinder.



The final non-printed parts to acquire are the bearings. The tall spiral lifting auger uses a generic 608 size (8x22x7mm) bearing commonly used in skateboards. It provides a low friction bottom support for the spiral lifting auger. Any quality of bearing can be used here. Either shielded or open styles will work.

The pendulum is supported using two small 623 (3x10x4mm) bearings. I use these bearings in all of my clocks and have not found anything else with lower friction that is readily available. The thick factory grease needs to be removed to lower friction enough for the clock to run properly. Open bearings or bearings with easily removable rubber seals (623RS or 623-2RS) are best. Do not buy 623ZZ bearings that have difficult to remove shields. Also, resist the urge to buy expensive high tolerance bearings for the pendulum support. I build all my clocks using the cheapest bearings I can find and they work great.

Printing the Parts

Despite its size, this clock is relatively easy to print. Every part has been optimized and is usually oriented to just load and print. Supports are never needed. The dial needs a color change for the numbers. This can be done automatically on some printers or manually by inserting a pause in the slicer.

The components have been divided into subdirectories to help keep parts organized. The “ball_tracks” subdirectory contains everything related to the ball tracks, as expected by the name. The gears are in the “gears” subdirectory.

There are three frame subdirectories for different size printers. Print everything in the frame_250x250 subdirectory If your printer has a 250x250mm or larger bed. Likewise, print everything in the frame_250x210 subdirectory for a Prusa MK4 size printer or the frame_220x220 subdirectory for an Ender 3 size printer. Most of the parts in the frame subdirectories are identical with differences as needed for the smaller printers. It seemed easier to have redundant files and say “print everything in one subdirectory” instead of picking files from multiple locations.

I use two printer presets for all of my clocks. Most parts use a preset with 0.20mm layer heights, except for the gears that work better with 0.15-0.16mm layers. The other critical parameter is to use four wall loops unless specified otherwise. A few parts are optimized for five wall loops.

Printer characteristics:

Material	PLA
Nozzle Size	0.4mm
Starting Preset	0.20mm SPEED in PrusaSlicer for most parts (gears use STRUCTURAL)
Layer Height	0.20mm for most parts (gears should use 0.15-0.16mm)
Perimeters (wall loops)	4 for most parts
Top Layers	7
Bottom Layers	6
Seam Position	Random
Scarf Joints	Enable this feature if available in your slicer
Perimeter Generator	Arachne for most parts (gears should use Classic)
Fill Density	15%
Fill Pattern	Cubic or other strong infill pattern
Elephant Foot	0.25mm (look at the slicer to determine what works best)
Supports	Never needed for any parts in any of my clocks
Orientation	Usually already optimal. Some parts may need to rotate to fit 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 default print settings for 0.15mm and 0.20mm layer heights. In addition, there is a SPEED and a STRUCTURAL setting for both layer heights. I have started using 0.20mm SPEED for most parts and 0.15mm STRUCTURAL for the gears. Taking a slightly longer time to print the gears is a small price to pay for the extra accuracy. Most other parts are less critical. Other slicers may have similar setups with slightly different names. The SnapMaker Orca slicer has 0.20mm standard and 0.16mm high quality settings.

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

Ball Tracks

The ball track components include the ball storage and collection ramps, plus the ball drop and spiral lifting auger. Some of these components are quite large. All combined these parts will take around 3.1kg of filament and 65 hours of print time on a SnapMaker U1 printer.

Parts that need multiple copies printed are highlighted in yellow.

Part Name	Color	Print	Notes
ball_drop_shield5_upper	tan	1	Prints best using 5 perimeters
ball_drop_shield5_lower	tan	1	Prints best using 5 perimeters
ball_drop_shield9	tan	1	Prints best using 5 perimeters
ball_drop_5	brown	2	Prints best using Classic mode with 5 perimeters
ball_drop_9	brown	1	Prints best using Classic mode with 5 perimeters
ball_ramp_lower_left	tan	1	
ball_ramp_lower_right	tan	1	
ball_ramp_upper	tan	1	The largest part using over 0.8kg when printed using 4 perimeters
ball_ramp_upper_cover	tan	1	
ball_ramp_upper_exit	tan	1	
spiral_lift_test_??mm	any	1	Use to test fit around support tube. See notes below
spiral_lift_center_??mm	brown	4	See notes below
spiral_lift_lower_??mm	brown	1	
spiral_lift_upper_??mm	brown	1	
toggle_body	tan	1	
toggle_bridges	tan	1	
toggle_lever	tan	1	
winding_key_handle	tan	1	
winding_key_knob	red/blue	1	

Table 2: Ball track components to print

Spiral lift notes:

The spiral lifting auger is built using multiple printed components around a rigid center support tube. 1/2” EMT conduit is a great choice in the US. It has an outer diameter of 0.706” (17.9mm) and can use the spiral lift components with the “_18mm” extension. Print spiral_lift_test_18mm first to check the fit.

If 1/2” EMT conduit is not available in your area, then find any other rigid tubing with an outer diameter between 15mm and 20mm. Print spiral_lift_test_??mm with the closest hole size that matches your tubing. Scale X and Y (not Z) up or down by up to 3% to get a good fit. Print the remaining spiral lift components using the same scale factor.

It may also be possible to use a wooden dowel instead of metal tubing. Select hardwood with straight grain for the best results. Sizes closest to 20mm should give the best results. It may be a good idea to glue the dowel into the spiral lifter to minimize the chances of warping.

Frame Parts

The frame is often printed in a neutral color so the primary focus can be on the ball tracks and gears. There are eight primary structures labeled a, b, c, d, e, f, g, and h. Each of these structures is further split up into smaller segments such as a1, a2, and a3, etc. More detail is included later in the assembly portion of this manual.

The table below shows the components in the “frame_250x250” subdirectory. Smaller printers will split a few components even further. For example, the frame_250x210 subdirectory splits the frame_c2 component into frame_c2a_250x210 and frame_c2b_250x210. There is also a frame_405x405 subdirectory at the request of a builder with a really large printer.

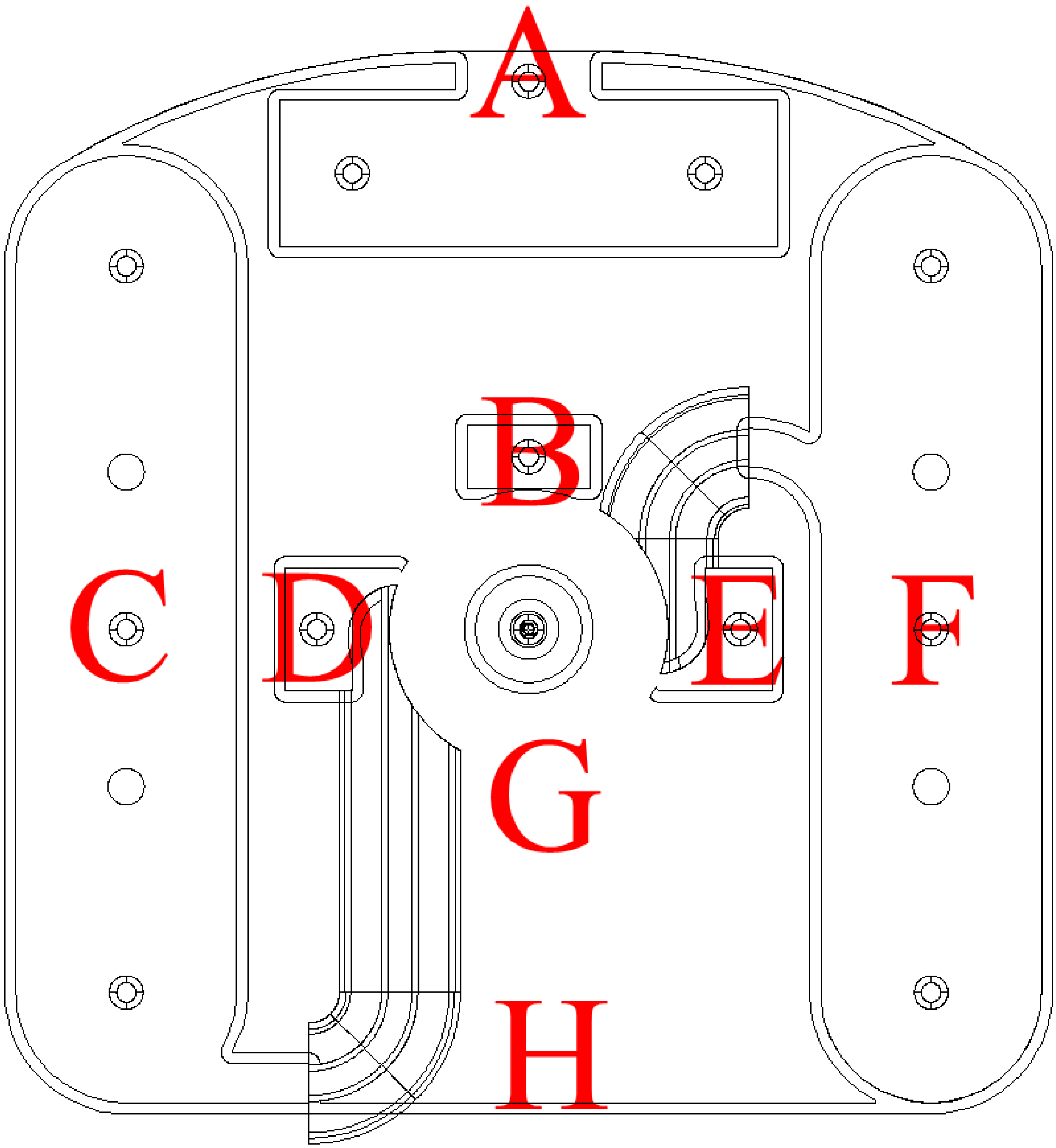
The frame dial needs a few color changes to highlight the numbers. Start with the same color as the rest of the frame. Switch to white for the dial background at 13.00mm and black for the numbers at 15.40mm

All parts in this section require around 1.9kg of filament and 37 hours of print time on an SnapMaker U1 printer using 0.20mm layers, 4 perimeters, 7 top layers, 6 bottom layers, and 15% cubic infill.

Part Name	Color	Print	Notes
frame_a1	tan	1	Four components making up the “A” portion of the frame.
frame_a2	tan	1	
frame_a3	tan	1	
frame_a4	tan	1	
frame_b1	tan	1	
frame_b2	tan	1	
frame_b3	tan	1	
frame_b4	tan	1	
frame_base	tan	1	
frame_c1	tan	1	
frame_c2	tan	1	
frame_d1	tan	1	
frame_d2	tan	1	
frame_d3	tan	1	
frame_d4	tan	1	
frame_e1	tan	1	
frame_e2	tan	1	
frame_e3	tan	1	
frame_e4	tan	1	
frame_f1	tan	1	
frame_f2	tan	1	
frame_f3	tan	1	
frame_g1	tan	1	
frame_g2	tan	1	
frame_h1	tan	1	
frame_h2_dial_roman	tan, white, black	1	Dial needs color changes at 13.00mm and 15.4mm

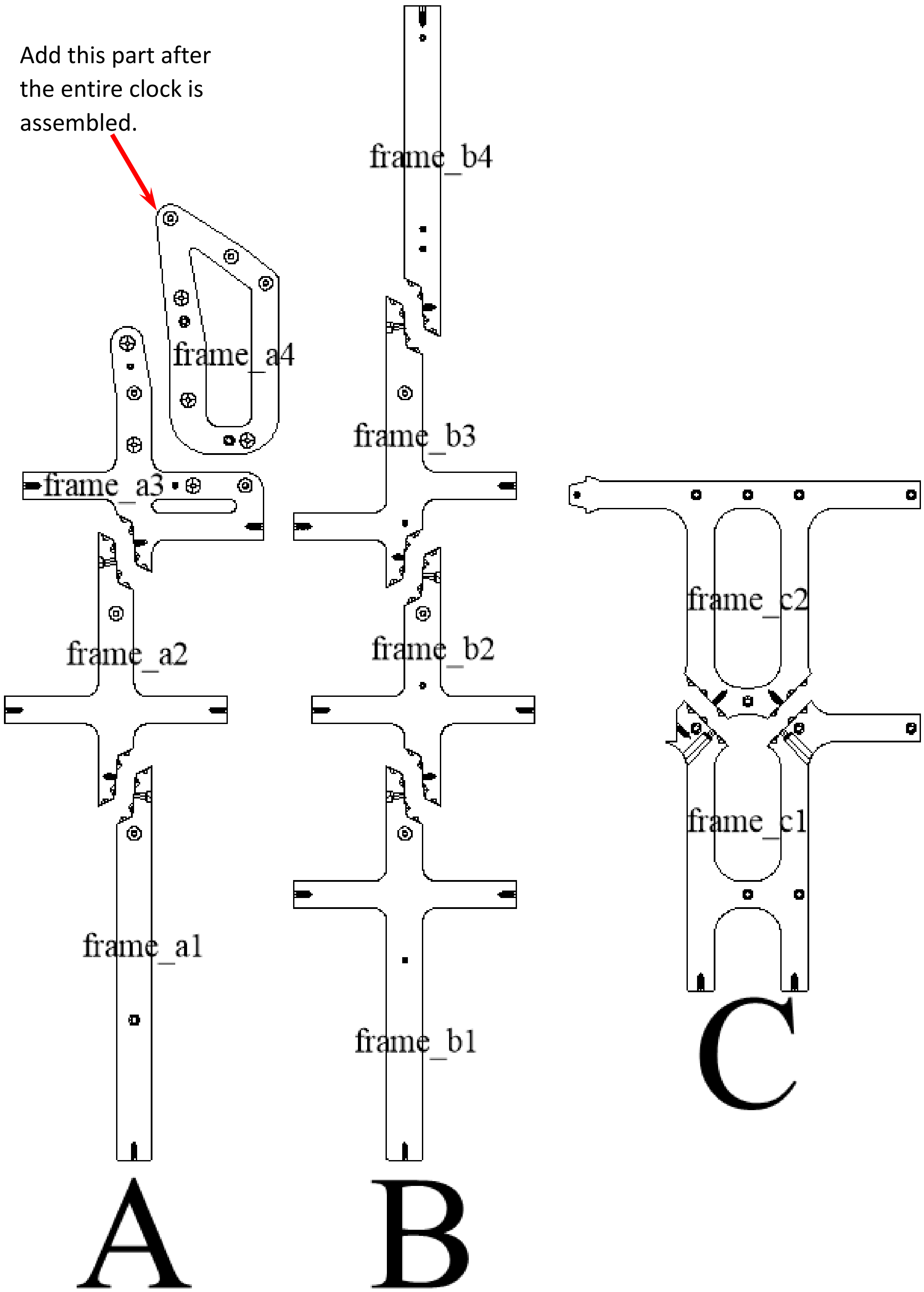
Table 3: Frame components to print

This image shows the base with the primary frame locations labeled. The frame_a1, frame_a2, and frame_a3 parts will all reside at the position labeled "A", etc. Some parts like B, D, and E have registration pockets built in to the base. C and F will have pockets in the lower ball ramps. G and H will be supported by the rest of the frame so they do not extend into the base.

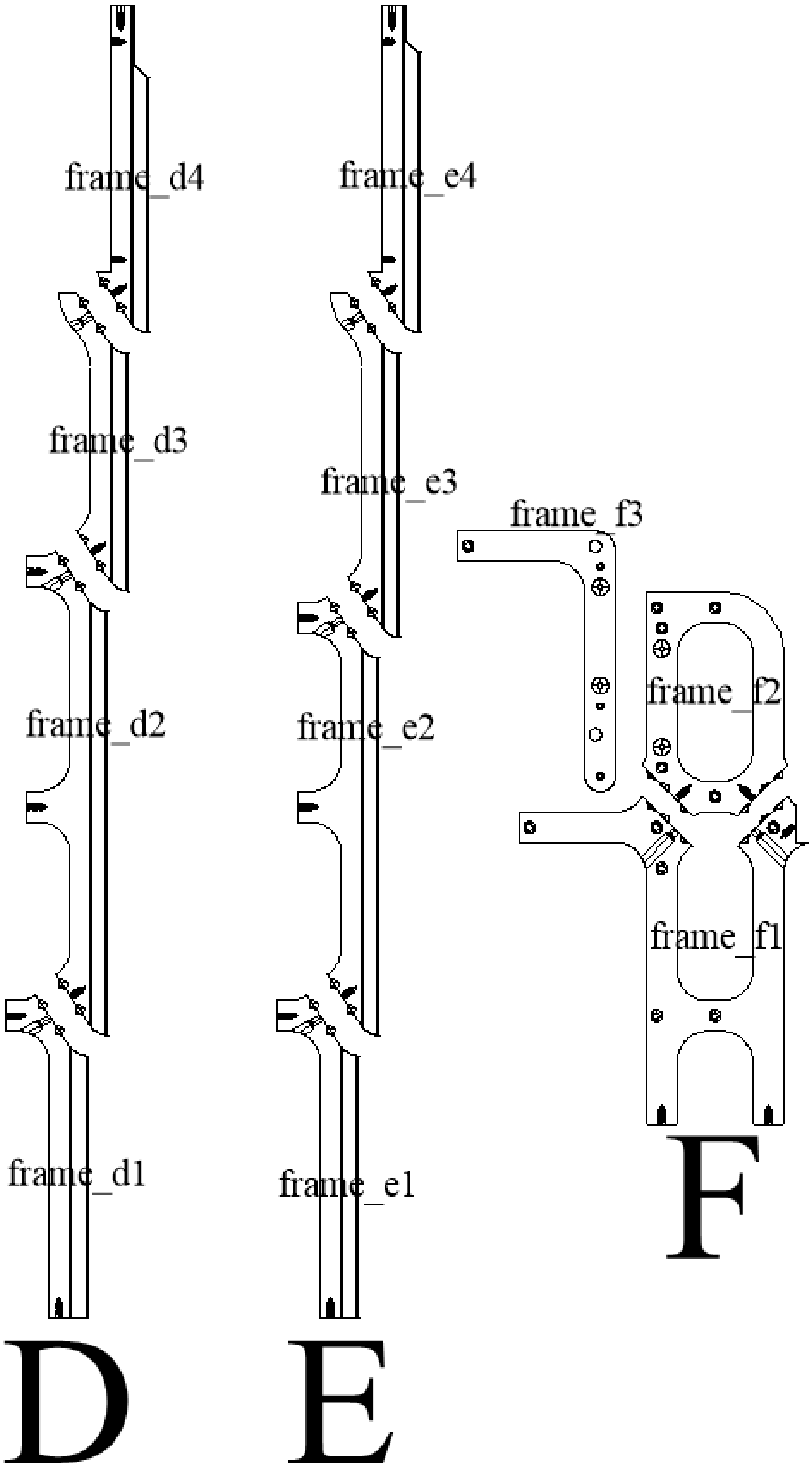


Here is a breakdown of the frame components used in the clock. The picture below shows the A, B, and C components. It is recommended to print all the "A" sub-components and connect them together before moving on to the "B" sub-components. Many parts look similar, but may have slight differences.

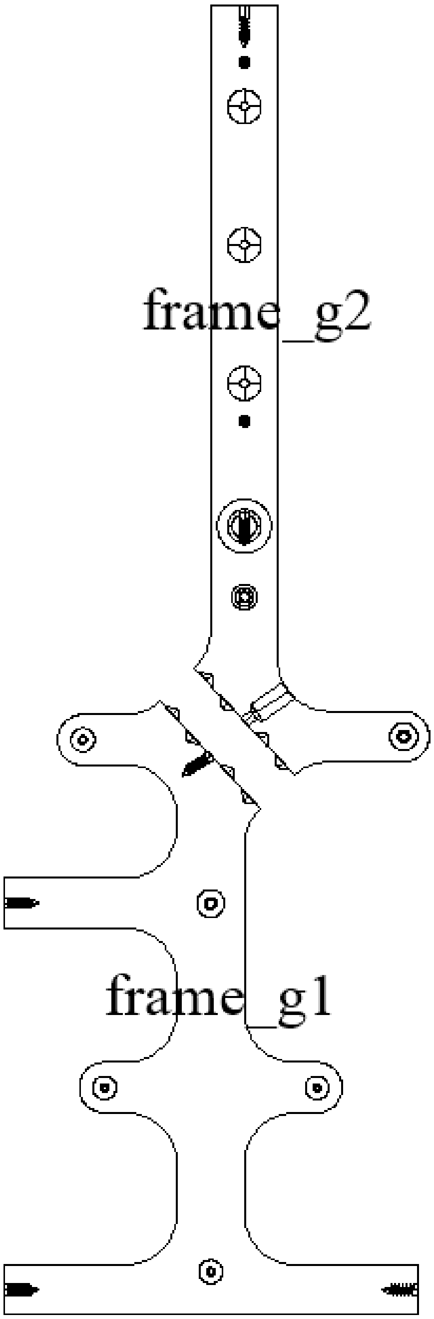
The images shown are from the frame_250x250 subdirectory. The other subdirectories for smaller printers will have a few additional splits. They should be easy to figure out using this basic reference.

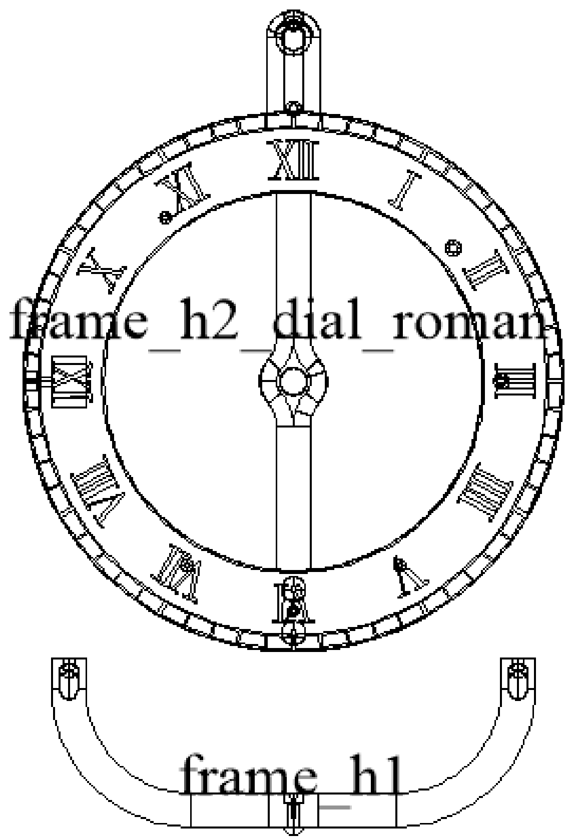


These are the D, E, and F frame components.



And the final frame components used for the actual clock.





G H

Gears

The gears will work better using finer 0.15-0.16mm layer heights. The thinner layers take slightly longer to print, but friction should be reduced because the layer line ridges will be smaller. Everything else in the clock works fine using 0.20mm layers.

IMPORTANT DETAIL: The gears in this clock are optimized for the classic slicer. Some of my other clocks are optimized for Arachne, but the algorithm kept changing, so I switched back to the classic slicer optimization for the gears. Everything else can use Arachne if you want.

Most parts print best using 4 perimeters, except the pallet that is optimized for 5 perimeters. Dual color silk PLA looks and works great. The cover photo uses red/blue silk PLA.

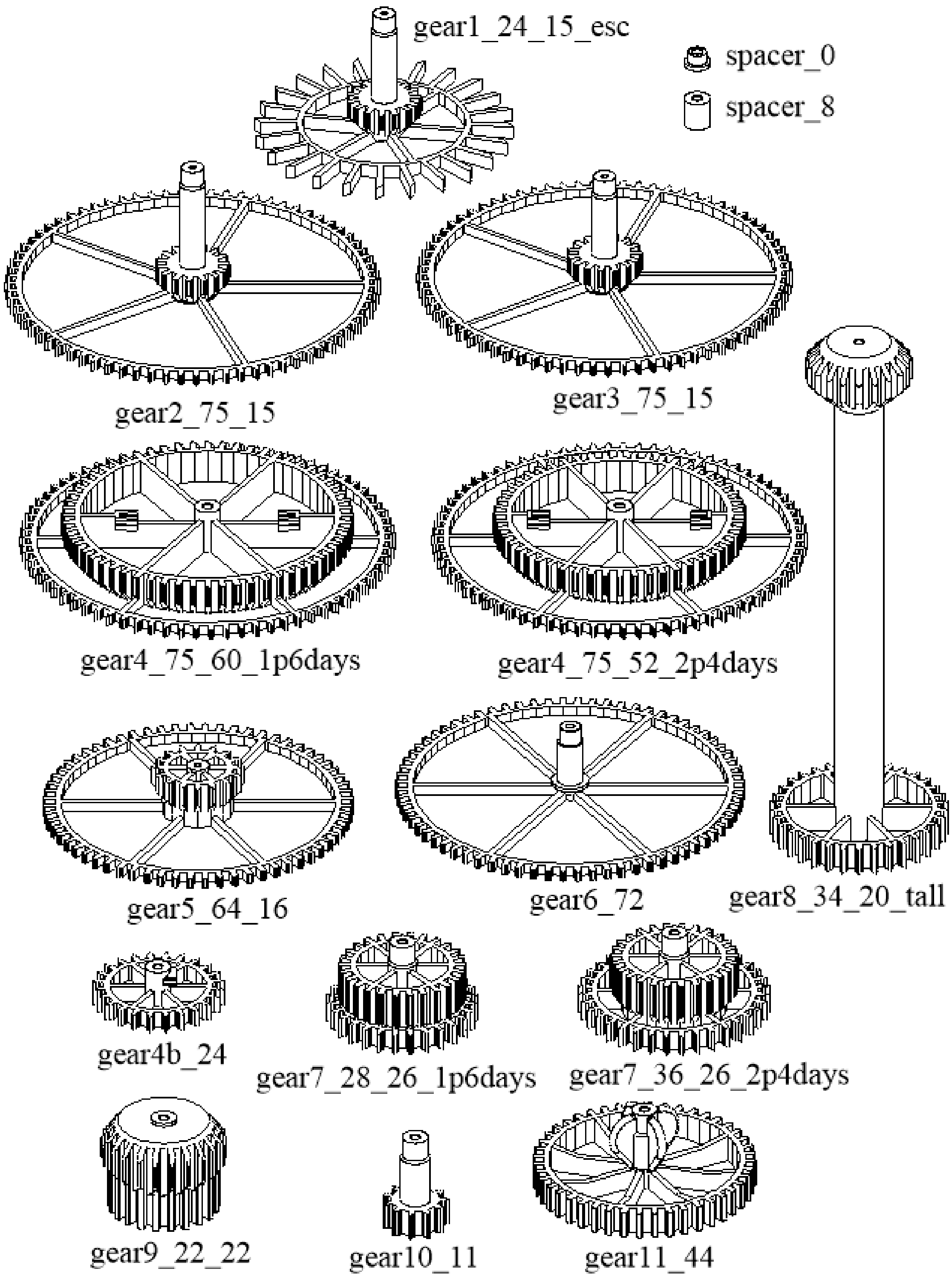
All files listed here require 0.3kg of filament and 17 hours of print time on a SnapMaker U1 printer using 0.16mm layer height, 4 perimeters, 7 top layers, 6 bottom layers, and 15% cubic infill.

Part Name	Color	Print	Notes
gear_spacers	red/blue	1	All spacers in one file
gear0_pallet_center	tan	1	Large pendulum/pallet component looks best in a neutral color. Prints best using 5 perimeters. The lower section is removable when loading the ball drop.
gear0_pallet_lower	tan	1	
gear0_pallet_upper	tan	1	
gear1_esc_24_15_esc	red/blue	1	
gear2_75_15	red/blue	1	
gear3_75_15	red/blue	1	
gear4_75_60_1p6days	red/blue	1	Default gear set for 1.6 day runtime
gear4_75_52_2p4days	red/blue	0	Optional gear set providing up to 2.4 days runtime
gear4b_24	red/blue	1	
gear5_64_16	red/blue	1	
gear6_72	red/blue	1	
gear7_28_26_1p6days	red/blue	1	Default gear set for 1.6 day runtime
gear7_36_26_2p4days	red/blue	0	Optional gear set providing up to 2.4 days runtime
gear8_34_20_tall	red/blue	1	Tall gear to connect ball drop to main clock. It may require a brim to give it a chance of sticking to the plate. An internal brim will be much easier to remove than an external brim that will want to stick to the gear teeth. Slow down the print speed as it gets near the top to reduce errors caused by vibration.
gear9_22_22	tan	1	Set of gears used to limit balls entering the upper ball drop
gear10_11	tan	1	
gear11_44	tan	1	
hands_gothic	gold	1	
pendulum_bob	gold	1	
pendulum_nut	tan	1	

Table 4: Gears to print

Note, gear 4 and gear 7 can be selected to provide runtimes of either 1.6 days or 2.4 days. It is recommended to start with the 1.6 day option, especially if this is your first clock. This will be the most reliable option with the best chance of success. It releases one ball every 20.14 minutes to provide a runtime of 30 hours with 100 balls or 38 hours with 125 balls. After getting the clock running reliably, you can print the gear 4 and gear 7 options with the 2.4 day runtime. It releases one ball every 29.88 minutes for a runtime of 45 hours with 100 balls or 57 hours with 125 balls.

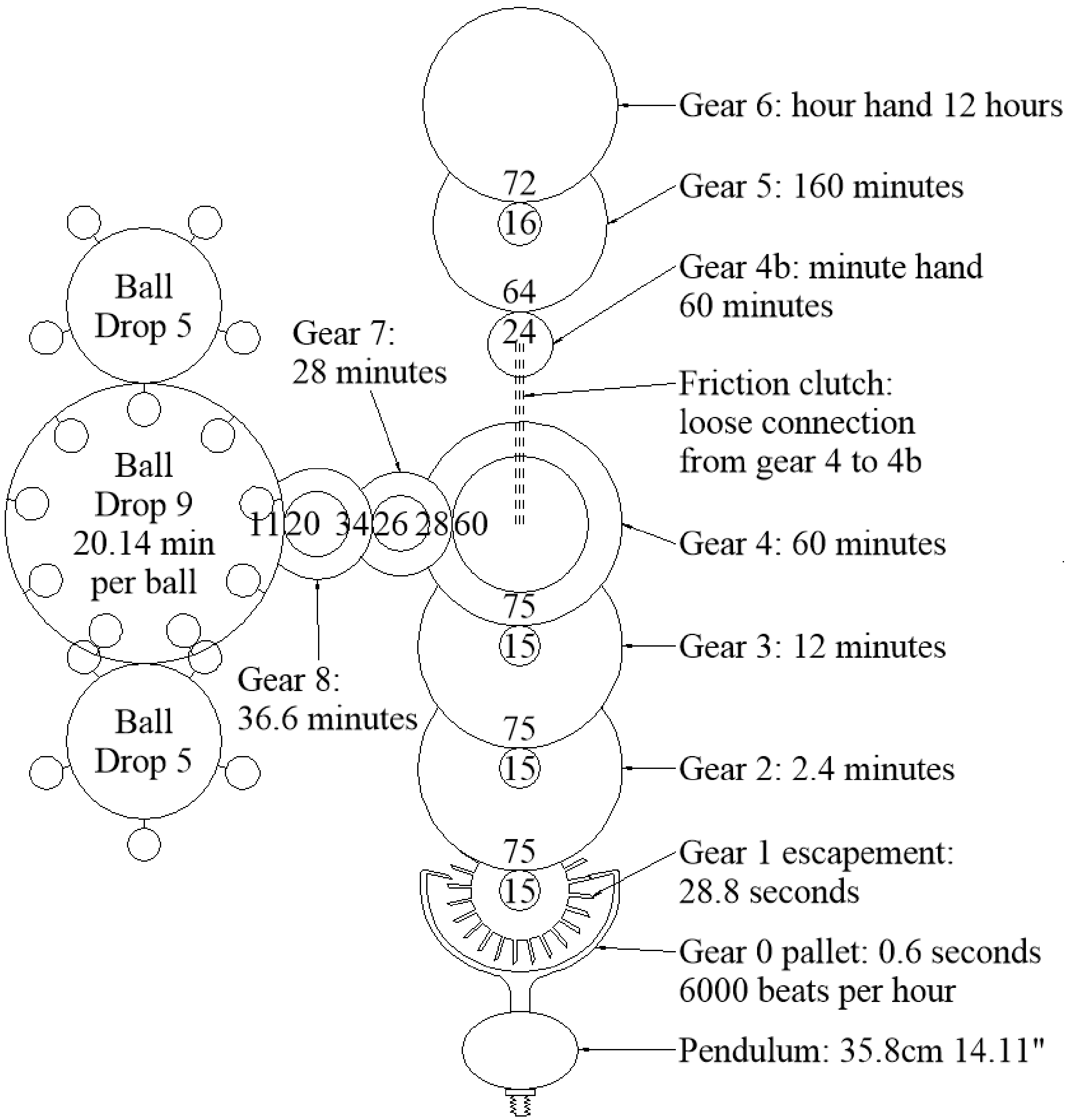
Here is a gear reference chart. Most are easy to identify by counting the teeth. For example, gear5_64_16 has 64 teeth in the primary gear and a 16 tooth pinion. It gets mounted on the gear 5 arbor. Gear 2 and gear 3 look very similar. They can be distinguished by the height of the center shaft. Gear 2 is slightly taller. The two spacers fit over the gear 0 and gear 8 arbors. Gear4 and gear 7 have two different runtime options. Select the same runtime option for both.



This diagram shows the gear tooth counts used in the clock. The 14.11” pendulum beats 6000 times per hour. The line of gears between the escapement and gear 4 are selected so gear 4 rotates once every 60 minutes. A friction clutch loosely connects gear 4b to gear 4 to rotate once per hour while the clock is running. Gear 4b is allowed to slip when setting the time. A 12:1 ratio from gear 4b to gear 6 moves the hour hand every 12 hours.

Gears 7 and 8 connect the ball drop to gear 4. If gear 4 rotates once every 60 minutes, one ball will drop every 20.14 minutes. Each ball pocket in the ball drop has 11 teeth, so ball_drop5 will have 55 teeth and ball_drop9 will have 99 teeth. Ball_drop9 is the largest gear I have ever used in any of my clocks.

The diagram below shows the 1.6 day runtime option.



Component Pre-Assembly

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

You will need:

- 3D printed ball tracks
- 3D printed frame parts
- 3D printed gears
- Pennies or small weights for the pendulum bob
- Screws and bearings from the bill of materials list on page 10
- Phillips head screwdriver with a 5” (12.5cm) reach for some of the screws
- 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

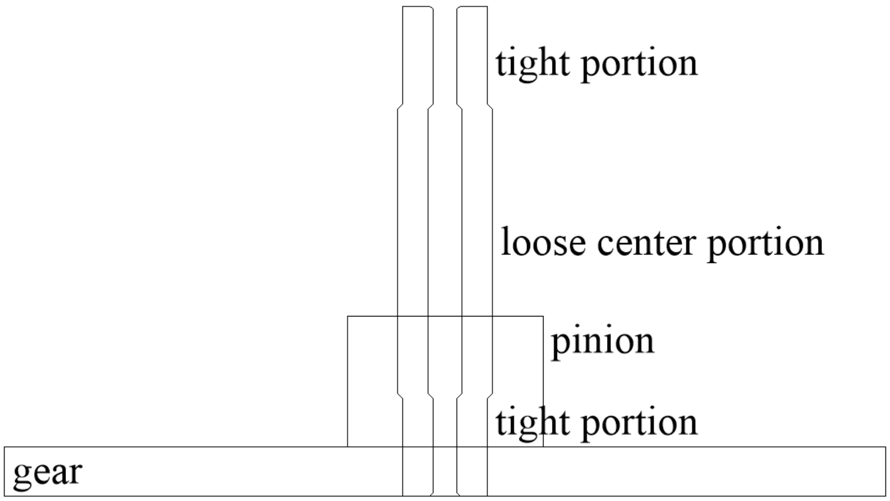
Optional tools:

- Sandpaper or small hand files
- Deburring tool

Component Pre-fit

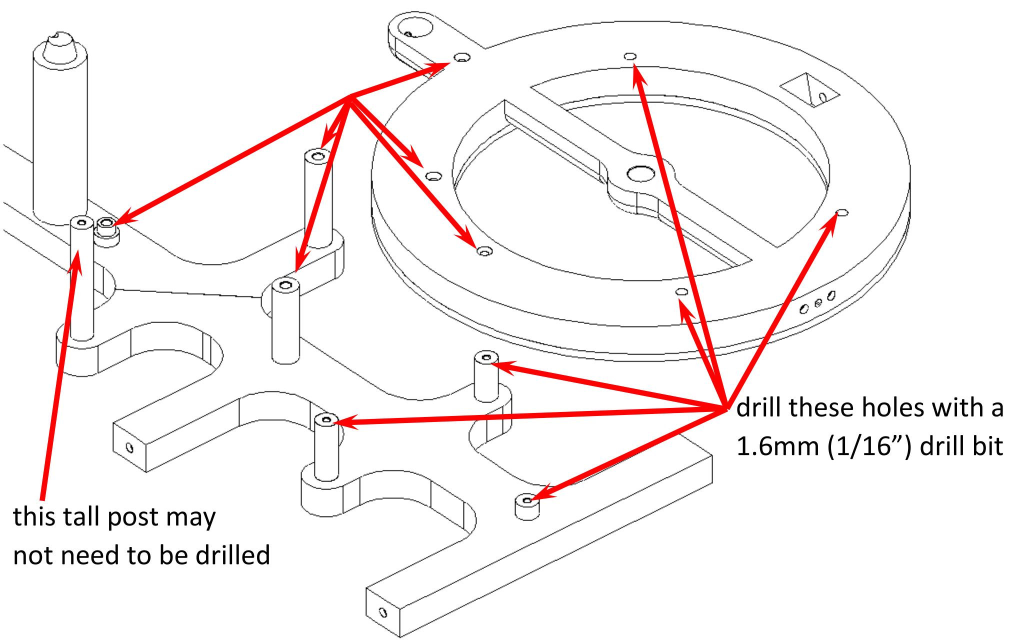
The most important step in reducing friction is to dry-fit the components and make adjustments as needed. The first step is to drill the arbor holes to the proper sizes. 3D printers often make holes smaller than expected. The easiest solution is to ream them to the proper fit. I use small pin vises to manually drill through the center of each gear. A power drill will also work, but go slowly to avoid melting the part.

Drill the ends of every gear to the proper size. The gears are designed so only a short portion at 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.

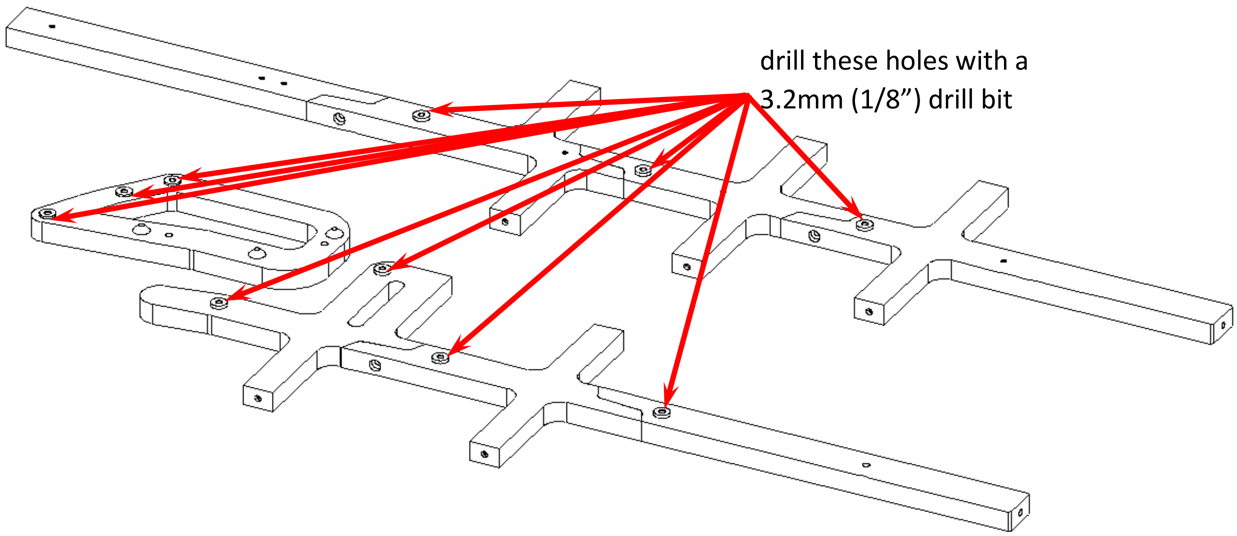


Drill both ends and blow through the hole to clean out the swarf. Test each gear by spinning it on an arbor. Gears with properly sized holes should spin for around 10 seconds. If it slows quickly, then drill it again. It should be obvious when the hole has enough clearance for the gears to spin freely.

The holes in the frame also need to be drilled out so the arbors spin freely. The holes use a combination of 1.5mm and 3mm sizes. The gear 5 arbor post is enlarged to reduce the need to drill all the way to the bottom with a 1.6mm drill bit.



These holes in frame_A and frame_B also need to be drilled out using a 1/8” or 3.2mm drill bit.



Notes on Friction

It is worth stating how important it is to reduce friction in a mechanical clock. My wall clocks use pounds of drive weight falling 48” or more. This clock uses ounces of drive weight falling only 16”. Keeping friction low is extremely important. The escapement ticks 6000 times per hour. Each ball passing through the ball drop needs to provide enough energy for the escapement to tick 2000 times with the 1.6 day runtime option and 3000 times with the 2.4 day option. There is not much excess energy to waste on friction.

The pendulum is the fastest moving component in the clock. It rests on two small 623 bearings. I have not found a lower friction method of supporting the pendulum that is easier to assemble and readily available. However, the thick factory grease must be removed to keep friction low enough for the clock to operate. The trick is to buy bearings with rubber seals (623RS or 623-2RS) that are easily removeable. Bearings without seals are sometimes available, but hard to find, so just look for the rubber seals. Avoid bearings with metal shields (623ZZ).

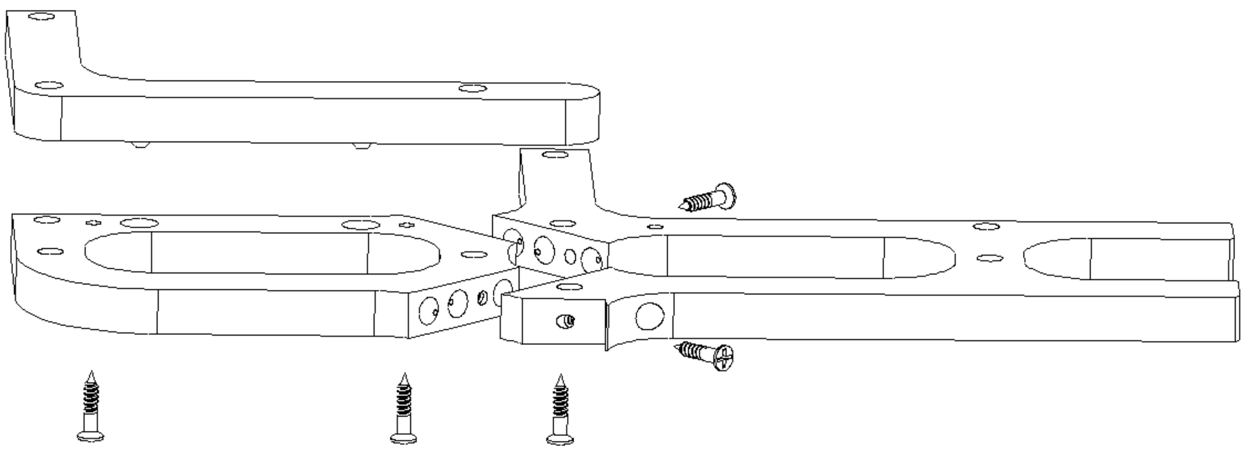
Remove the rubber seals using a needle or safety pin. Wash the grease using solvent (paint thinner, mineral spirits, acetone, 90%+ alcohol, etc.). 91% isopropyl alcohol used for cleaning the print bed usually works for removing the factory grease from the bearings. Let them soak overnight and brush out the grease or use a blast of compressed air, then let them soak again in fresh alcohol. Add a drop of dry PTFE (Teflon) lubrication or lightweight oil to minimize rust if desired. Do not add powdered graphite lubricant to the bearings.

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

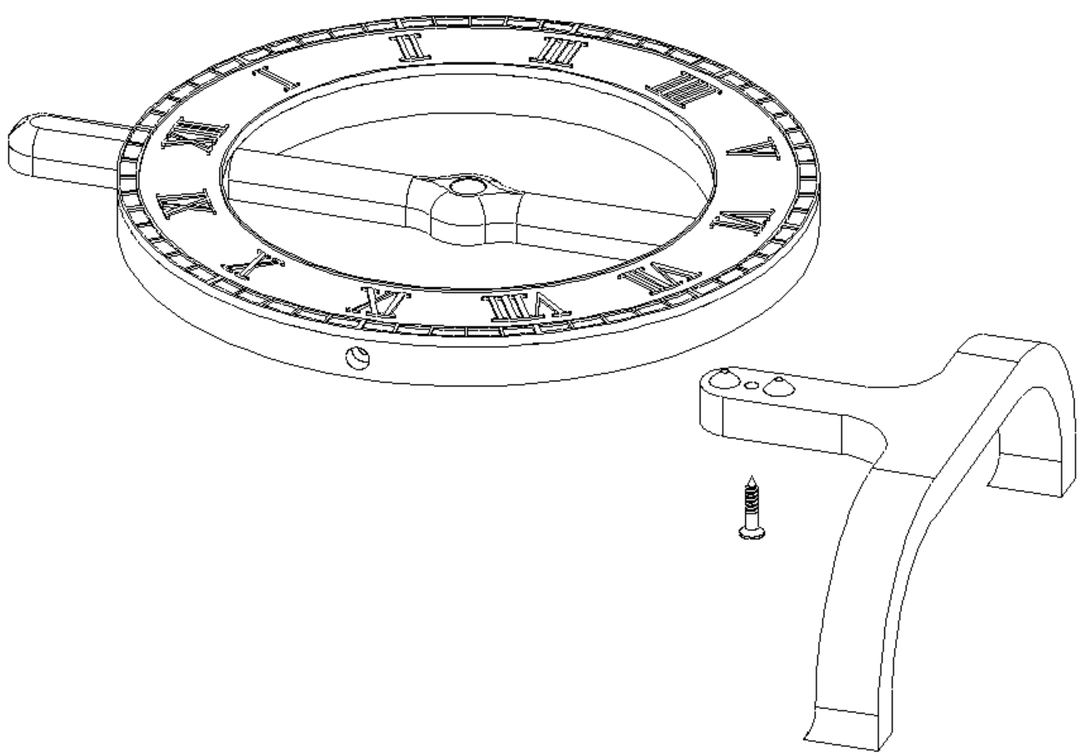
Pre-Assembly

Most of the frame segments go together as shown in the previous diagrams. Print all of the sub-components for one frame component and add #6x3/4" screws at each junction to match the diagrams. It helps to print all of one category and connect them before printing the next category. For example, print frame_a1, frame_a2, and frame_a3 first. Frame_a4 will be added later. Connect the first three frame_A components, then start printing the frame_B components.

Most frame components fit together as flat objects. Frame_F has three sub-components that stack together. Frame_f1 and frame_f2 connect using two screws. Frame_f3 fits on top connecting with three more screws.

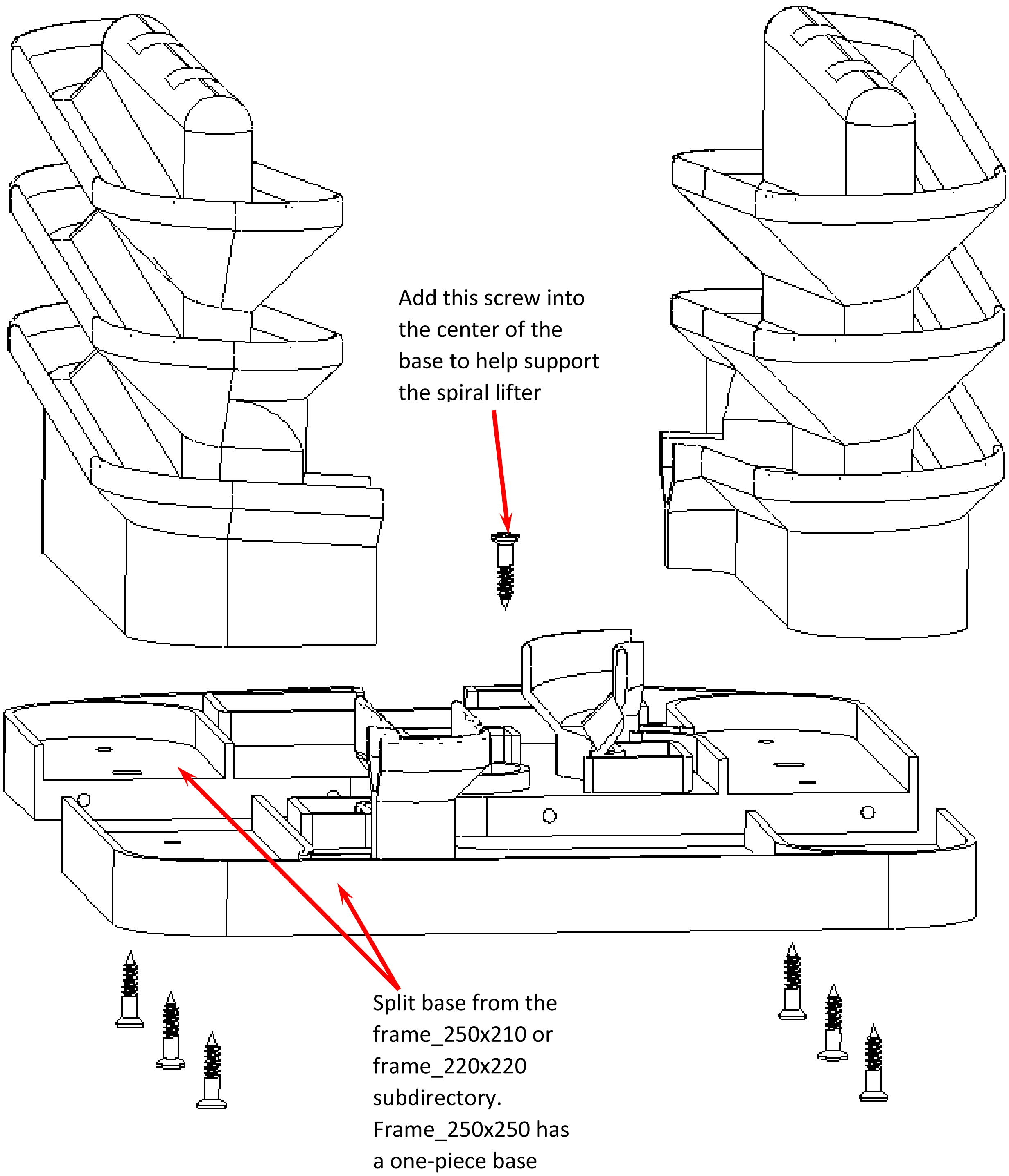


The dial is the only other non-flat frame component. Attach frame_h1 to frame_h2_dial_roman with one screw.

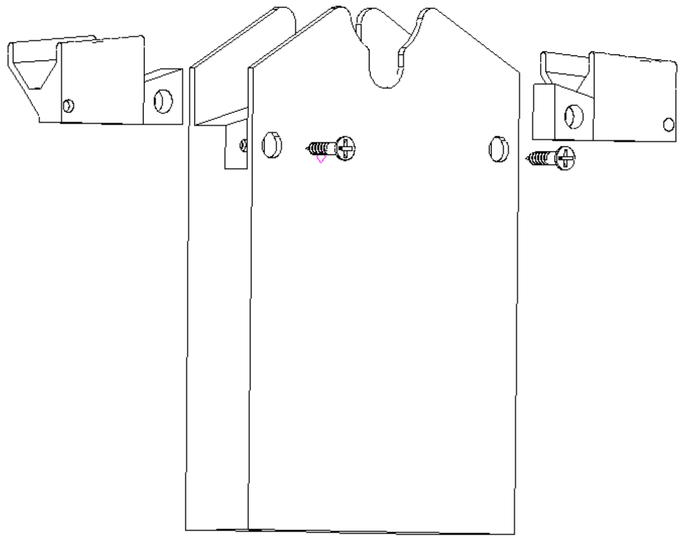


The lower ball tracks can be assembled into the base. Start by adding a #6x3/4" screw in the center of the base to support the post where the spiral lifter will be positioned later.

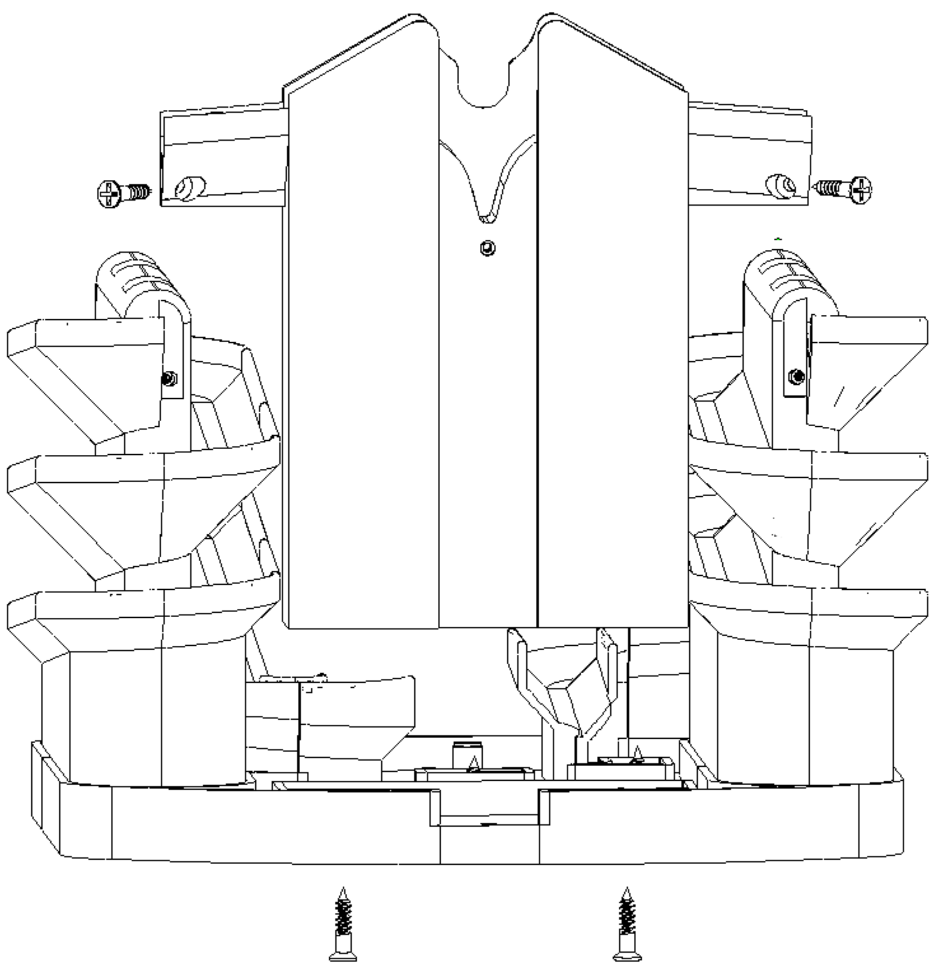
Attach the lower ball tracks using three screws on each side from the bottom. The split base for smaller printers is shown in the diagram. Connecting the ball tracks will join both base sections securely.



Attach the toggle bridges to the toggle body using two screws.



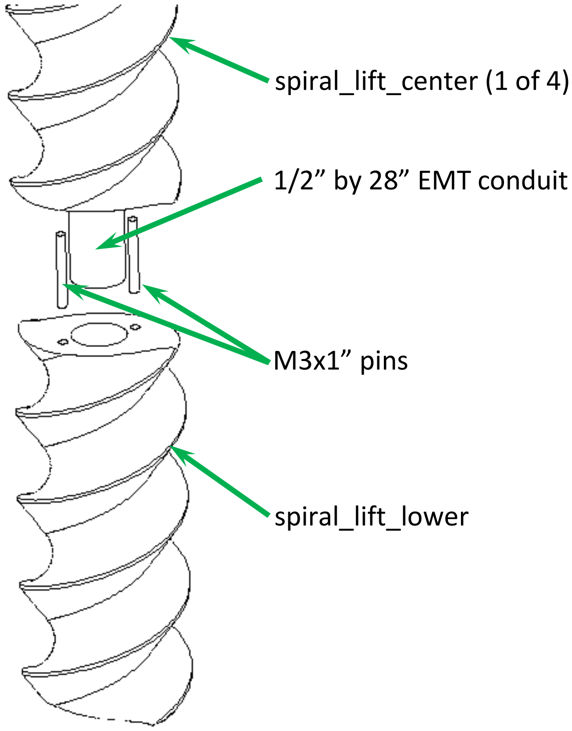
Add the toggle body into the base near the back using two screws on the bottom and two screws to connect the toggle bridges to the lower ball tracks. Below is the view from the back.

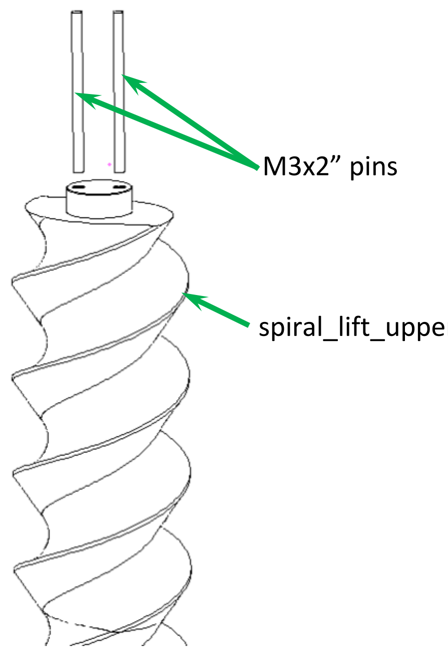


Assemble the spiral lifting auger from the bottom and work towards the top. Add two M3x1” pins into spiral_lift_lower. The holes may be tight, so they will need to be drilled out using a 1/8” or 3.2mm drill bit. Then add the 28” EMT conduit into spiral_lift_lower.

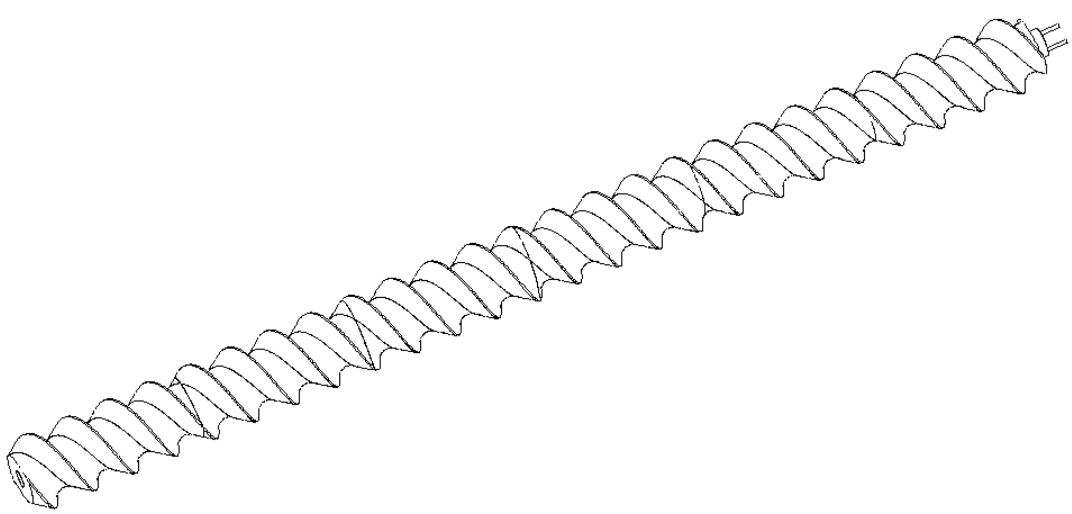
Repeat the process of adding M3x1” pins into the remaining segments and placing them over the EMT. Pay attention to the orientation so the segments are not upside down. Add four spiral_lift_center segments with two M3x1” pins at each junction segments followed by spiral_lift_upper.

The final step is to add two M3x2” pins on the top for the winding key. They should extend around 0.6” (15mm) above the top.

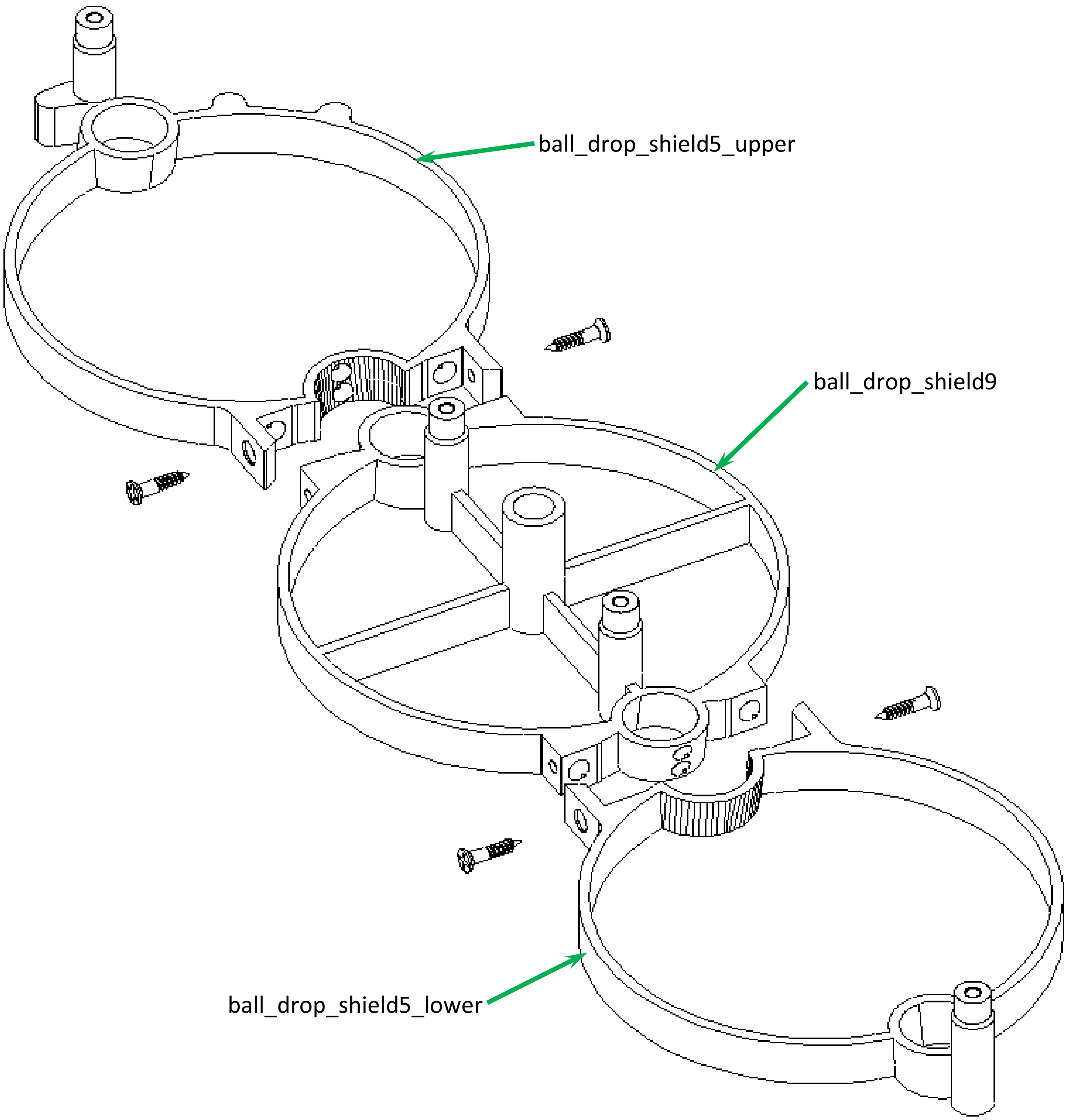




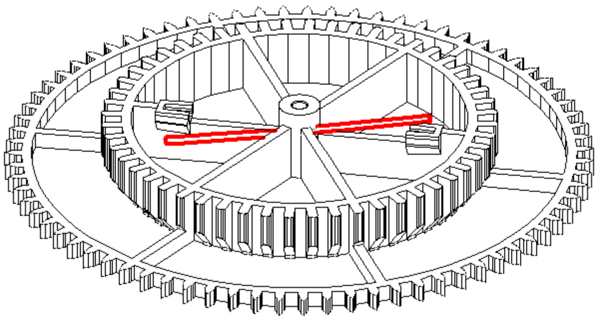
The completed spiral lift is almost as tall as the complete clock.

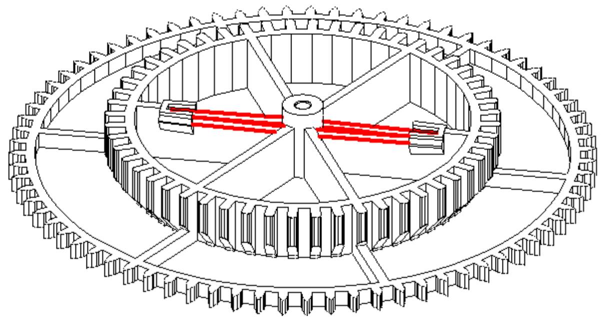


Connect ball_drop_shield5_upper, ball_drop_shield9, and ball_drop_shield5_lower using four screws as shown below. Ball_drop_shield9 is symmetrical so the other components can go on either end. The final assembly should sit flat on the table with the posts sticking up.

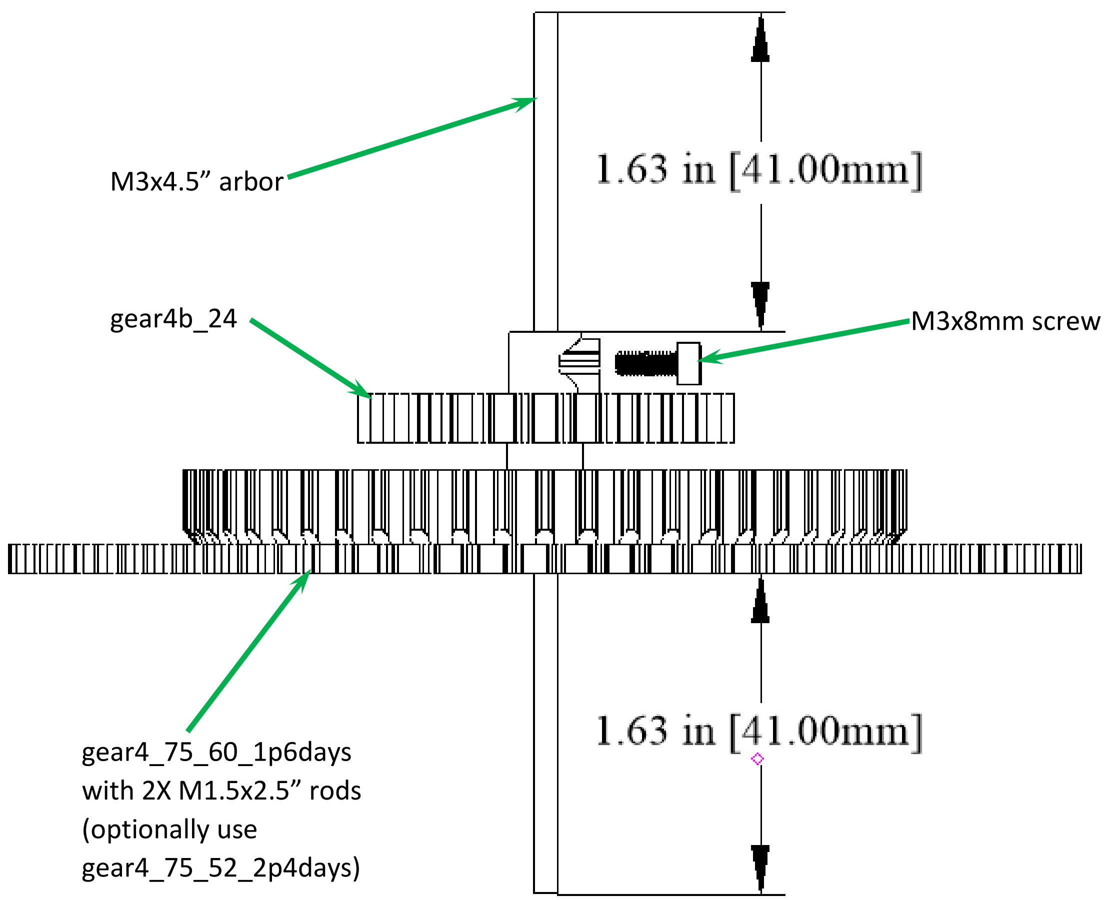


Gear 4 is the only gear needed some pre-assembly. Slide a piece of M1.5x2.5” music wire (red) into the holes in the gear4_75_60_1p6days or gear4_75_52_2.4days shaft. Clip it into the retaining hooks. Add a second piece of music wire so it looks like the image on the right. These will create a friction clutch to allow changing the time while the clock is running.



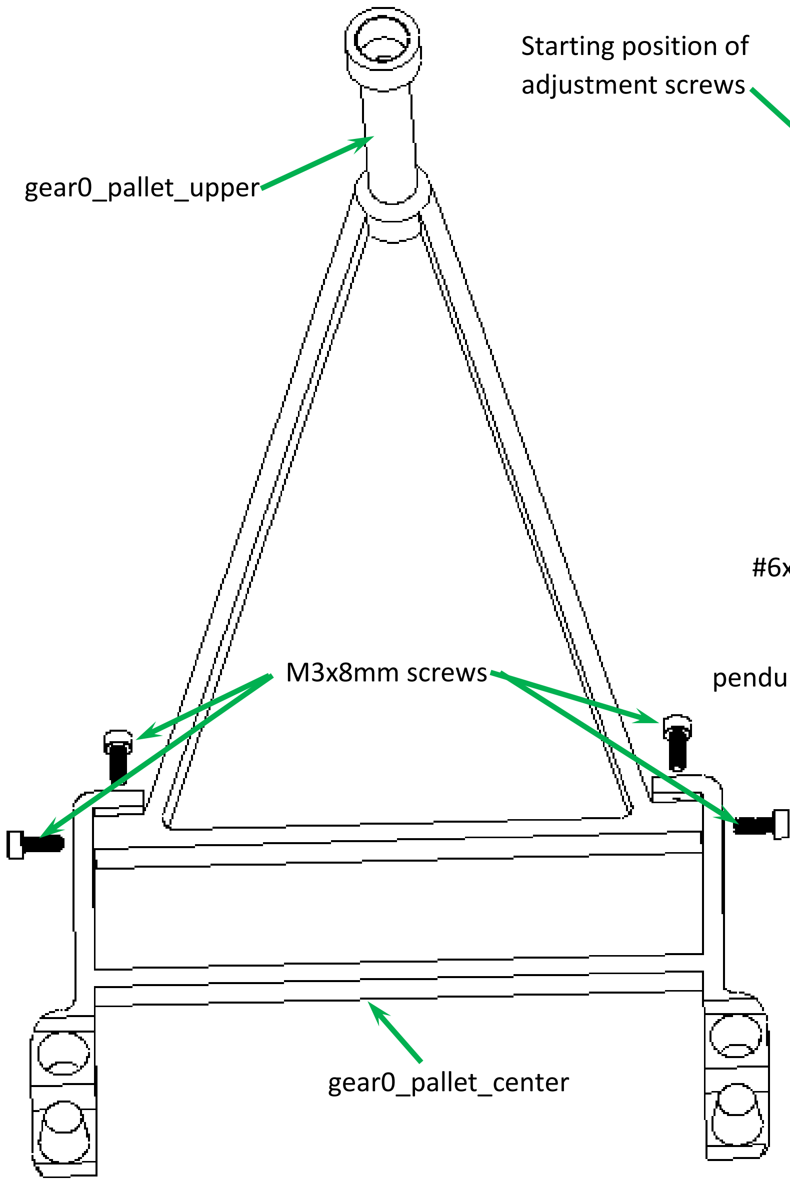


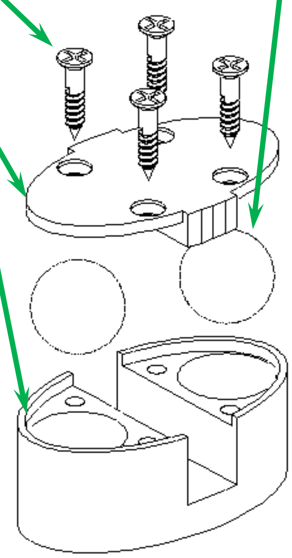
Add the gear4_75_60 assembly and gear4b_24 to the long M3x4.5” arbor. Secure gear4b_24 using an M3x8mm screw. The screw doesn’t need to be very tight. It only needs to be tight enough so the friction clutch slips before gear4b_24 slips on the arbor.



The upper and center pallet segments join together using four M3x8mm screws. The upper screws are used to adjust the pallet position. Start at the center of the adjustment range. The side screws hold the position and allow some side to side adjustment if the pallet is warped.

The pendulum bob has two pockets that can be filled with US pennies, washers, or two 3/4” steel balls. The total weight is not too critical. Mine weighs around 3 ounces (85g).



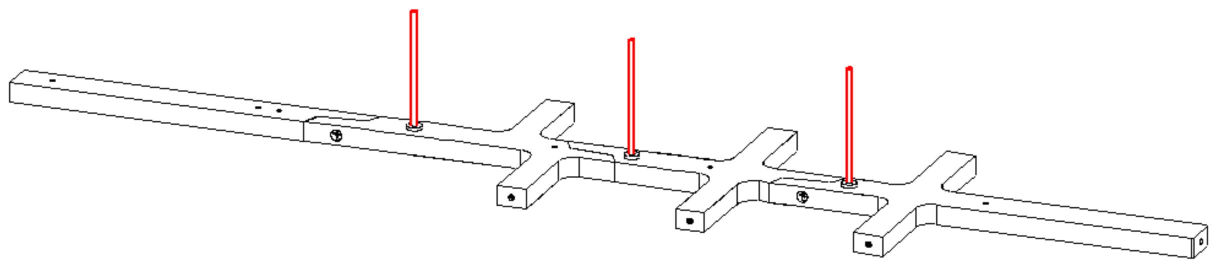


The pendulum bob can be placed over gear0_pallet_lower. Add the pendulum_nut to the threaded portion of the lower pallet arm. It will be adjusted later to set the rate of the clock. Start somewhere near the middle of the adjustment range.

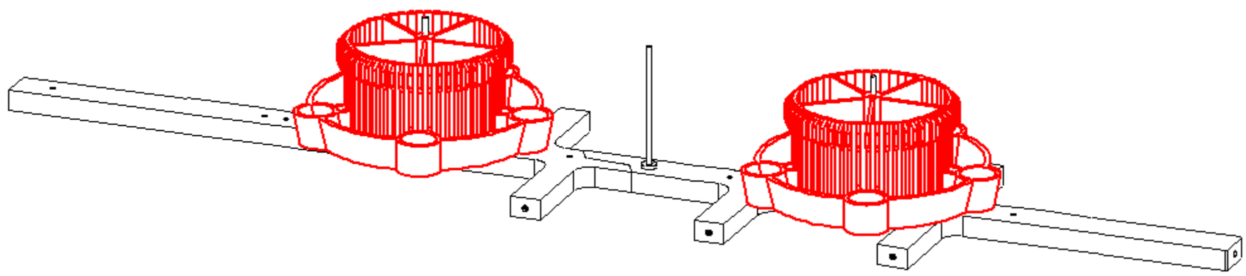
Assembling the Clock

We can now start assembling the clock. The base and eight frame modules should have already been assembled. The arbors have been cut to length. All of the pre-assembly steps have been completed. All of the gears spin freely on their arbors, etc.

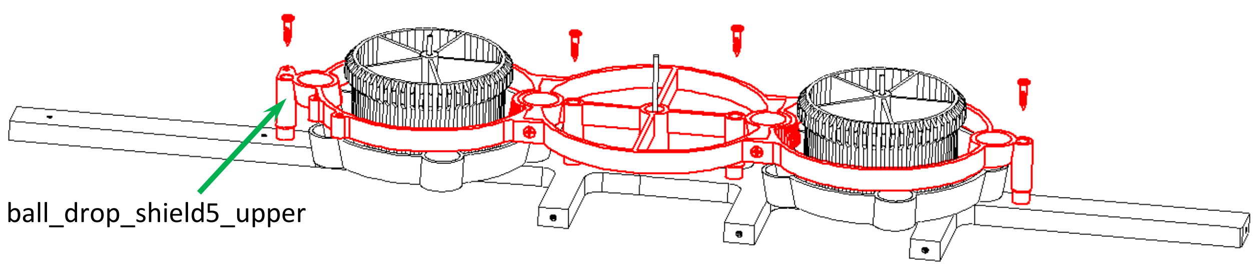
Start with frame_B flat on the table. Add three M3x3.35" arbors into the three raised holes.



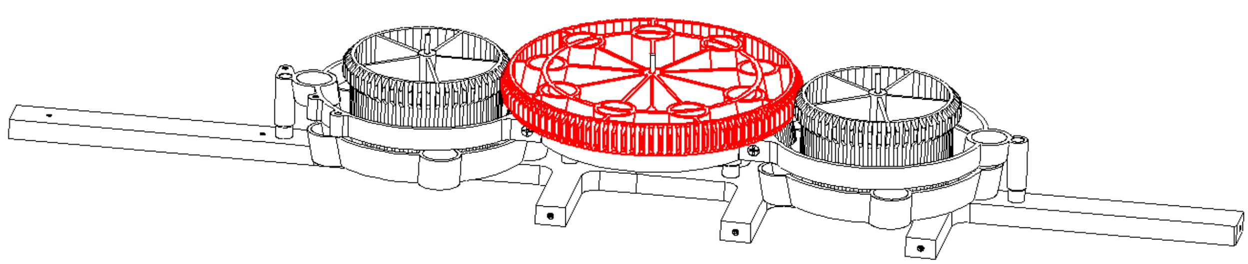
Add both copies of ball_drop5 to the upper and lower arbors.



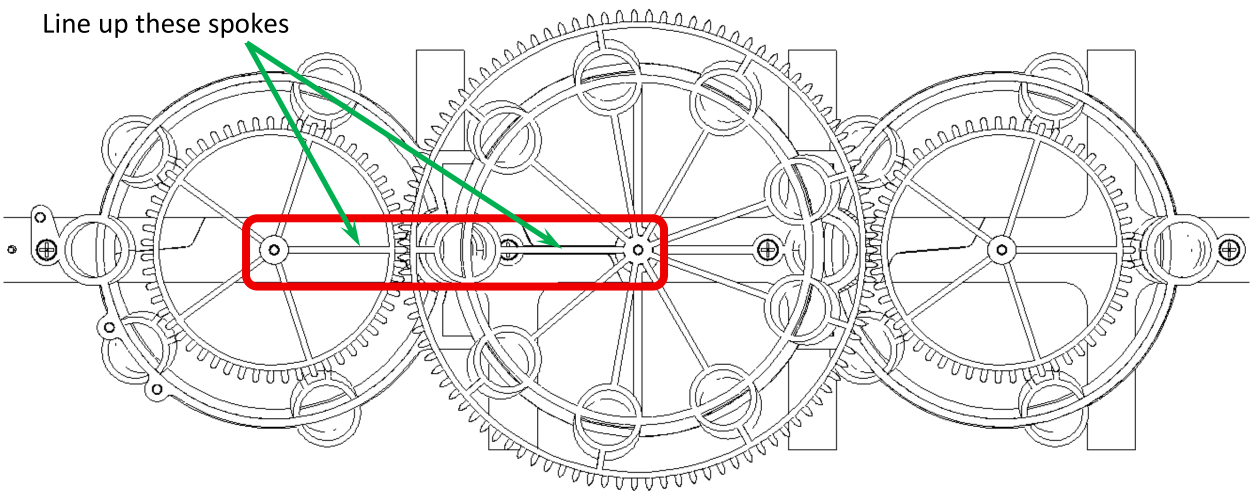
Add the previously assembled retainer over the ball drops. The arbor holes in ball_drop_shield5_upper should be positioned at the top (on the left in the image). Attach it using four screws.



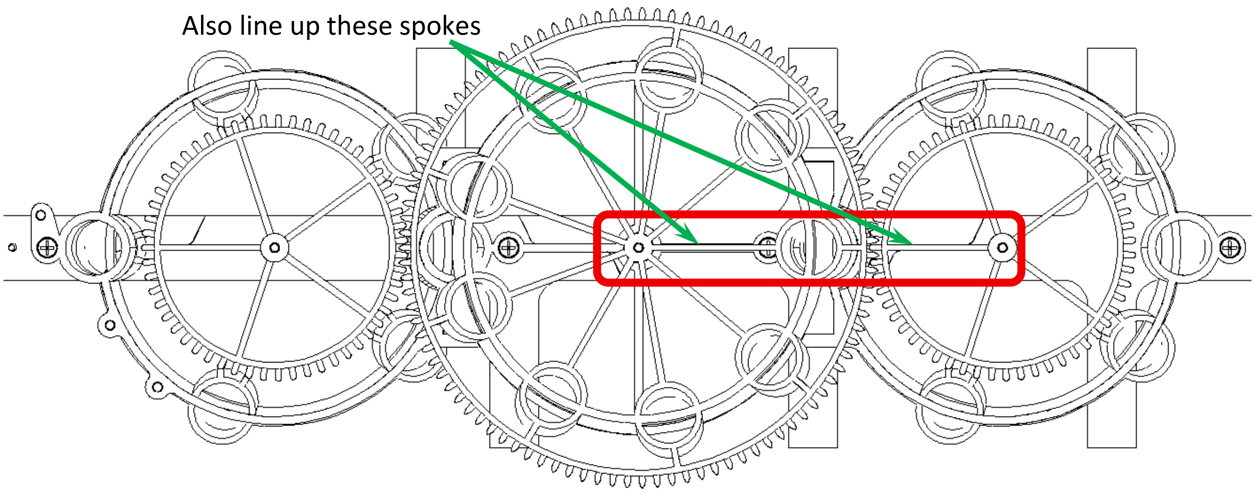
Add ball_drop9 to the center arbor.



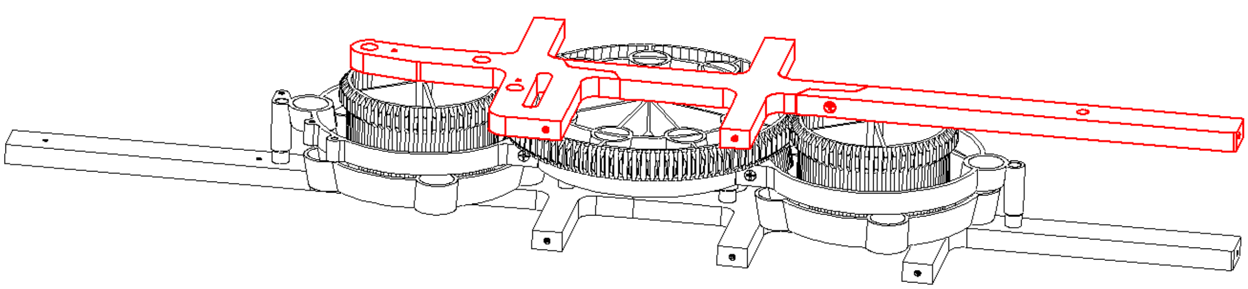
It is very important to synchronize the ball drops so the balls transfer properly. Position ball_drop9 so its spokes line up with the spokes in the upper ball_drop5. Lift ball_drop9 to adjust the spoke alignment if needed.



Rotate the gears and line up the lower spokes. Go back and check the upper spoke positions after adjusting the lower spokes.



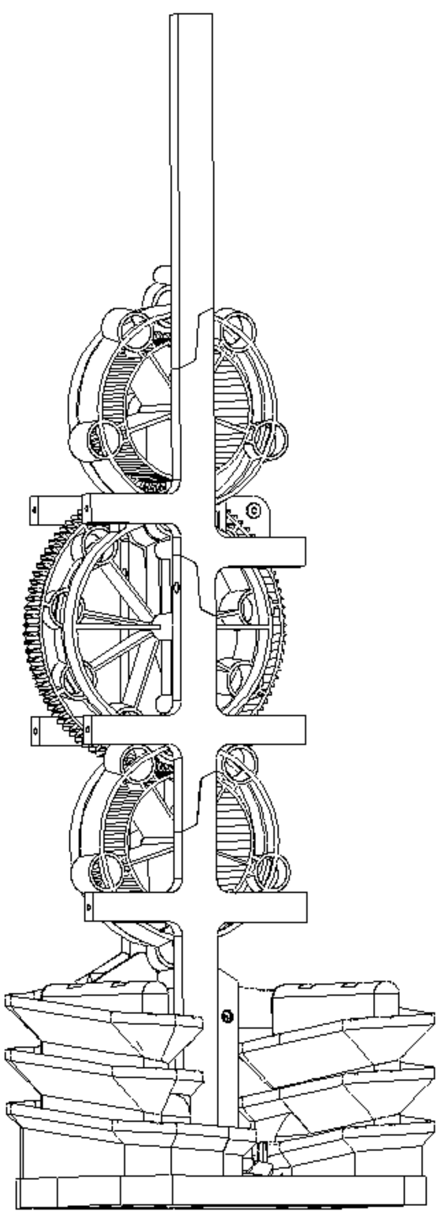
Finally, add lower portion of frame_A onto the three arbors. Frame_a4 will be added later.



The ball drop wheels should spin easily.

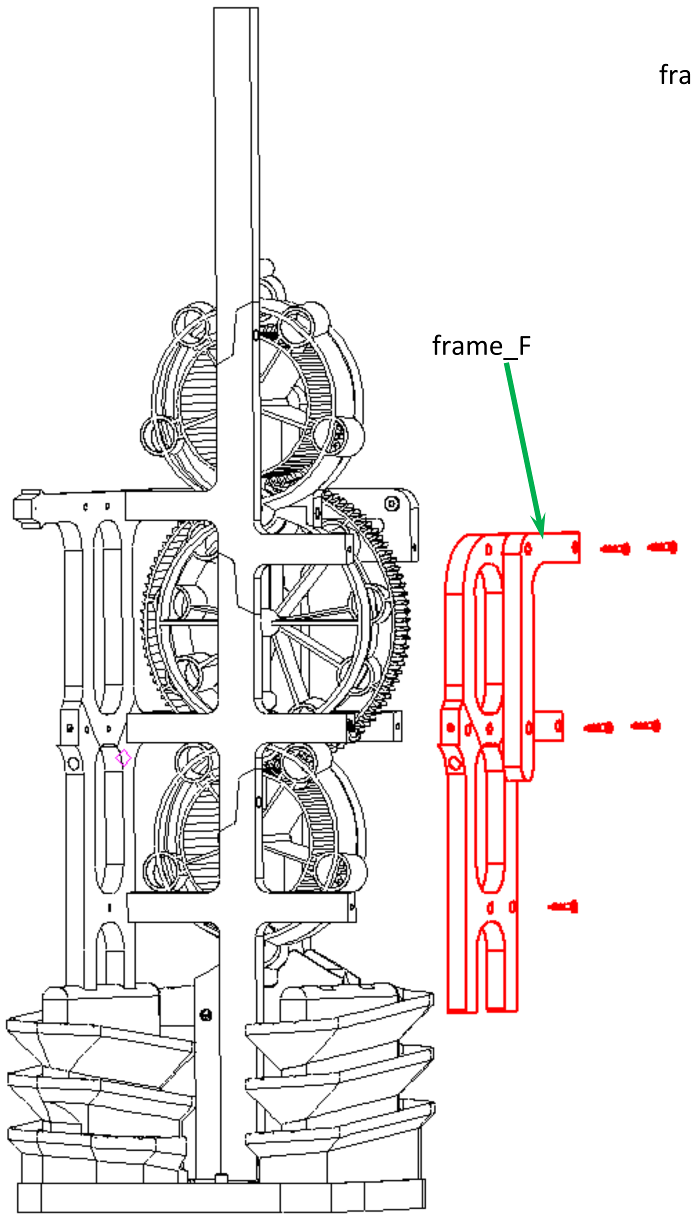
Set the completed ball drop module into the base at the “A” and “B” position. Secure frame_A to the toggle body using a #6x3/4” screw. Two additional screws below the base can be added later.

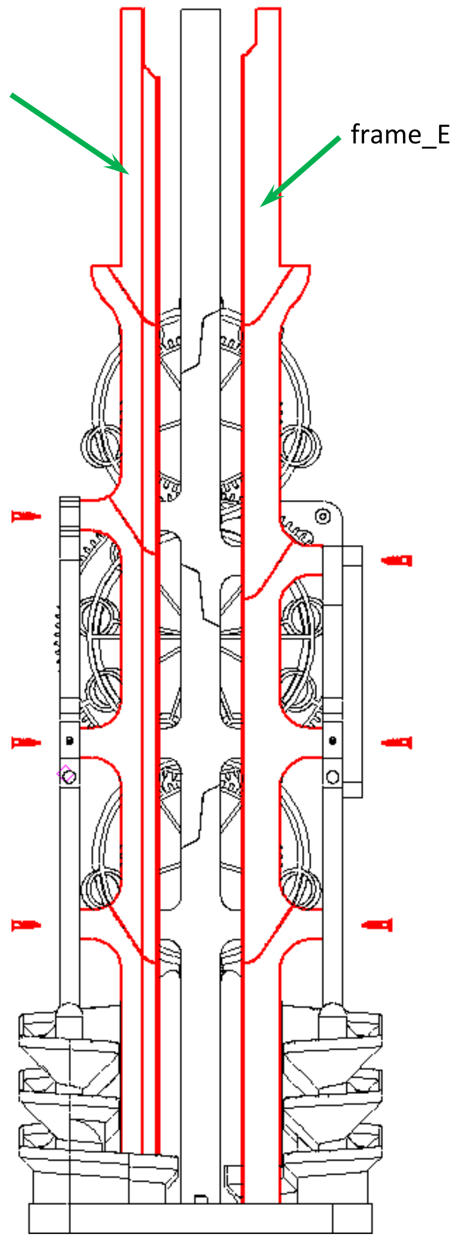
The second image on the right shows frame_C added to the left side of the clock. Insert the legs into the left ball ramp and connect everything using five screws. The bottom screws can be added later.



Frame_F goes on the right side as shown in the first image below. Insert the legs into the right ball ramp and add the five screws.

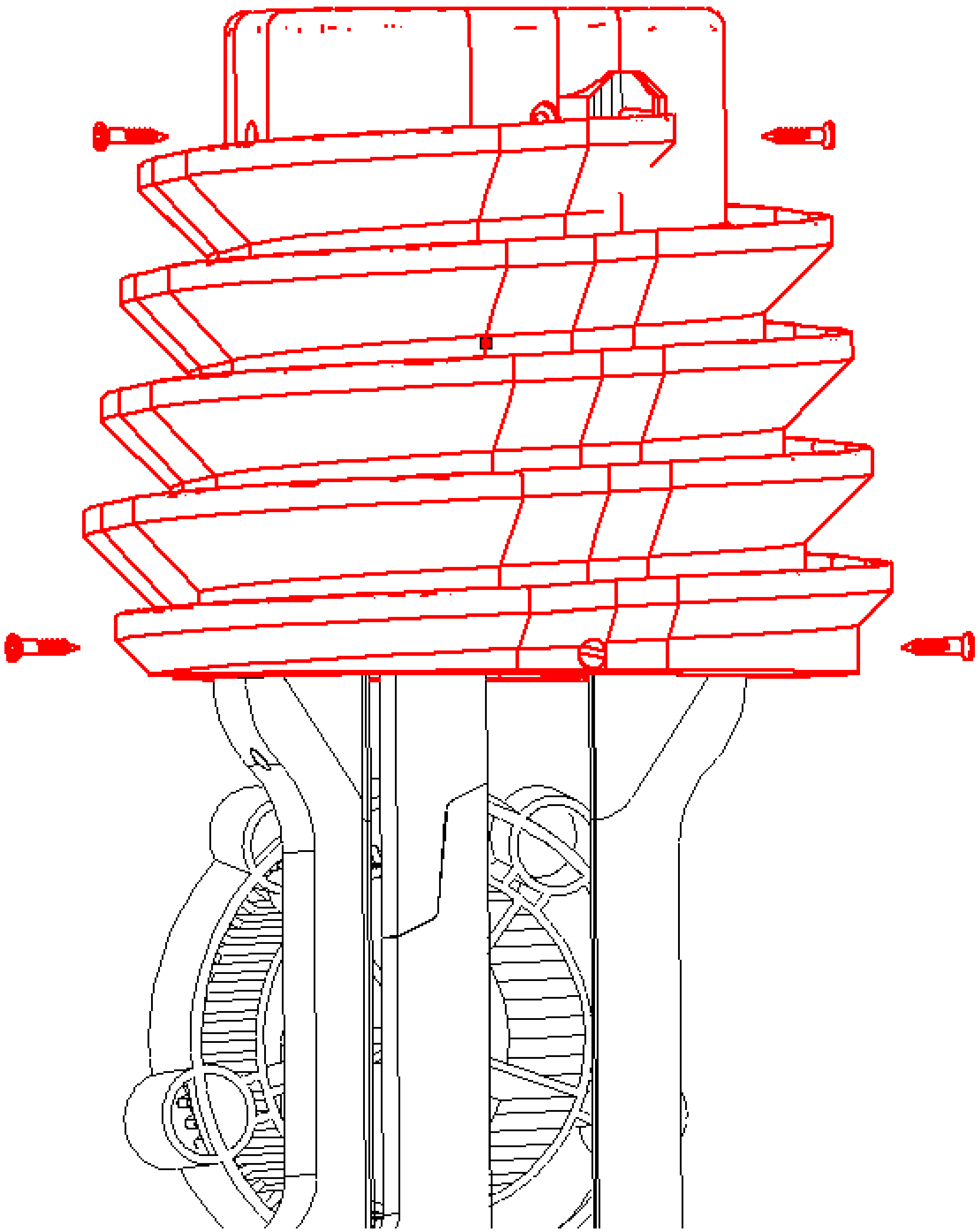
Add frame_D and frame_E to the center of the base as shown in the second image. Connect them with three screws on each side.



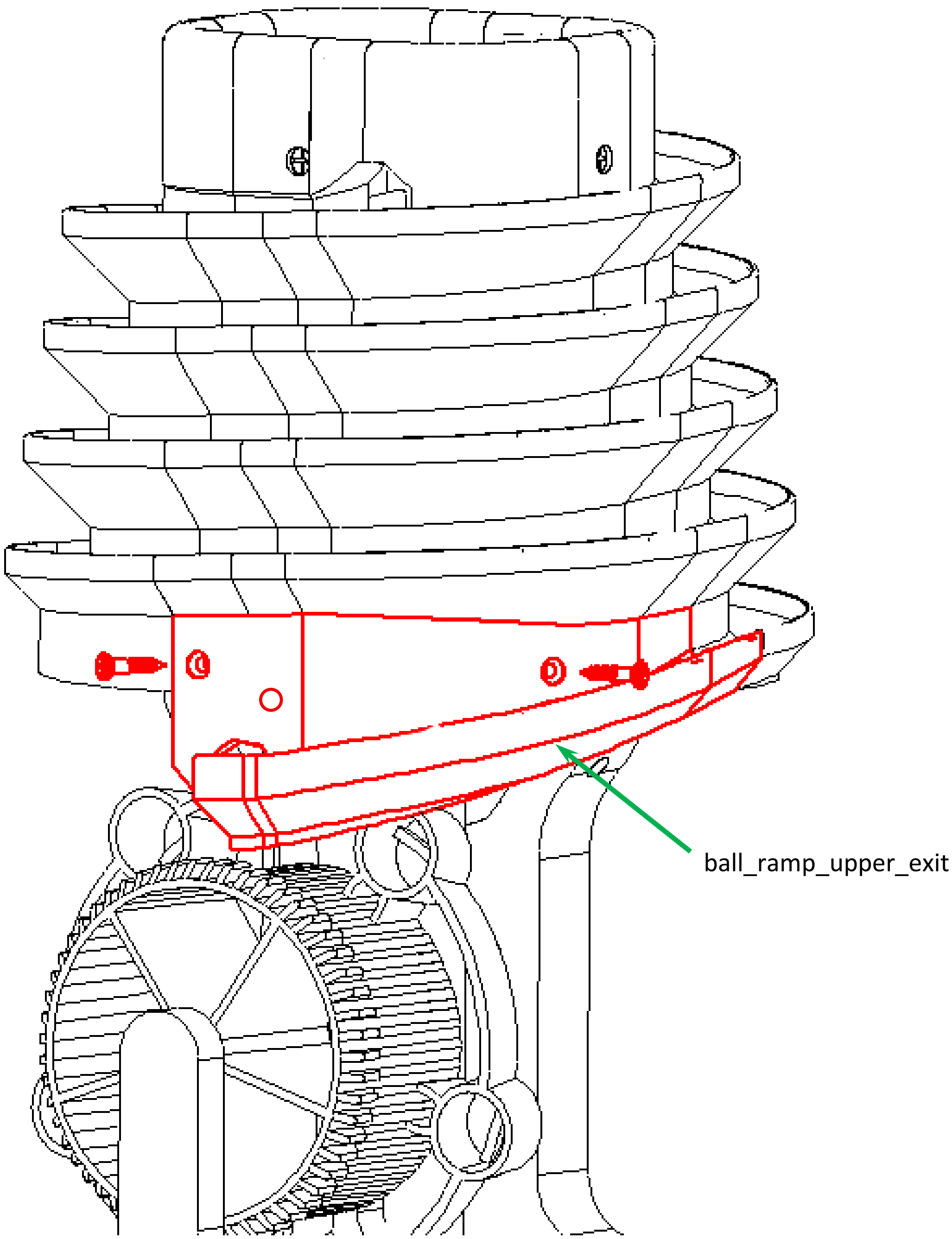


The frame scaffolding should be stable now. Lay the clock on its back and add the remaining screws under the base. The ball ramps and toggle gate should already have screws. There should be eight more locations to add screws including the deep screws for frame_C and frame_F.

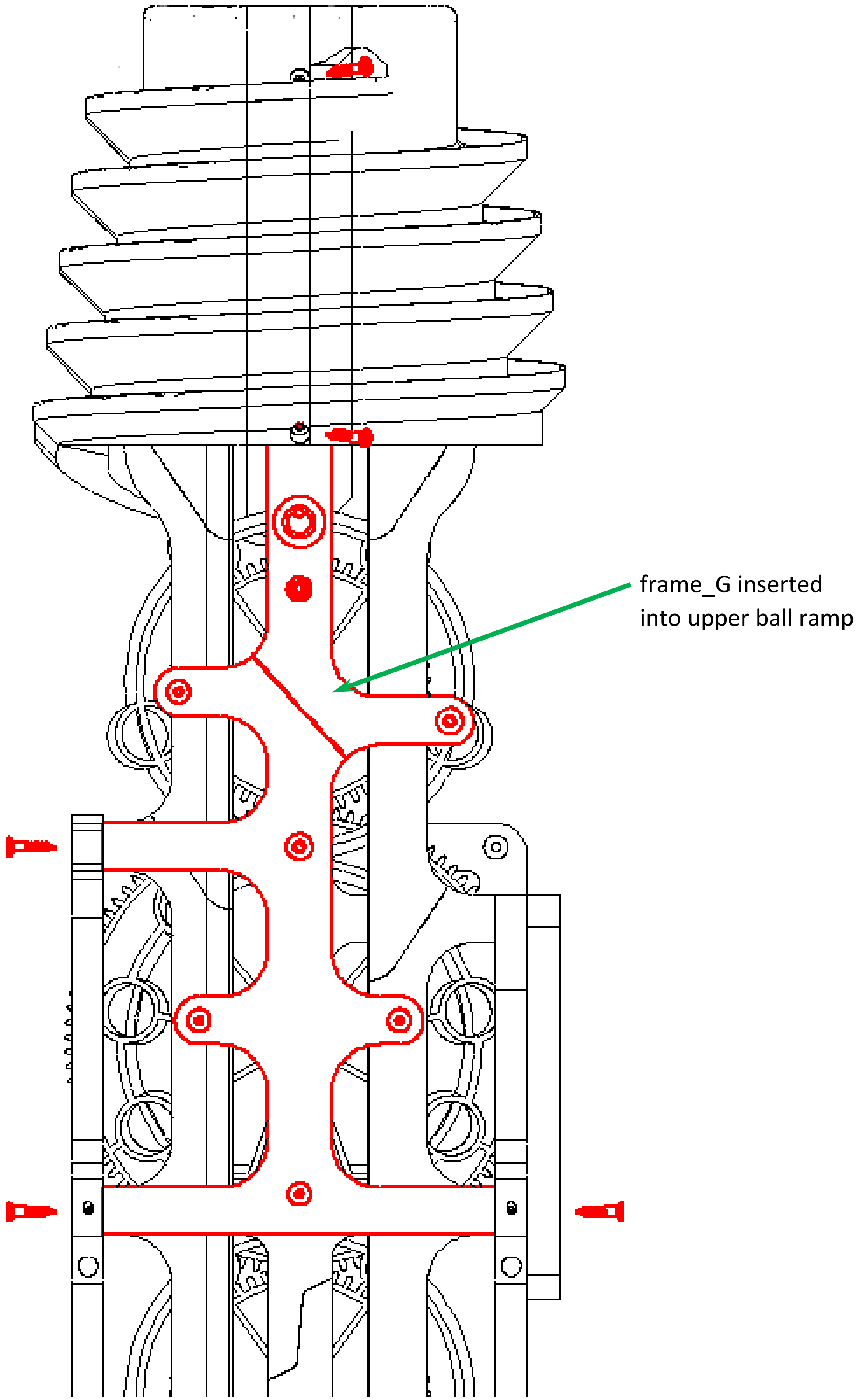
Add ball_ramp_upper to the top of the clock. It slides over the three upper frame posts. Position it so the lower exit ramp is on the left. It may need to be wiggled to drop into position. Secure it using six screws, two from each side and two in the back.



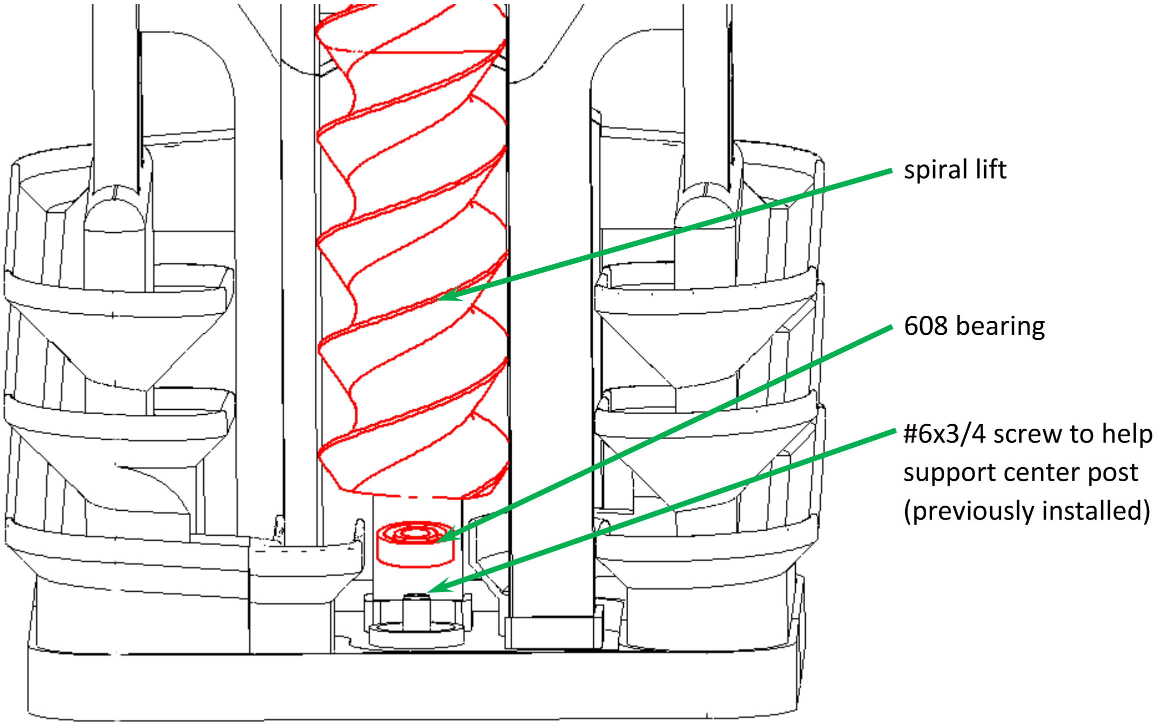
Add ball_ramp_upper_exit using two screws. Below is the view from the back left corner. Check that balls roll smoothly past the transitions. Sand or file any bumps if needed.



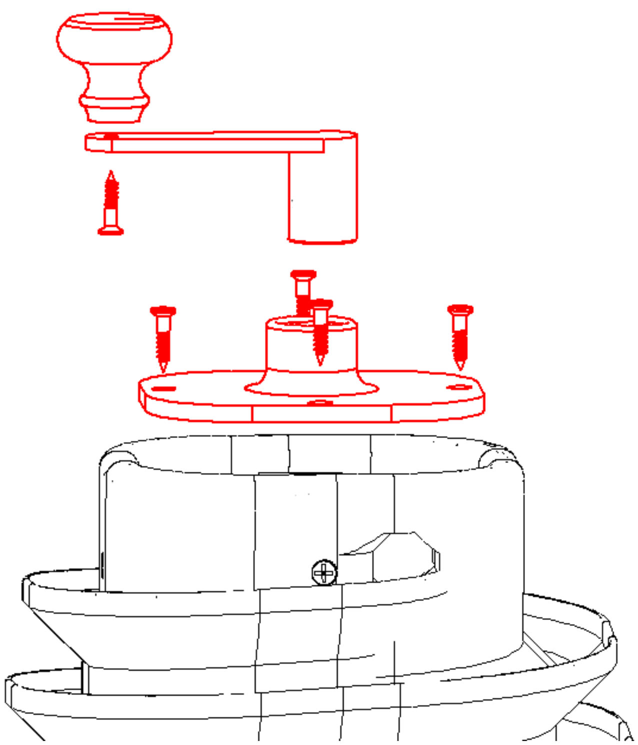
Slide frame_G into ball_ramp_upper. There are some alignment bumps used to help position frame_G inside the ball ramp. Secure it using two screws at the top and three screws from the sides.



Add the large 608 bearing onto the post in the center of the base and lower the spiral lifting auger onto the post. The center post should already have the strengthening screw added during pre-assembly.



Add ball_ramp_upper_cover to the top of the clock using four screws. Add the winding_key_knob to the winding_key_handle using another screw. The spiral lift should rotate easily on the lower 608 bearing.



Assembly of the frame and ball drops is now complete. Add the toggle_lever into the toggle_body. It will slide in from either side below the lower ball drop. Test the ball tracks by loading 2-3 balls into each lower ball ramp. Resist the urge to fill the ball ramps with balls until after the gears have been installed. They will fall through the ball drop too fast when running without the other gears in place.

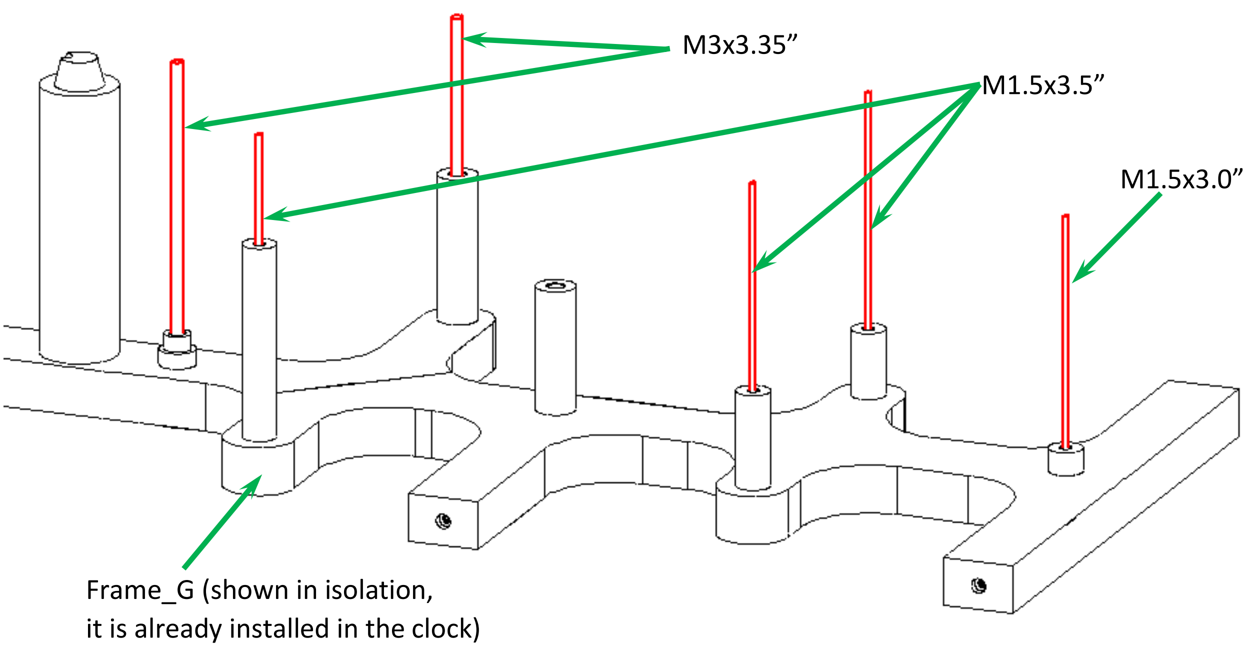
Crank the balls to the top. Balls should exit from each side of the upper ball ramp. Rotate the ball drops slowly to let the balls enter. Watch the balls work their way down the ball drop into the lower ball ramps. The toggle lever should alternate feeding balls to both sides of the lower ball ramps.

Adding Gears

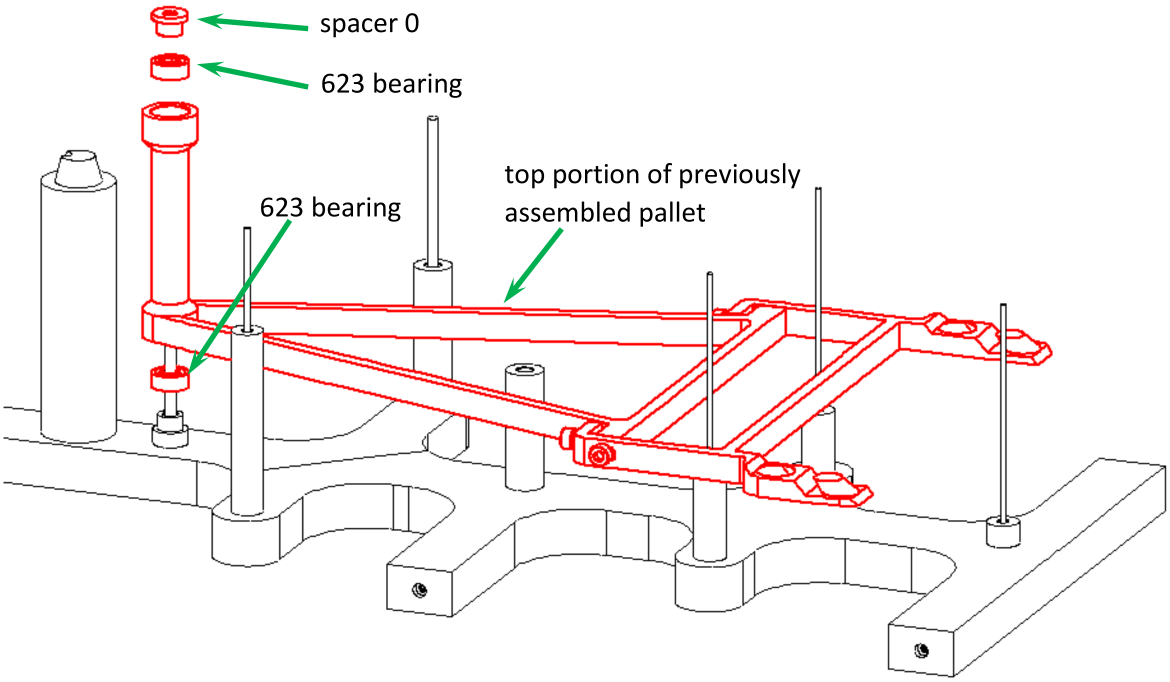
The clock gears can be added with the frame standing up or laid on its back. I will show assembly with the clock on its back. Frame_G is shown is isolation, but it is actually installed in the clock. The rest of the clock is not shown to reduce clutter in these images.

Assembly starts with the lowest mounted components and progresses through the order of gear 0, 1, 2, 3, 4, 5, **7**, **8**, then **6**. Gears 6, 7, and 8 are highlighted because they get installed out of sequential order.

Start by adding M3x3.35” and M1.5x3.5” arbors in the highlighted locations. The center hole will have the gear4 arbor added later. The bottom position for the escapement gets the shorter M1.5x3” arbor.

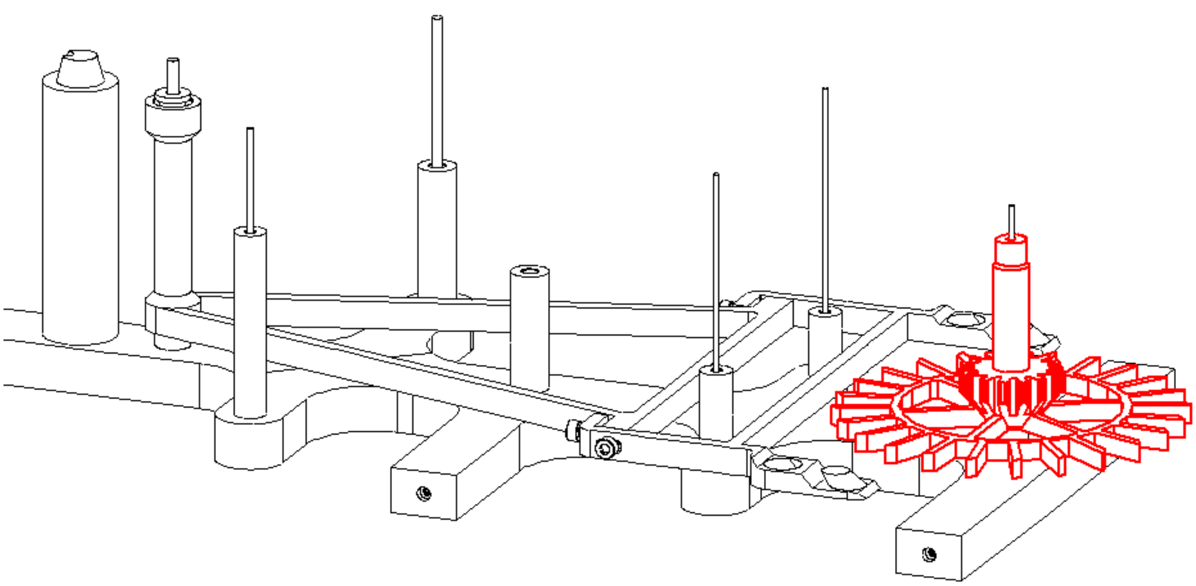


Add a 623 bearing, the upper portion of the pallet (previously assembled), another 623 bearing, and spacer_0 to the upper M3x3.35” arbor. Sand or file the ends of the M3x3.35” arbor if the bearings do not fit. To do this, I usually put the arbor in a power drill and pinch a piece of sandpaper around the shaft. Only the ends of this arbor need to be reduced in diameter. All other arbors can tolerate slightly larger diameter rods.

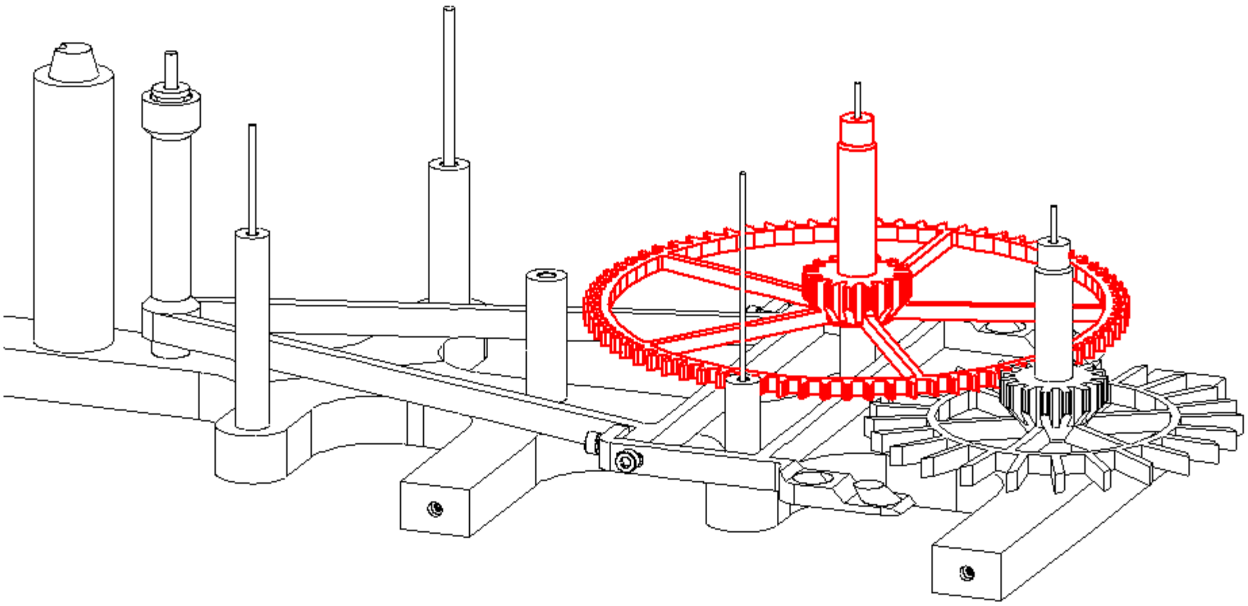


It would be a good idea to perform the pendulum free swing test before adding the escapement into the clock. See the debug portion of this assembly guide on page 50 for instructions.

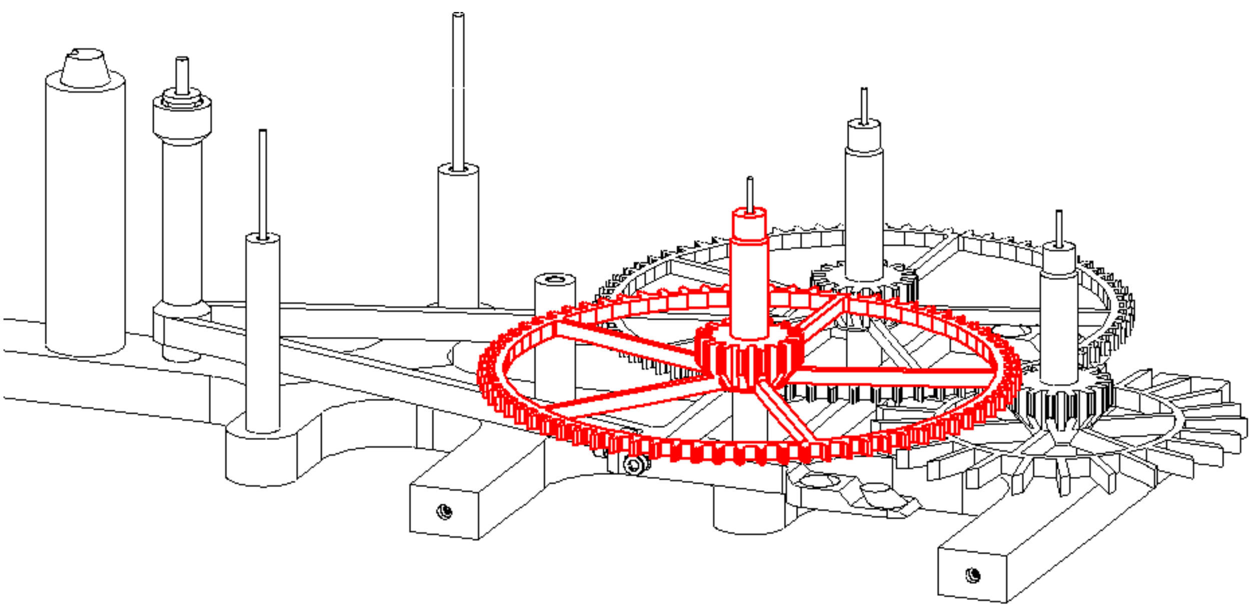
Continue with clock assembly after running the pendulum free swing test. Add the escapement gear1_24_15_esc to the lower arbor.



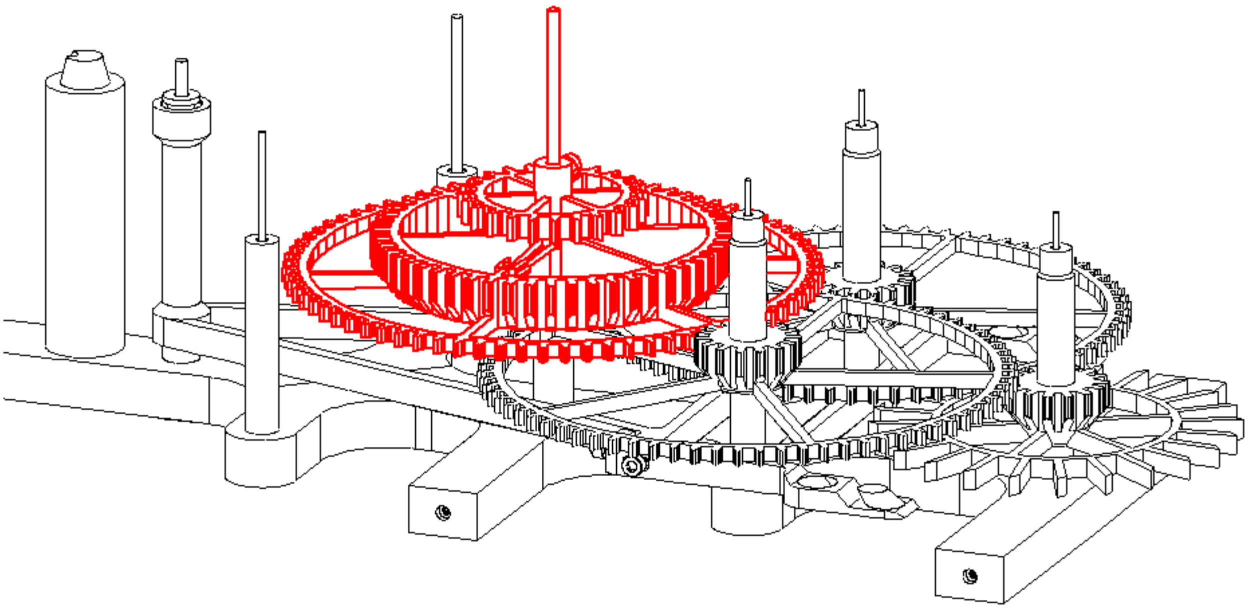
Add gear2_75_15 to the lower right arbor position. Gear 2 is the taller of the two similar looking gears.



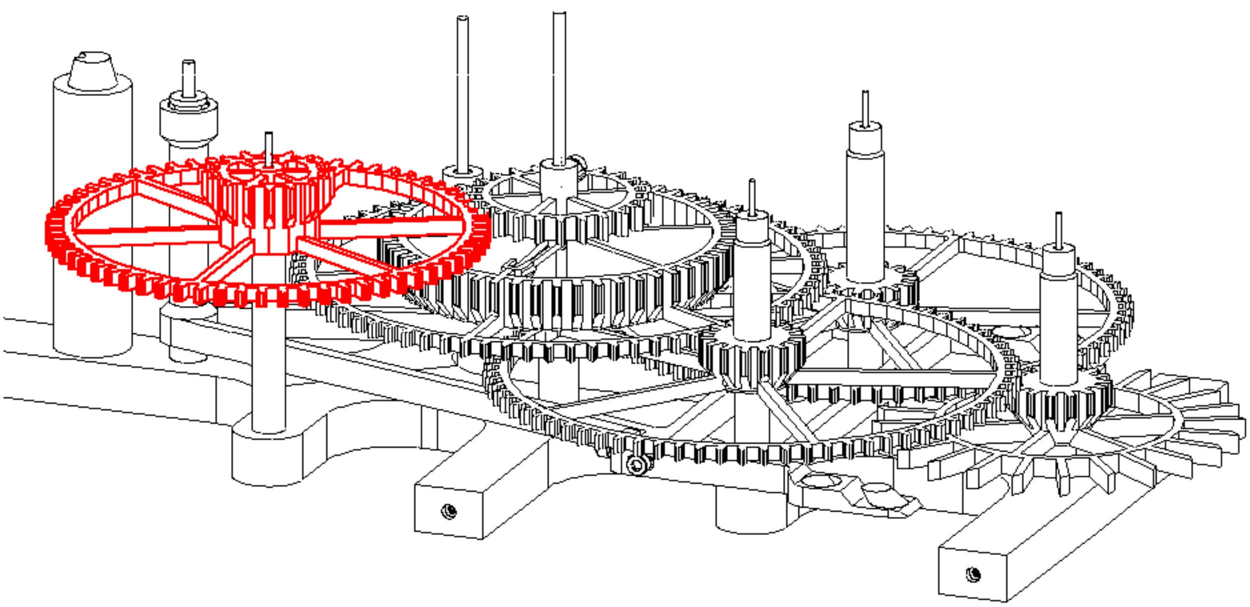
Add gear3_75_15 to the lower left arbor position.



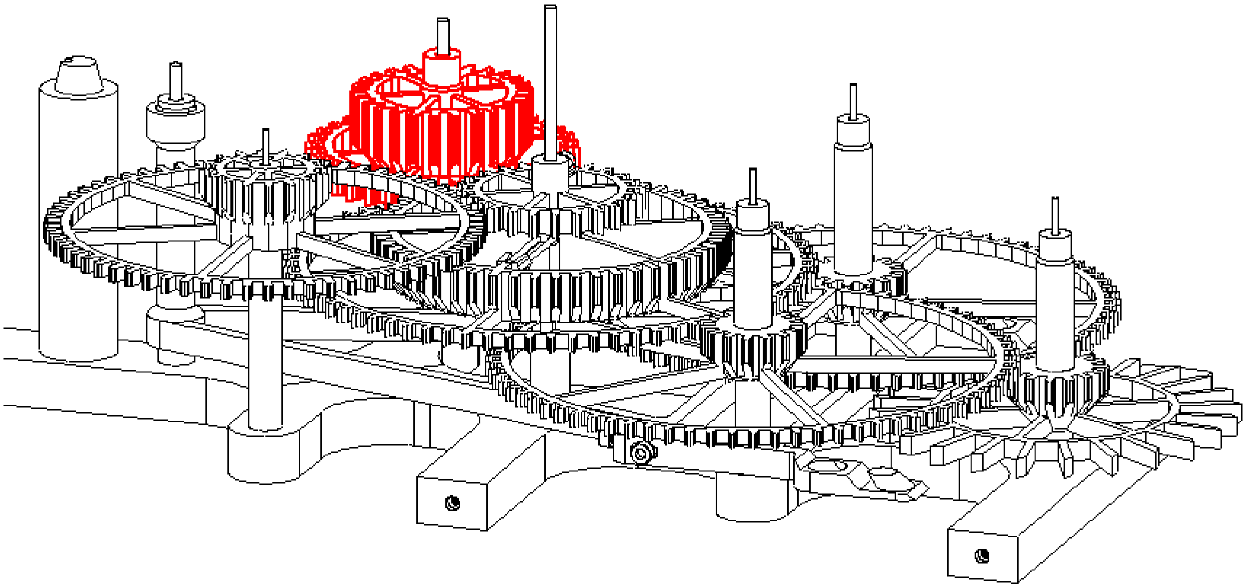
Add the previously constructed gear4 assembly to the center arbor location.



Add gear5_64_16 to the upper left arbor position.

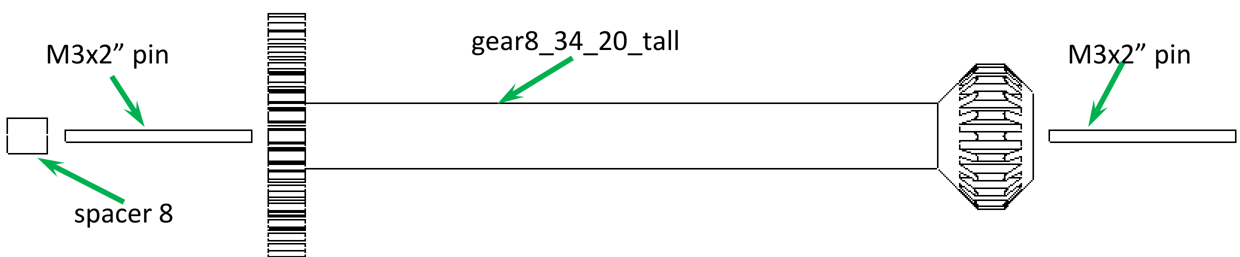


Add gear7_28_26_?p?days to the upper right arbor. Select the runtime option to match gear 4. If you use gear4_75_60_1p6days, it will only mesh properly with gear7_28_26_1p6days.



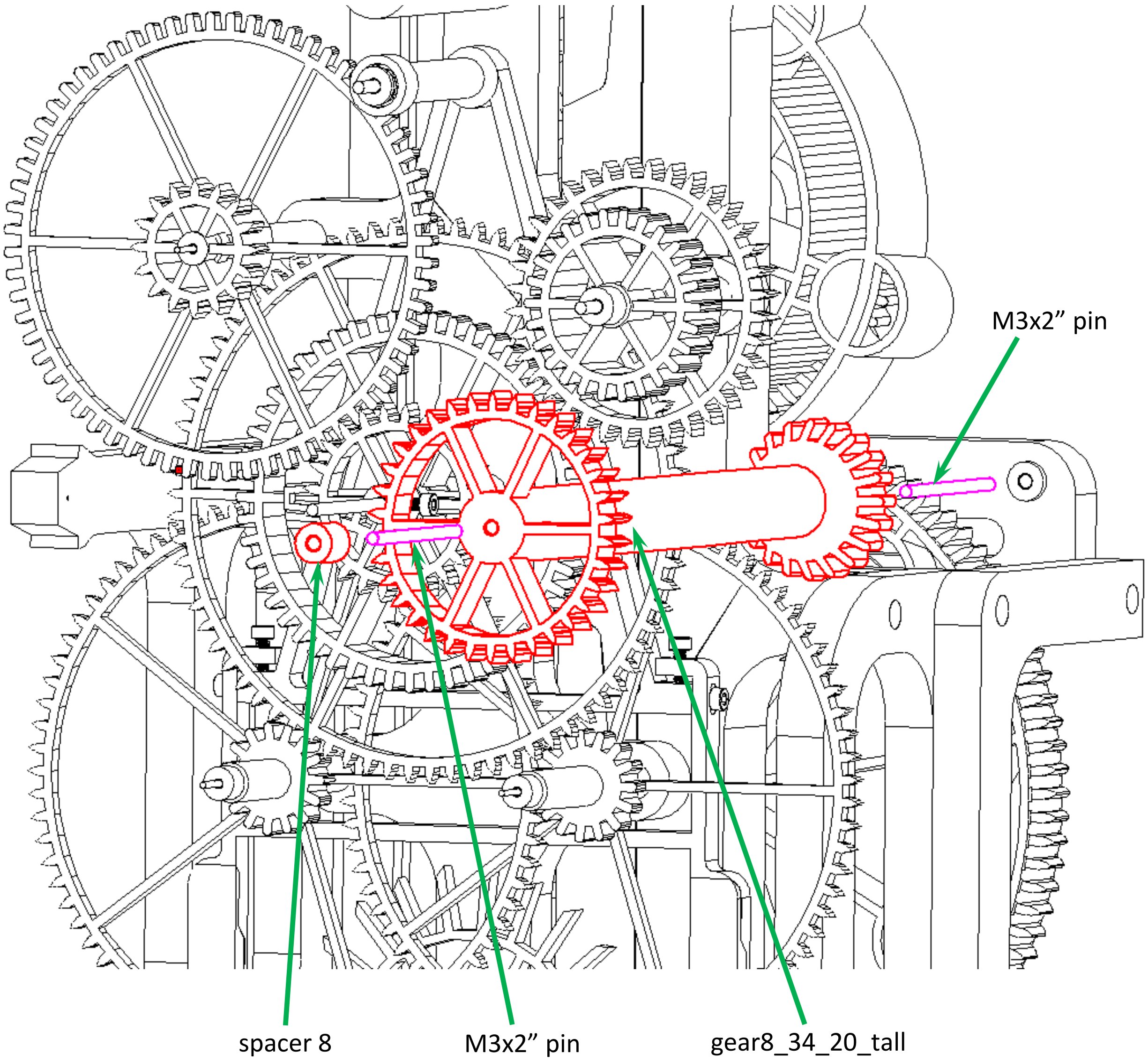
Gear 8 is the tall gear connecting the ball drop with the clock module. It uses two M3x2" (M3x50mm) pins instead of a single 9.5" long M3 arbor. An easy way to assemble this section is to install the M3x2" pins as a tight fit in gear 8 and a loose fit in the frame. This keeps the pins in place if you need to take the clock apart multiple times when debugging.

Here is a breakdown of the gear 8 components.

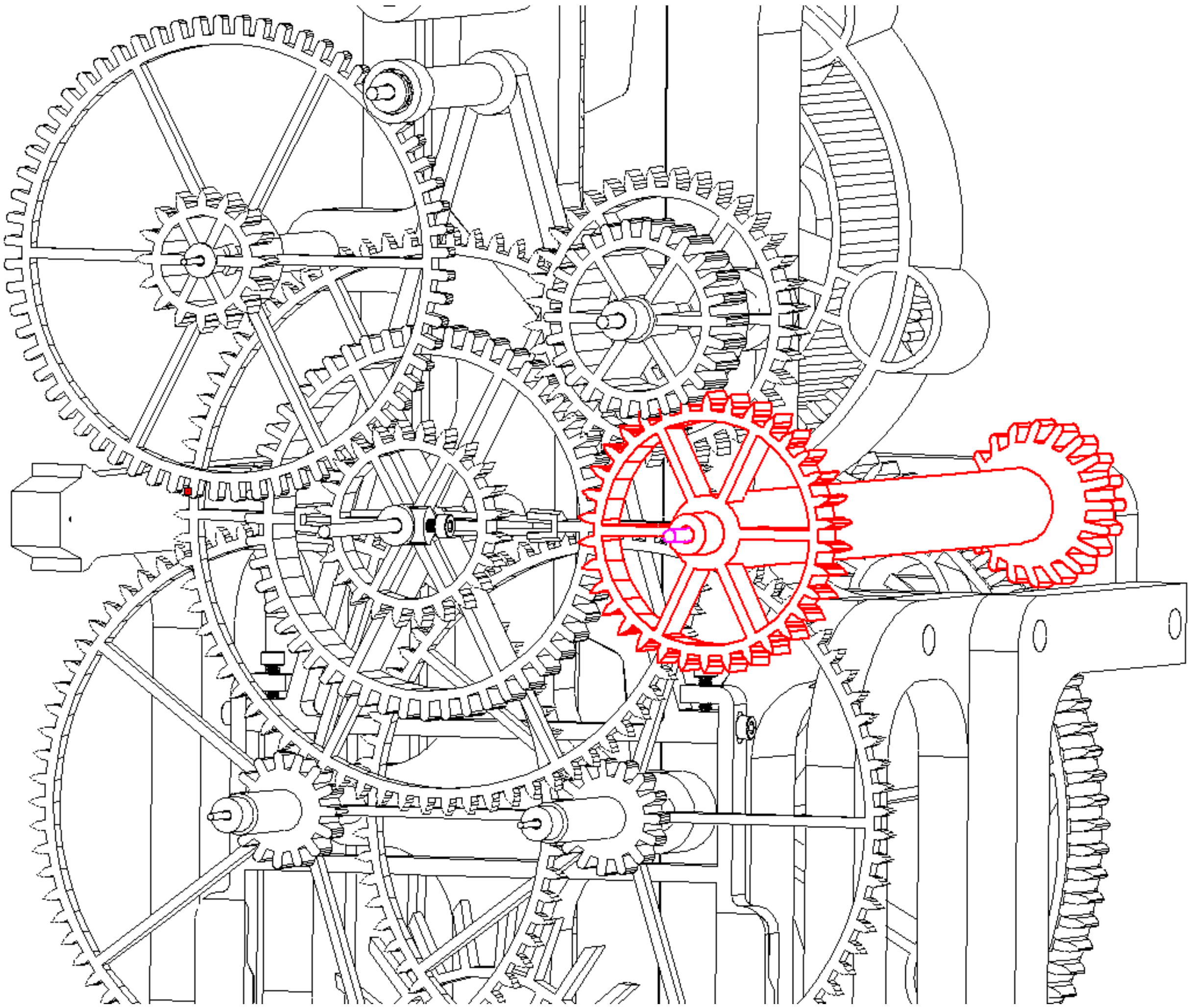


Note that gear 8 has a tall aspect ratio with very little contact area on the bottom layer. It has almost no chance of staying on the print bed if printed without a brim. A single layer brim inside the spokes has been built into the model. This brim should be removed before placing gear 8 into the clock so the spokes look similar to the other gears. Another external brim can be added around the gear teeth if needed. This brim will have to be removed and the teeth cleaned up.

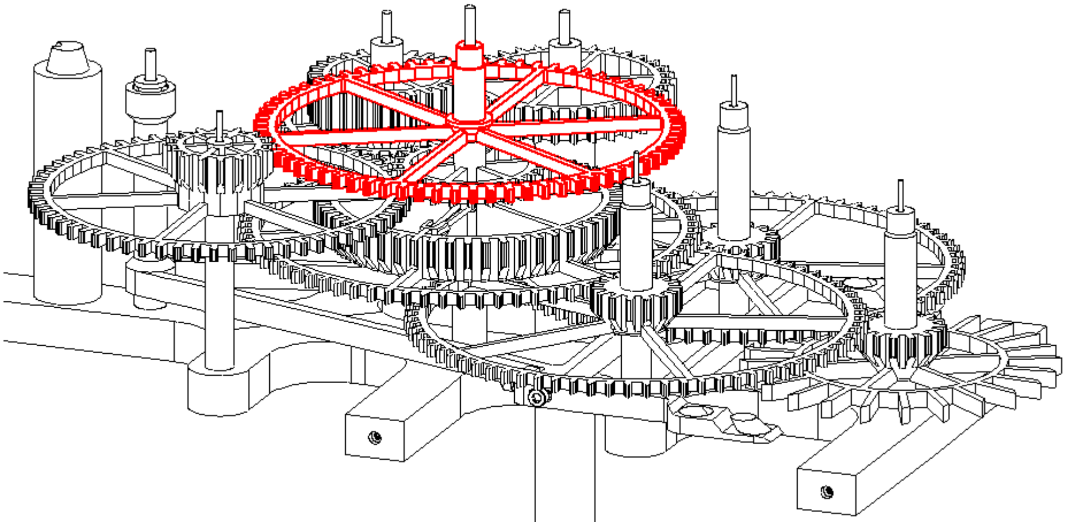
Here is the view of the gear 8 components as they will be assembled in the clock.



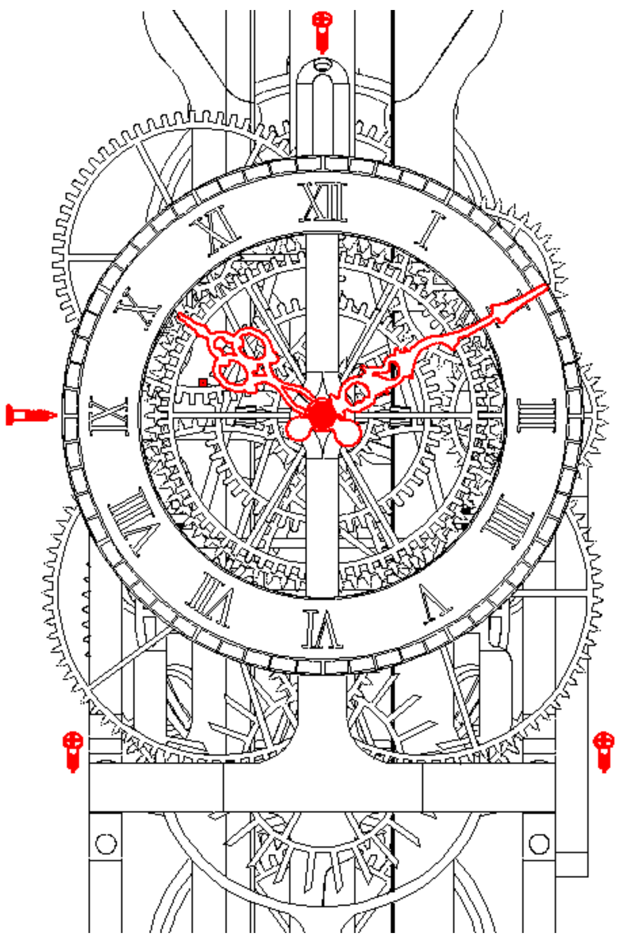
And another view with the gear in its final position. The narrow end meshes with ball_drop9 at the back of the clock. The larger end meshes with gear 7 towards the front.



Shifting back to the previous orientation. Add gear6_72 onto the central arbor.



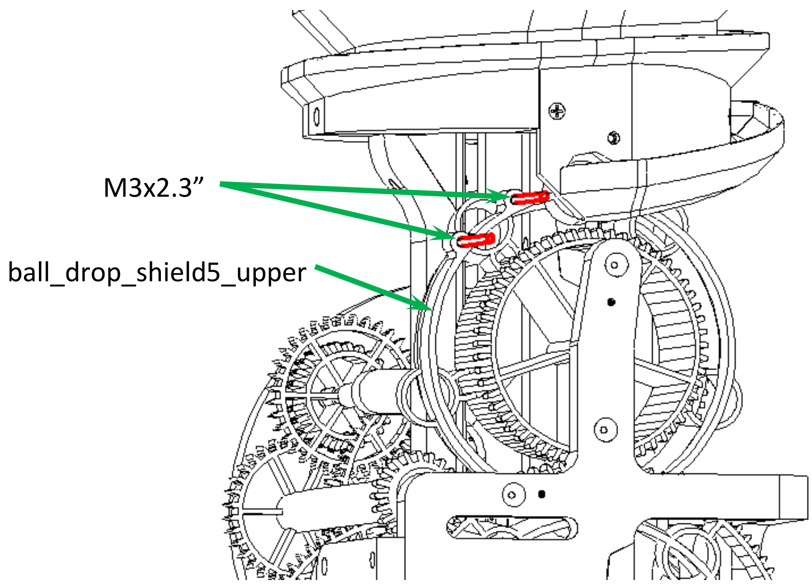
Add the dial (frame_H) and hands. Start by positioning the dial over the gear 4 arbor. Adjust the arbors one by one until they line up and the dial drops into position. Secure the dial with one screw at the top, one screw at the 9o'clock position, and two screws in the lower standoffs. Add the hands using two M3x8mm screws.



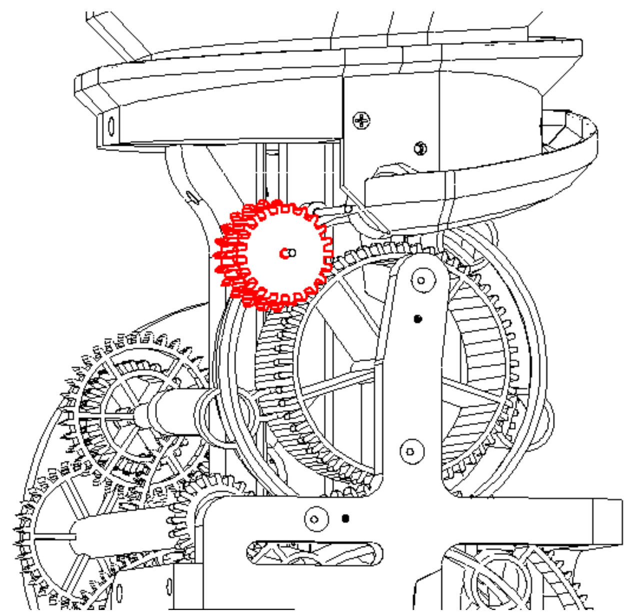
Gears 9, 10, and 11 are the last remaining gears placed behind the clock. This is a late design update created after several builders reported balls getting stuck as they enter the upper ball ramp and stopping the clock. Interestingly, my prototype clock ran perfectly without this edit. However, my second clock experienced the issue so this update seems like a good reliability improvement. This edit was made around two months after the initial release. Download the design again if you have the original release. It can be added to the original release with a minor amount of rework.

Gear 11 has a paddle wheel to feed balls one at a time into the ball drop. Gears 9 and 10 synchronize gear 11 with the ball drop gears.

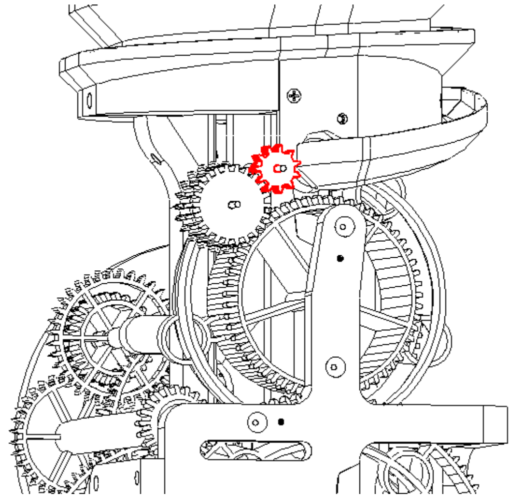
Turn the clock around to add this update. Start by adding two of the M3x2.3" (M3x58mm) arbors into the ball_drop_shield5_upper.



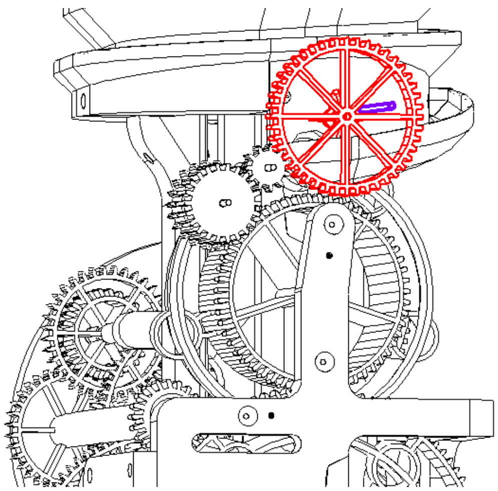
Add gear9_22_22 to the lower arbor with the large end meshing with the ball drop gear.



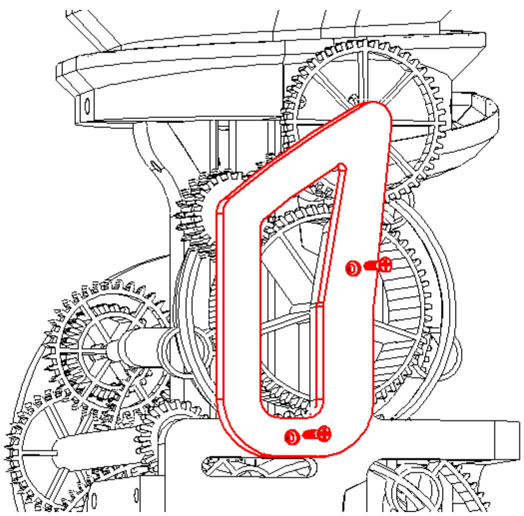
Add gear10_11 to mesh with gear9_22_22.



Gear11_44 needs to be put into position before adding the M3x2.3" arbor.



The last component is the cover plate frame_a4 secured with two #6x3/4" screws.



Running the clock

Getting this clock to run is fairly easy. Here is a quick summary of the steps:

1) Set the clock on a level surface. I considered adding leveling feet under the base. However, the clock is already quite tall. Leveling feet would have added another inch, so I decided against them. Therefore, a level surface is required. Use playing cards s shims under the base if needed.
2) Load the balls into the lower ball ramps and crank them to the top. You could load them directly into the upper ball ramp, but cranking them to the top is more fun. If you have the clock loaded with 125 balls, they might not all fit in the upper ramp until after the ball drop is loaded.
3) Remove the lower pallet arm and pendulum bob. This allows the ball drop to rotate.
4) Rotate gear 11 or the upper ball drop gear near the back of the clock. The ball drops will feed in either direction, but the clock will only run if the hands are rotating clockwise. Make sure the hands are moving clockwise when loading balls. The spinning gears between gear 8 to the escapement act as a natural speed limiter for how fast the balls can load.
5) Continue rotating the upper ball drop gear until balls start exiting into the lower ball ramps. This indicates that the ball drop is fully loaded.
6) Hold the escapement to keep it from spinning. Add the lower pallet arm and pendulum bob onto the pallet hooks. The lower pallet arm is a drop in component that allows easy removal when loading the ball drops.
7) Loading the ball drops changes the time by several hours as the entire gear train will be spinning. Set the minute hand to the correct time.
8) Push the pendulum to one side. The clock should start ticking.
9) Show off your new clock to all your friends.

This should be all you need to do to load the balls and get the clock working. The next section has debug hints if needed.

Debugging

Pendulum Free-Swing Test

All of my pendulum clocks use small ball bearings to support the pendulum. I find them to be extremely reliable and long lasting. Traditional clock designs use pendulum suspension springs that may have slightly lower friction, but they are hard to find and very delicate. Small ball bearings are much more forgiving for the typical hobbyist.

Testing the pendulum free swing time needs to be done without any obstructions interfering with the pendulum motion. Specifically, the escapement needs to be removed. That is why the free swing test is easiest to run before installing the clock gears.

Add the lower pallet arm including the weighted pendulum bob. Move the pendulum all the way to one side and release it. Measure how long it takes for the amplitude to reduce from the maximum swing in each direction down to a small amount. Good clean bearings should allow the pendulum to swing for at least 8 to 15 minutes. This is lower than the free swing test on some of my other clocks because the starting amplitude is lower. If the swing time is less than 8 minutes, try swapping the bearings or cleaning them again. I usually purchase the cheapest bearings I can find on Amazon, eBay, or AliExpress and have never found a set of 10 bearings with more than 1 or 2 bad bearings. There is no need to buy super expensive ceramic bearings for the light loads used in this clock.

Debug Steps

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 adjustments 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 arbor holes
4) Gear 6 fits through the front dial and spins easily
5) Pendulum free swing test runs for at least 8 minutes, preferably closer to 15 minutes
6) All arbors have some end shake inside the frame

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

7) Do the balls move smoothly through the ball drops?
   This is easy to check by simply removing the pallet and letting the balls feed through their normal path. Sand or file any sticking spots as needed.

8) How fast do the gears rotate without the pallet?
   The pallet needs to be removed when loading the ball drops. If the gears are installed, the escapement acts as a natural speed limiter to prevent the ball drops from spinning wildly. The minute hand rotates at a rate of around 16.5 seconds per rotation on my clock without the pallet. This is a good indication of the overall friction in the gear train. If the minute hand moves significantly slower than 16.5 seconds in your clock, try to reduce friction in your gear train.

9) Is the clock in beat?
   Listen to the escapement sound. It should sound like “tick . . . tock . . . tick . . . tock” instead of “tick . tock . . . . . tick . tock . . . . .”. There are only a few adjustments on this clock. Make sure the clock is level. A ball set in the base below the pendulum should not roll to the side. Add shims under the base if needed. The adjustment screws on the side of the pallet can be used to raise or lower either side of the pallet. Hopefully, this adjustment is not needed. Start with the side screws positioned near the center of the adjustment range. The sideways position of the pallet meshing with the escapement can be adjusted to compensate for any component warp while printing.

10) Does the escapement rotate quickly when the pallet arms clear the escapement teeth?
This clock has a Graham deadbeat escapement that allows the pendulum to swing freely to its natural amplitude without pushing the escapement backwards. The escapement needs to rotate quickly when it changes from the “dead” portion to the active portion where the angled teeth engage and the escapement pushes on the pendulum.
If the escapement starts spinning slowly, it might not add enough energy before the pallet moves past. Some energy may be 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. 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.

11) Does the pendulum slowly loose amplitude and eventually stop?
This could be too much friction somewhere. 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 5 or 10. Try different bearings from your set if needed.

12) Does the clock stop in less than a minute?
If the pendulum free-swing test runs for 8 minutes, then the clock should run for several minutes unless the escapement is getting in the way of the pallet. You may see the escapement jump from the pallet arms hitting it. This may be caused by friction in the gear train not allowing the escapement to rotate quickly. Repeat the pre-check tests looking for where the excess friction is coming from.

13) 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. The friction clutch in this clock provides a small clamping force around the arbor. Gear 6 passing through the dial needs to have less friction than the friction clutch provides. If gear 6 is binding, 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. The good news is that the primary gear train is working so the clock is almost completely functional.

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

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

16) Make sure the pallet engages near the center of the escapement.
    The pallet hanging angle can be changed using the adjustment screws so the escapement teeth mesh at the center of the pallet arms.

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

Once the clock is working properly, it should continue to work for many years. I have been running mine for a few weeks so far and it has been working flawlessly. I only run it during the day because of where it is located while testing. This is long enough to know that the clock is running reliably.

You can ask questions on MyMiniFactory or the forum at https://www.stevesclocks.com/groups Try to provide as much information as possible. Mention your pendulum free swing time and the minute hand speed when running without the pallet. Describe the escapement characteristics, especially just after the clock stops. Move the pendulum back and forth to observe how quickly the escapement responds. The more information you can provide, the faster you can get you clock running properly.

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

Adjusting the Rate

The clock should be reasonably accurate with the pendulum nut near the middle of the adjustment range. Lowering the pendulum bob will make the clock run slower and raising it will make the clock run faster. Every 0.02" change in pendulum length should change the rate of the clock by about a minute per day.

The threads below the bob have around 12.3 threads per inch. One full rotation changes the length by 0.081". This would change the time by about 4 minutes per day. It is relatively easy to make small adjustments to get the time accurate to a minute or two per week.

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

Winding

Wind the clock by placing the key in the winding hole and rotate clockwise when viewed from the top. This should start lifting balls into the upper storage ramp. The lifting auger has a two start thread with a reasonably tall pitch. It takes around a dozen turns to feed the first ball to the top. It then feeds two balls per rotation. Continue winding until all the balls are at the top.

You will need to load the ball drops to get all 125 balls to fit on the upper ball ramp. Follow the procedure shown in a previous section.

Design Challenges

This has been my most challenging clock design so far. The clock portion was relatively straight forward, since I have already designed many working clocks. The ball tracks had many interesting issues to figure out. Here are a few of the challenges and their solutions discovered while designing this clock.

The first step was to design the power delivery system for the clock. Power is defined by the weight, drop distance, and drop time. Increasing the weight or drop distance will increase the total power. Likewise, releasing balls more often will increase the power.

My wall mounted clocks use a simple falling weight for power. A 7.5 pound weight falling 48" is usually sufficient to power a clock for 7.5 days. A desktop clock like this one limits the available drop distance. The obvious solution was to connect several waterwheels together to increase the total drop distance.

I selected 3/4" (19.05mm) steel balls as a good starting size. Smaller balls would provide less energy and would need significantly more balls using larger storage ramps to fit them. Larger balls weigh more, but are often only sold in packs of 10 or 25 balls at a higher price per unit weight. 3/4" balls are readily available on Amazon in packs of 100 or more. Each 3/4" ball weighs 1.002 ounces. They felt like a good size.

100 balls at just over 1 ounce each is only about 6.25 pounds. This is less than the typical 7.5 pounds used in my wall clocks. And the ball drop will certainly be less than 48" tall. It was obvious that the runtime would be less than 7.5 days. The minimum acceptable runtime would be 30 hours for once per day winding. I needed to build some sample ball drops to be able to calculate the available runtime.

Here are a few prototype ball drops designed for this clock. All are around 16-17” tall. The first image is a thin and wide design. It looks great, but each transfer between stages loses about 1” of drop. Also, the balls can fall out of the wheels if the clock is moved. The center image is the prototype that was eventually used in this clock. The balls roll gently between stages, only losing around 0.2” of drop. The last image shows the side profile. The 2.6” thickness fit nicely with the size of the finished clock.

The actual design of the ball drop had some interesting challenges. The largest wheel was limited to the print bed size. The two most common printer sizes when the design started were 220x220mm and 250x210mm. I always use the smaller limit of 210mm when designing clocks. One wheel with a 210mm diameter would not have enough power for the clock, so three wheels were cascaded.

Gears between stages are needed to keep everything synchronized. This ensures that when a ball leaves a pocket there is a pocket lined up to receive it. The design started with the large center wheel. It uses an odd number of pockets to prevent all the balls from transferring at the same time. Nine pockets were chosen and distributed around the perimeter. The balls can’t travel through the gear teeth, so the pockets need to either be inside or outside of the gear. Placing the pockets inside the large gear means they must be outside on the smaller wheel.

The small wheels also wanted to have an odd number of pockets. They could have been designed with either five or seven pockets. Nine pockets extended outside the gear teeth would have been too large. Five pockets were randomly selected instead of seven. It made the overall height around 16” which seemed like a good size. I didn’t realize that this was a great choice until after the entire clock was finished. The exposed five pocket gear is the perfect size to hold onto when loading the clock.

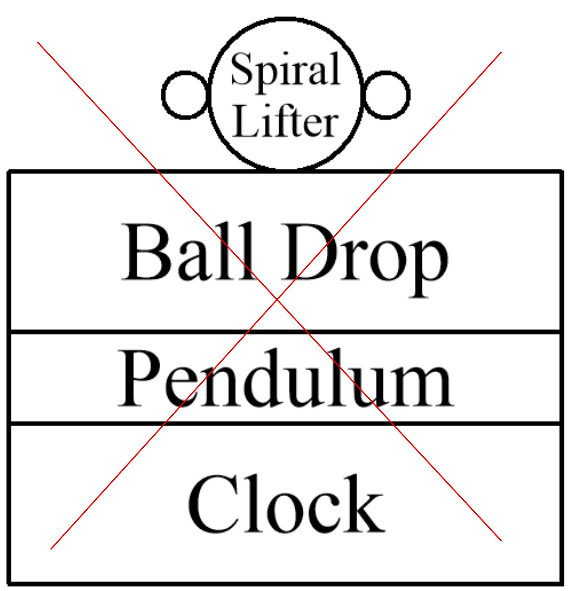
The ball drops are the most important feature of the ball delivery system. They do the actual work of providing power to the clock. The rest of the ball delivery system is overhead to keep the ball drops supplied with balls. There needs to be a method of feeding balls into the ball drop and collecting them as they exit. I considered using a funnel at the top and a bucket at the bottom. Every day, the user would pick up the bucket and dump it into the funnel. This is simple, but not very elegant. Balls could easily jam in the funnel. It seemed natural to constrain the balls to single file channels. The balls would be held in long serpentine or spiral tracks.

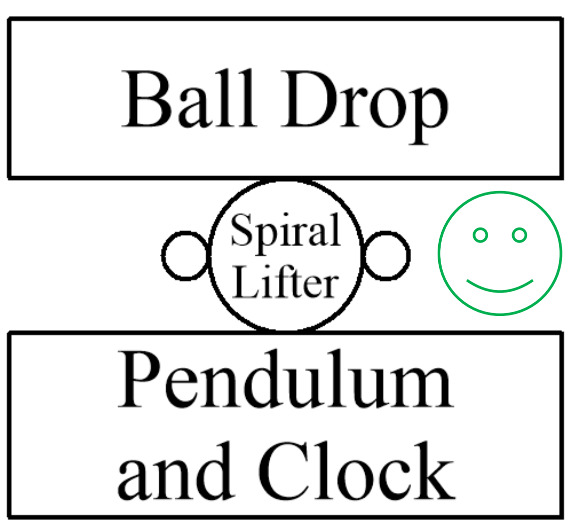
The next step was deciding how to move the balls from the lower storage back to the top. A bucket was ruled out. Some choices include a conveyor belt, rotating gears, or a spiral auger. A conveyor belt was ruled out as having too many moving parts. Rotating gears, essentially the reverse of the ball drop, is also overly complicated. A hand cranked spiral auger is the obvious choice in simplicity and efficiency.

One issue is the overall size of the spiral lifting auger. The clock is going to be tall. There is no way to print a spiral lifter as a single component, yet it needs to function as a single solid object. A simple solution is to embed a metal rod inside the spiral lifter. EMT conduit is readily available in the US. It is hollow to reduce weight, yet strong and cheap. A column of balls would apply a sideways pressure against the auger. This can be cancelled out if balls push equally from multiple directions. Lifting two balls at a time is an easy solution. It also reduces the amount of winding required.

The design choices so far have been straightforward. The rest of the clock would be designed around a vertical ball drop and a spiral lifting mechanism. The first floorplan shown below uses a standard structure with the pendulum in the center. The ball drop needs to be in the back so the clock can be in front. And the spiral lifter needs to be placed somewhere. This felt like an awkward design.

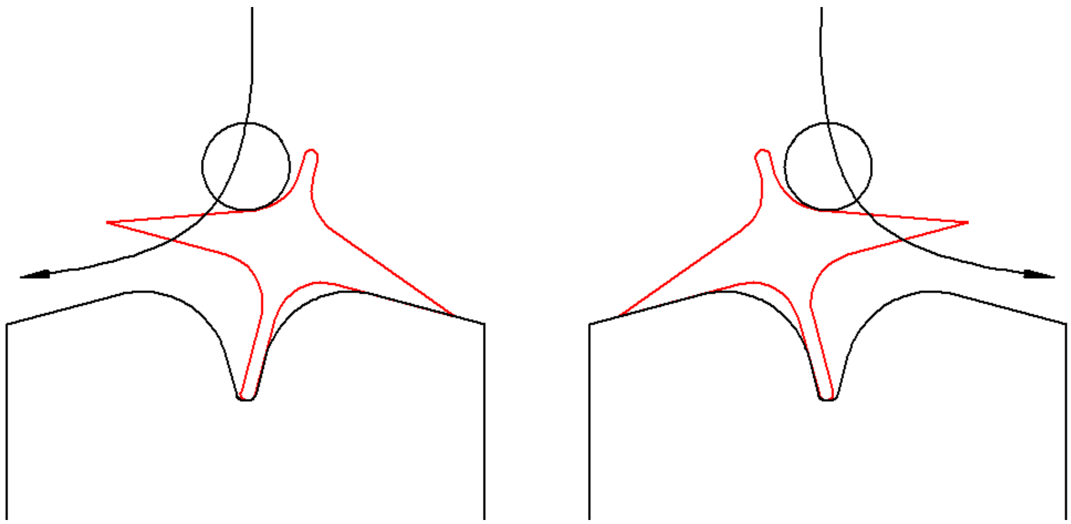
A better floorplan is shown on the right. The spiral lifter is moved to the center. It should be easy to feed balls into the spiral lifter and have them exit to the upper ball ramp. Integrating the pendulum with the clock will add a few obstructions that the pendulum needs to avoid, but this should not be too difficult. Overall, the image on the right is a good workable floorplan.





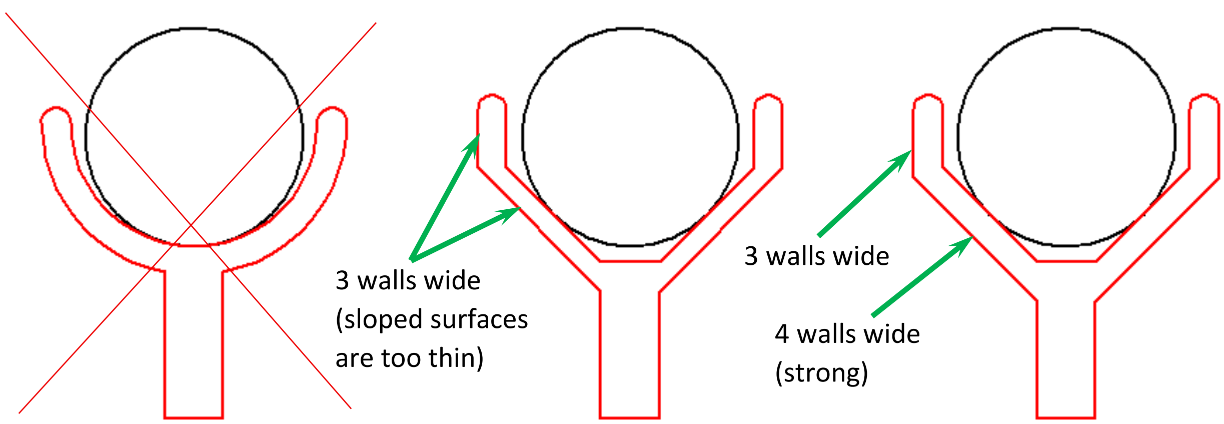
This floorplan adds a few constraints. Balls enter and exit the ball drop as a single column. The lower ball ramp needs to split into two paths for the spiral lifter. The two outputs of the spiral lifter will need to join back into a single track for the upper ball ramp. Merging two tracks can be a simple "Y" shape. Splitting one track into two needs a ball divider so balls fill the lower ball ramps equally. Rolling ball sculptures do this all the time.

Here is a solution for 3D printing the ball splitter. A toggle gate (red) is designed to fit into a pocket in the toggle gate body. The pivot point is wide enough for the toggle gate to roll instead of creating a sliding contact area. A ball entering when the toggle gate is tilted to the right will tip the gate left and the ball will exit left. This leaves the toggle gate ready for the next ball to exit on the right.



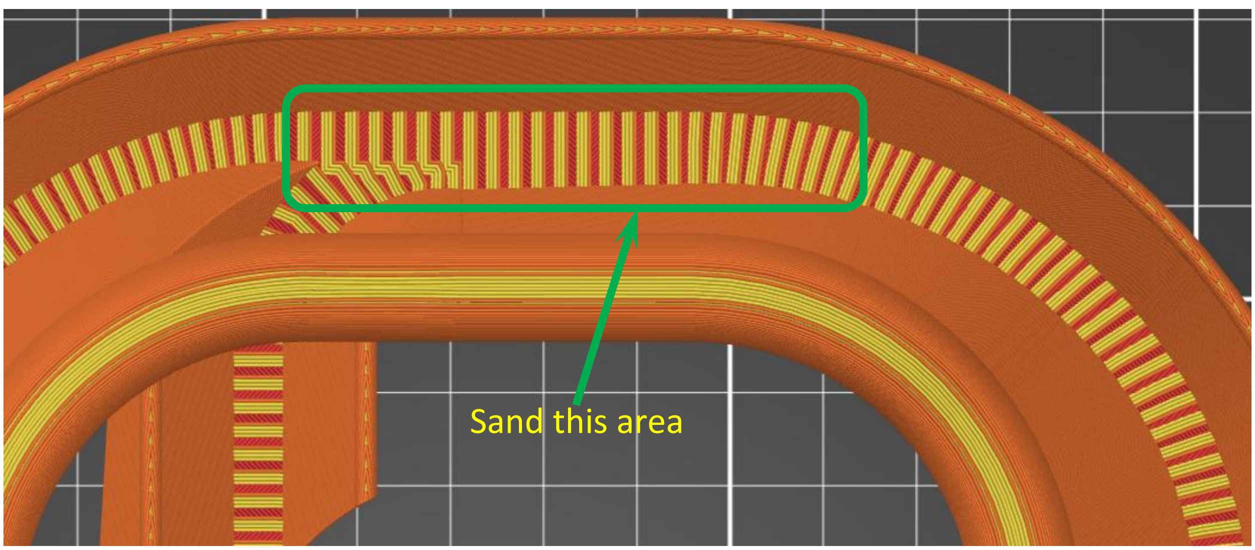
The lower ball ramp module was designed with two separate ramps. Each side alternatively receives a ball from the toggle gate. The two lower ball ramps each feed one side of the spiral lifter.

Designing tracks for the balls sounds simple, but has a few caveats. The first attempt shown below on the left used semicircles slightly larger than the ball diameter. The balls roll on the bottom surface of the track. This creates an interesting problem when 3D printed. The track looks like a smooth surface, but the bottom is actually a series of 0.2mm stair steps. A ball can stop on these steps without rolling downhill.



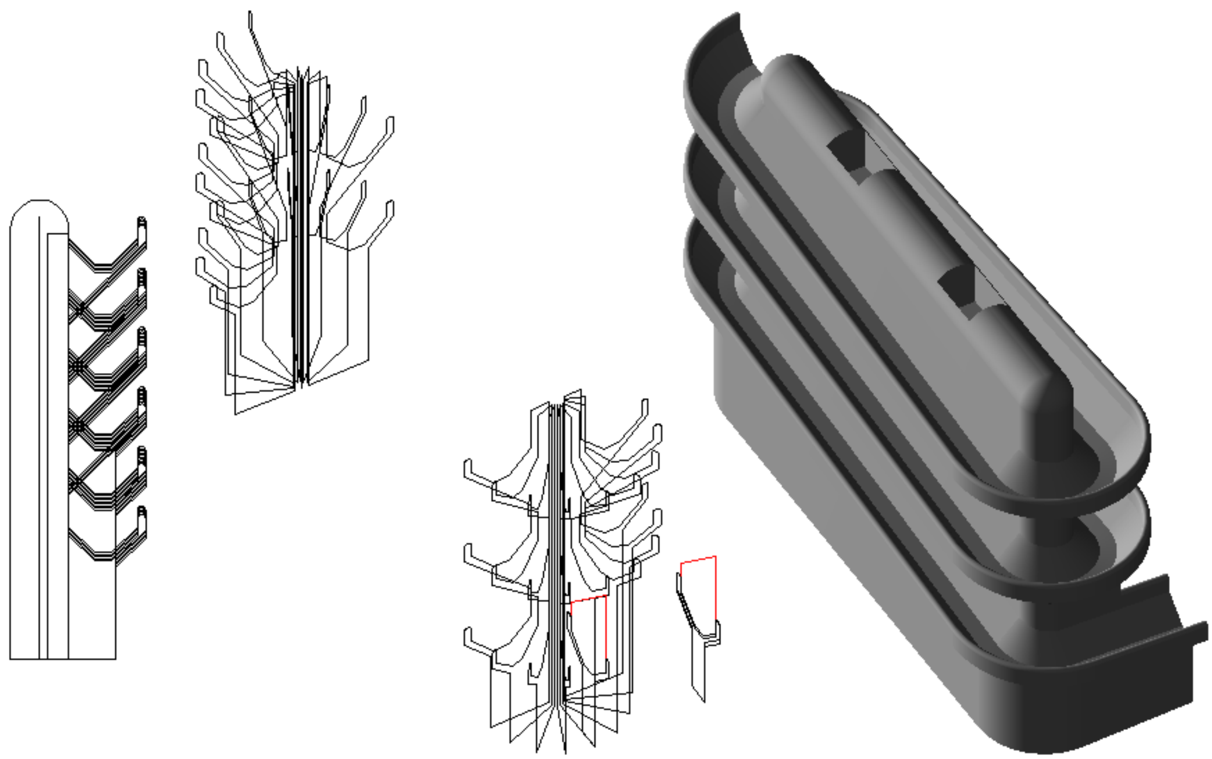
The solution is to design the track so the balls roll along 45 degree sloped side wall surfaces. The flat bottom still has the stairstep effect, but the balls won't touch it if they roll along the sides. The initial rail profile is shown in the center picture. Vertical safety walls were added to keep the balls on the track. All the features were optimized to print using exactly 3 perimeter wall loops. However, the 45 degree slopes end up being thin and weak. The fix was to widen the 45 degree slopes to 4 walls wide while keeping the vertical segments 3 walls wide. This adds a lot of strength to the rails, especially where the balls actually touch the rails. The final profile is shown on the right. This is why the ball tracks need to be printed using 4 walls.

The "Y" shaped merge from the spiral auger into the upper ball ramp required some special attention. The junction where the tracks meet has a wide spot where the ball falls down from the sloped side walls. The balls have to climb upwards to get back onto the sloped side walls. A ball would get trapped in the pocket and block many balls behind it. The solution was to widen the "Y" section so the balls can gradually make their way back to the preferred side wall positions. There is no way to keep the balls off the bottom surface in this tiny area, so it was made as easy as possible to get back to the preferred side walls. The area shown below in green can be sanded to reduce the stair step effect. Leaving it unsanded may hold one or two balls. A single ball behind them will push them forward, so it will not trap a long line of balls.

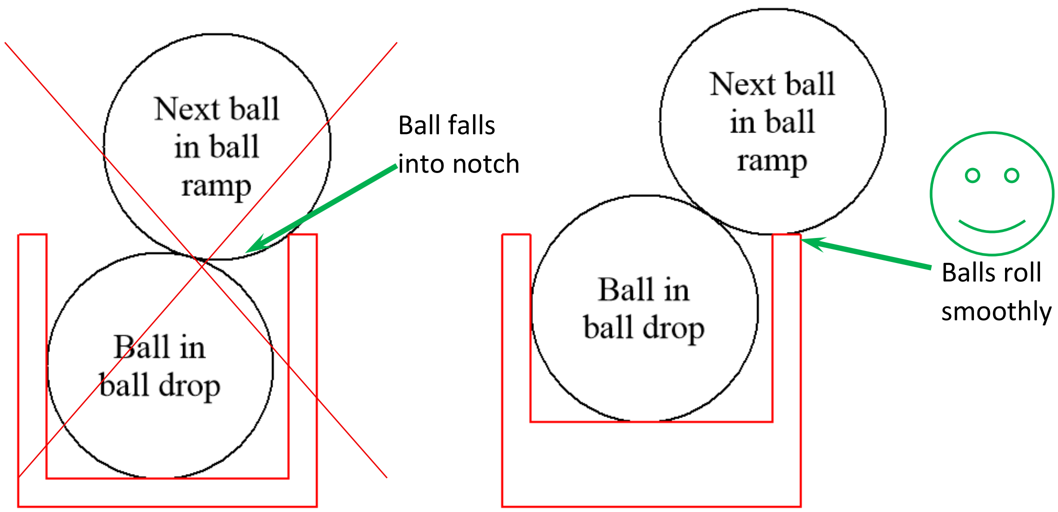


The previous images define the basic shape of the ball tracks. They need to be integrated into a complete ball ramp, which was challenging in CAD. Gears can be designed as 2D shapes and given thickness to convert them into 3D components. The spiral ramps needed to be fully designed as 3D objects. The available tools were rail sweeps, spiral revolves, or lofts. I could never get rail sweeps to work properly in the desired shapes. Spiral revolves were also difficult. Ultimately, I generated the ramps using lofts. Track profiles were designed with various amounts of drop for each position. Straight sections only need to be defined at the ends. Curves needed to be defined with at least 5 profiles to achieve smooth surfaces.

Here are the steps used to create one of the lower ball ramps. The left image shows all the profiles used in the lower left ball ramp. The middle image shows these profiles positioned and ready to create the lofts. After lofting, everything is merged as shown on the right. Additional features are added for mounting screws and the center column. Each iteration took a while to get adjusted properly.



Another challenge was designing a method to feed balls smoothly into the ball drop. My first ball drop was designed so the balls sat below the surface in the pockets. This felt like the safest approach, but had a dangerous side effect. The balls feeding the ball drop form a line pushing to get into the top pocket. If the balls sit below the surface, the next ball would drop into the notch. The next ball and all balls behind it would have to be pushed backwards so the ball drop could rotate. The result was a ball ramp that refused to rotate. The simple solution was to raise the balls so they proud of the surface. The next ball does not fall into the pocket and the ball drop rotates with minimal friction.



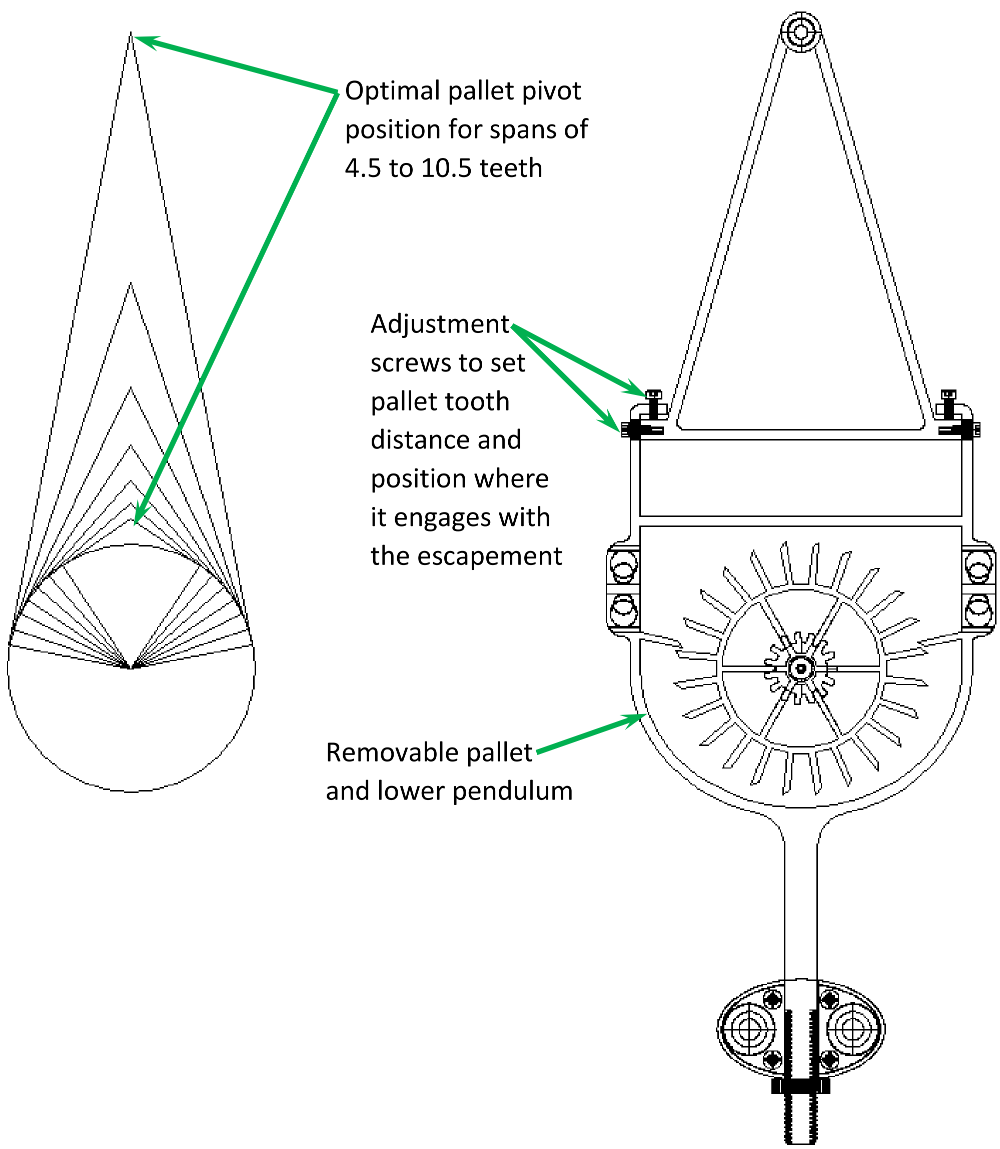
My first prototype clock ran perfectly with this simple edit to prevent balls from getting jammed up as they enter the ball drop. However, some builders reported that their clock would still stall if the upper ball ramp was completely full. The edit made on 10-Sep-2026 added a ball limiter to feed balls to the ball drop one at a time. It acts like a freeway ramp meter feeding individual balls so there is never a pileup. This edit appears to completely eliminate the risk of balls getting jammed as they enter the ball drop. It is worth retrofitting to your clock if you built one of the original designs. Only three parts need to be replaced plus the new gears. If you downloaded the design at a later date, then it should already have this update.

Another design challenge was figuring out how to load the ball drop. The retainers used to hold ball in the ball drop also prevent adding new balls from the side. The only path is to feed them serially from the upper ball ramp. Normally, the pendulum limits the feed rate into the ball drop to one ball every 20 minutes, taking several hours to fully load the ball drop. The ball drop must be allowed to rotate faster for loading. This can be made possible by removing any gear in the path, removing the escapement, or removing the pallet. Removing gears or the escapement requires taking the clock apart, which would not be acceptable. Adding a mechanism to slide a gear out of the way would be complicated. A simpler solution was found to allow the pallet to be removed.

The key to the making the pallet removable is to pick a pendulum pivot location with long pallet arms. This moves the escapement to a low position. The pallet can be removed by lifting it off the upper pendulum arms. A few adjustment screws were added to help set the pallet tooth distance and escapement position. They are rarely needed and can usually be left in their default position near the center of the adjustment range.

The first image below shows multiple options for the pallet pivot position. A gear train was selected using a 24 tooth escapement with a 14.11” long pendulum. The pallet can be designed to span any number of teeth. The span always needs to have an integer number plus one half of a tooth. The diagram shows different pivot positions for spans ranging between 4.5 and 10.5 teeth. A 4.5 tooth span would pivot really close to the escapement. The 10.5 tooth span would pivot much higher.

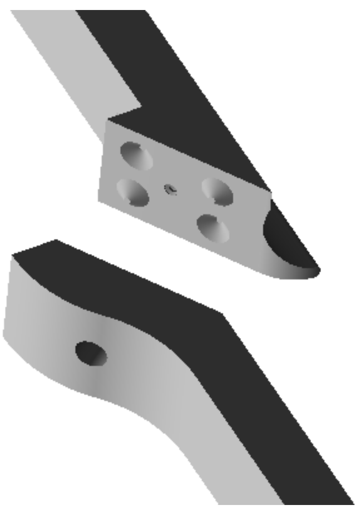
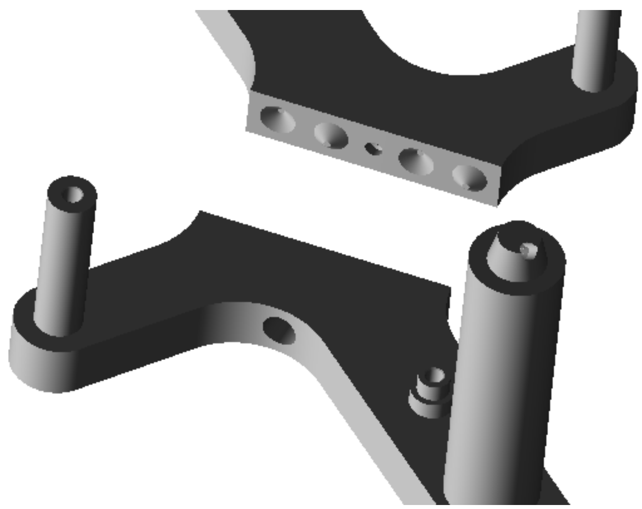
The final arrangement uses a 10.5 tooth span as shown on the right. The pendulum arm integrates nicely just below the pallet. The easily removeable lower section is used when loading the ball drops.



The frame needed to be designed after planning all the submodules. It started with vertical columns and horizontal bracing in a scaffold like structure. The ball drop sits between two vertical columns. The main clock also sits on vertical columns with side arms to support gears placed outside the center line. Side "H" shaped plates were added to tie the columns together. Two more vertical columns were added around the spiral lifter. This created a ring of four vertical columns around the spiral lifter for the upper ball ramp to be designed around.

I built the complete scaffolding then started taking away the segments that were not needed. The vertical posts under the main clock are not needed below the escapement, so they were removed. This gives some extra room for the pendulum bob and also makes it easier to remove the pallet. The horizontal support under the clock was curved to make the dial more prominent. Trimming the vertical column behind the ball drop gives great access to the gear that needs to be turned to load the clock.

After trimming down the frame to the bare minimum, most of the segments were still too large to be printed on normal size printers. They needed to be split into smaller pieces. I wanted to avoid pins and screws as much as possible, so each frame split included alignment bumps and a single screw. This same style was used on several of my other clocks. Each split has a few alignment bumps in both directions with a single screw holding the pieces together. Test show this to be more than strong enough. Most of the 92 wood screws used in this clock are holding the frame together. It is quite strong and stable, even holding 125 balls in the top ramp.

These are just a few of the unique design challenges encountered while designing this clock.

Final Comments

Clock design has been a hobby of mine for many years. It really expanded in 2018 when I got my first 3D printer. The ability to quickly go from prototype to working clock is easy with a 3D printer. I usually have several works in progress at any time. Some are grand plans that may take years to complete. Others are minor revisions. This is one of my grand plans. Prototype sections were completed many years ago. It took a long time to bring everything together to make this clock.

I am extremely pleased with how this clock turned out. Everything fit together perfectly. It has great symmetry in all directions. The dial is offset by ball ramps above and below. The spiral lifter is offset by the clock module in front and ball drop behind.

Of all the clocks I have designed, this one gets the most attention. There are no other clocks like it.

This clock has been released on MyMiniFactory. Feel free to check out my other clocks over there as well. They are easy to find by searching for "Steve Peterson clocks". You can find additional information on my web site at https://www.stevesclocks.com

Parts kits for all the non-printed parts except the balls and EMT conduit will be available on my Etsy store. Check the main description on MyMiniFactory for a link.

This is my 17th published 3D printed clock. Each design builds upon the learnings of the previous clocks and they get better with each new release. This clock uses the most reliable gear profiles with optimizations specifically for printability. If you are curious about some of these optimizations, check out my eBook at https://www.myminifactory.com/object/3d-print-clock-design-guidelines-pdf-714119 for a description of some of my design secrets.

Another of my grand plans is to start designing wooden gear clocks. I have been experimenting with wooden gears, but have not yet completed a fully functional wooden clock. I started trying to build a wooden clock, but switched to printed clocks as soon as I received my MK3 printer. I may have a few more printed designs in progress, but I hope to get back into the workshop to start making a wooden gear clock soon. Stay tuned for more information.

Good luck with your clock build.

Steve

Addendum 1: Bug Fixes

This clock underwent the same rigorous debug and testing that goes into all of my clocks. The scrap pile of experiments and refinements is usually as large as 2-3 complete clocks. This clock is no exception, especially considering that the ball track experiments started 5-6 years ago.

I design most of my clocks with every component in a single CAD file. This file includes both 2D and 3D representations of every component plus a few additional experiments. This usually works quite well. A separate composite model is built to test everything before starting the print.

This clock is an order of magnitude more complex than any of my other clocks. The ball ramps and ball drop are complex structures that I have never built before. The frame is 2-3X more complicated than any of my other clocks. The best way to manage the complexity was to split the design across multiple CAD files. The ball ramps, gears, and frame each became separate files. This appeared to be manageable, until it wasn't.

The prototype clock was built and fully functional before I started writing this assembly guide. I often add a few minor improvements that only become obvious during the documentation phase. At some point, one of the CAD files got out of sync and a few bugs were introduced. I don't even know what really happened because the CAD files were missing changes that were in the actual physical clock. The CAD files were out of sync with my prototype clock. The first release of this clock on MyMiniFactory was inadvertently released with a few of these bugs. Luckily, they are relatively minor.

The required changes have been made to restore the CAD files and make the clock functional again. By the time you read this assembly guide, all of the buggy files on MyMiniFactory have been fixed and you should be able to print a fully functional clock. I apologize to all the early adopters. A few components may need to be reprinted.

Here is a list of all the stl files updated by these bug fixes:

1) The toggle_lever was updated to the correct size. The "wings" on the original design were 0.1" too low preventing lever from toggling properly. This is a small file that is easy to reprint.
2) The shaft on ball_drop9 was 2mm too tall and could bind in the frame. A quick fix is to trim 2mm off the top of the shaft. Or reprint ball_drop9 so is the same height as ball_drop5.
3) The clearance between gear 4 and the gear 8 shaft was too small. It worked without issue on my initial test clock, but rubbed on a second set of gears using different filament. Gear8_34_20_tall was updated with a smaller diameter shaft to provide more clearance. The internal built-in brim was removed, although adding an internal brim in your slicer is recommended.
4) Frame_g1 and frame_g2 were updated to reduce the height of the arbor posts by 2mm. This provides extra clearance for the gears siting inside the frame. This clearance is often called "end shake". There is minimal clearance in my clock, but might not be enough on your printer. If you already have the old frame printed, a simple check will tell you if there is enough room. Test each gear inside the frame to see if there is 1-2mm of end shake. If it is less than 1mm, trim a small amount off the post on frame_g. The center arbor needs to be checked with gear 4, gear 4b, and gear 6. A secondary improvement was to enlarge the bottom of the gear 5 arbor post. The initial design was impossible to drill using standard length 1.6mm bits, so the design was enlarged to eliminate the need for drilling this one arbor post.

5) The lower frame section below the dial (frame_h1) was accidentally released with a different style that doesn't match the images shown. It attaches using two screws from the bottom instead of a single screw from the back. I made this change while writing the assembly guide. Both styles are functionally identical, but the escapement is different. The escapement arbor in the new design is 3.0" long and matches the text in this manual. If you printed the old style, then you will need to print the matching taller escapement from the original release. The old style design will need a 3.5" long escapement arbor. The pictures on page 9 show the old style front frame. It is only marginally different than the image on the front cover. Either style is acceptable as long as the matching escapement is used. The new style matches the text within this assembly guide.

Here is a summary of the files that need to be reprinted if you downloaded the original release:

toggle_lever
ball_drop9 (reprint or trim shaft length by 2mm)
gear8_34_20_tall
frame_g1 and frame_g2 (reprint or trim posts by 1-2mm if needed)
frame_h1 and frame_h2_dial_roman (this update is optional. The old design needs a matching escapement from the original release and a M1.5x3.5" arbor)

If you downloaded the release after seeing this assembly guide, then these updates should already be included in your zip file. You will be able to print everything normally and build your clock.

A few file enhancements were also made. These add functionality, but are not fixing any bugs:

1) The spiral lifter was originally designed to fit 1/2" EMT conduit that is readily available in the US. Builders in other countries requested different sizes to work with tubing that they have easy access to. The three components in the spiral lifter were updated to include hole sizes ranging from 15mm to 20mm. Pick the closest size and add up to 3% additional scaling to fit your tubing.
2) I design most of my clocks to be as efficient as possible so they can have long runtimes. The typical target is at least 7.5 days of runtime to allow winding once per week. However, the balls used in this clock have less potential energy than the weights used in my wall mounted clocks. The minimum target for this clock became 30 hours to allow winding once per day. The default gear set in the original release would drop a ball every 20 minutes and have a runtime of just over 38 hours (1.6 days). However, I also designed a gear set that releases a ball every 30 minutes. The runtime increases to 57 hours (2.4 days). Print gear4_75_52_2p4days and gear7_36_26_2p4days to get the longer runtime. I have been running the 2.4 day option for over a month. It has been completely reliable, although the 1.6 day option will be a bit more robust. The 1.6 day option is recommended for first time builders as the pendulum will receive 50% more energy compared to the 2.4 day option.

In addition, the 10-Sep-2026 update adds a ball drop limiting valve to eliminate the possibility of a full upper ball ramp allowing balls to get stuck in the ball drop.

I often display my clocks at local Maker Faires. Many visitors attend to see the large robots, but there is also a constant stream of visitors in the clock booth. It is refreshing to see so many young people asking how to design a clock. Here are some of the wall mounted clocks.

And the desktop clocks.