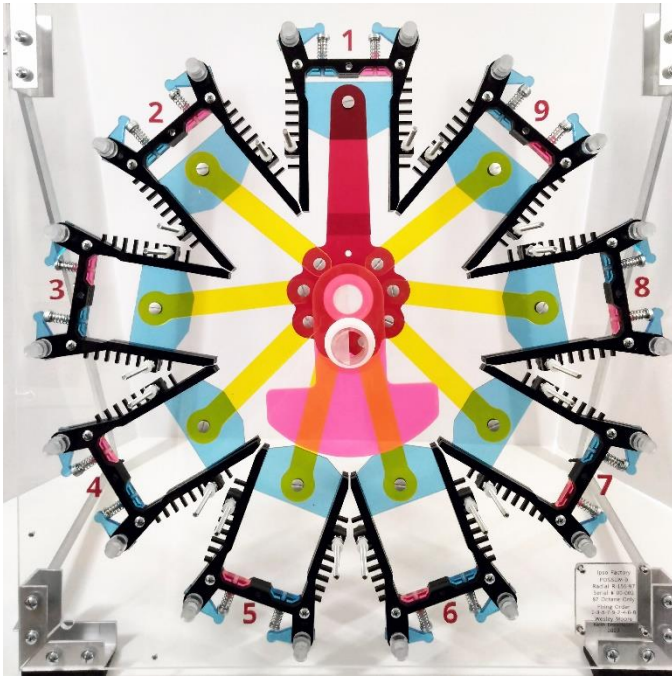


Radial Engine Model Assembly Manual



Partially assembled.



Fully assembled.

Model by Wesley Moore, modified by Keith Enevoldsen.

Document, diagrams, and photos by Keith Enevoldsen.

thinkzone.wlonk.com/Radial/RadialModel.html

CC BY-SA Creative Commons Attribution-ShareAlike 4.0 International License.

©2024 Keith Enevoldsen, thinkzone.wlonk.com, based on a design by Wesley Moore.

Contents

| | | |
|-------|--|----|
| 1 | Introduction | 7 |
| 1.1 | Purpose of the radial engine model | 7 |
| 1.2 | Purpose of this manual..... | 7 |
| 1.3 | Assembly time and effort | 7 |
| 1.4 | Conventions..... | 7 |
| 1.4.1 | Tables..... | 7 |
| 1.4.2 | Measurement units | 7 |
| 1.4.3 | Abbreviations..... | 7 |
| 1.5 | Overview of the model..... | 8 |
| 1.6 | Model photos | 9 |
| 1.7 | Model diagrams | 11 |
| 2 | Tools for assembly | 12 |
| 3 | Materials for assembly | 13 |
| 3.1 | Threadlocker | 13 |
| 3.2 | Dry lubricant | 14 |
| 3.3 | Plastic cleaner | 14 |
| 4 | Parts and assemblies | 15 |
| 4.1 | General info about parts | 15 |
| 4.1.1 | Custom parts and standard parts | 15 |
| 4.1.2 | Acrylic parts..... | 15 |
| 4.2 | Fasteners..... | 16 |
| 4.2.1 | Screw sizes | 16 |
| 4.2.2 | Main screws..... | 16 |
| 4.2.3 | Pivot pins | 17 |
| 4.3 | Plates | 18 |
| 4.3.1 | Parts list..... | 18 |
| 4.3.2 | Back plate..... | 18 |
| 4.3.3 | Front plate | 19 |
| 4.3.4 | Middle plate..... | 19 |
| 4.4 | Rings..... | 20 |
| 4.4.1 | Parts list..... | 20 |
| 4.4.2 | Rings | 20 |
| 4.5 | Sleeves | 21 |
| 4.5.1 | Parts list..... | 21 |
| 4.5.2 | Sleeves | 21 |

| | | |
|---------|--|----|
| 4.6 | Power system: Crankshaft, driveshaft, propeller..... | 22 |
| 4.6.1 | Parts list..... | 22 |
| 4.6.2 | Crankshaft-driveshaft-propeller assembly | 22 |
| 4.6.3 | Shaft connectors..... | 23 |
| 4.6.4 | Crankshaft assembly..... | 24 |
| 4.6.5 | Middle driveshaft with gear33 | 25 |
| 4.6.6 | Propeller assembly..... | 25 |
| 4.7 | Power system: Cylinders, pistons, con rods | 26 |
| 4.7.1 | Parts list..... | 26 |
| 4.7.2 | Cylinders | 27 |
| 4.7.3 | Pistons | 28 |
| 4.7.4 | Con rods | 28 |
| 4.7.5 | Master rod | 29 |
| 4.7.6 | Rods-&-pistons assembly..... | 29 |
| 4.8 | Small shafts for gears and rocker-pushers..... | 30 |
| 4.9 | Gears..... | 31 |
| 4.9.1 | Parts list..... | 31 |
| 4.9.2 | Gears..... | 31 |
| 4.9.3 | Gear train..... | 32 |
| 4.10 | Valve system: Valves, rocker-pushers, pushrods, cam disk | 33 |
| 4.10.1 | Parts list..... | 33 |
| 4.10.2 | Valves..... | 33 |
| 4.10.3 | Valve assemblies | 34 |
| 4.10.4 | Valve pushers | 35 |
| 4.10.5 | Rocker arms..... | 35 |
| 4.10.6 | Rocker-pusher assemblies | 36 |
| 4.10.7 | Pushrods | 37 |
| 4.10.8 | Cam followers..... | 37 |
| 4.10.9 | Pushrod assemblies | 38 |
| 4.10.10 | Cam disk | 39 |
| 4.11 | Electrical system: Distributor..... | 40 |
| 4.11.1 | Parts list..... | 40 |
| 4.11.2 | Distributor | 40 |
| 4.11.3 | Rotor spline connector | 41 |
| 4.11.4 | Rotor-&-contacts assembly | 42 |
| 4.11.5 | Distributor cap | 43 |

| | | |
|---------|---|----|
| 4.12 | Electrical system: Wiring, LEDs..... | 44 |
| 4.12.1 | Wiring diagram..... | 44 |
| 4.12.2 | Parts list..... | 46 |
| 4.12.3 | Cable connectors..... | 47 |
| 4.12.4 | Front cable..... | 47 |
| 4.12.5 | Distributor-cap-&-cable assembly..... | 48 |
| 4.12.6 | On-off switch..... | 48 |
| 4.12.7 | Spring clips..... | 49 |
| 4.12.8 | Battery pack..... | 49 |
| 4.12.9 | Cable clips..... | 50 |
| 4.12.10 | Back wire harness, LEDs..... | 51 |
| 4.12.11 | LED holders..... | 52 |
| 4.13 | Stand..... | 53 |
| 4.13.1 | Parts list..... | 53 |
| 4.13.2 | Stand..... | 53 |
| 4.13.3 | Brackets..... | 55 |
| 4.13.4 | Legs and crossbars..... | 55 |
| 4.13.5 | Assembling the stand..... | 56 |
| 4.13.6 | Setting up the stand..... | 58 |
| 4.14 | Backlight..... | 59 |
| 4.14.1 | Parts list..... | 59 |
| 4.14.2 | Backlight..... | 59 |
| 4.14.3 | Installing the backlight..... | 60 |
| 4.15 | Plaque..... | 61 |
| 4.15.1 | Parts list..... | 61 |
| 4.15.2 | Plaque..... | 61 |
| 4.15.3 | Installing the plaque..... | 62 |
| 4.16 | Storage box..... | 63 |
| 5 | Assembly instructions..... | 64 |
| 5.1 | Assembly sequence..... | 64 |
| 5.2 | Assembly diagram..... | 65 |
| 5.3 | Assembling the stand (Ref.)..... | 66 |
| 5.4 | Assembling the back levels..... | 67 |
| 5.4.1 | Assembling the rods-&-pistons assembly..... | 67 |
| 5.4.2 | Preliminary placement of the cylinders..... | 68 |
| 5.4.3 | Installing the valve pushers..... | 70 |

| | | |
|--------|--|-----|
| 5.4.4 | Installing the crank and rods-&pistons assembly..... | 71 |
| 5.4.5 | Installing the valve assemblies..... | 73 |
| 5.4.6 | Tightening the cylinders | 74 |
| 5.5 | Assembling the middle levels..... | 76 |
| 5.5.1 | Installing the cam disk..... | 76 |
| 5.5.2 | Assembling the pushrod assemblies..... | 78 |
| 5.5.3 | Installing the pushrod assemblies..... | 79 |
| 5.5.4 | Installing the middle driveshaft | 81 |
| 5.5.5 | Assembling the middle-plate-&gears assembly..... | 82 |
| 5.5.6 | Installing the middle-plate-&gears assembly..... | 83 |
| 5.5.7 | Setting the valve timing (Ref.) | 83 |
| 5.6 | Assembling the front levels | 84 |
| 5.6.1 | Assembling the front-plate-&gear assembly..... | 84 |
| 5.6.2 | Installing the front-plate-&gear assembly..... | 86 |
| 5.6.3 | Assembling the propeller assembly..... | 88 |
| 5.6.4 | Installing the propeller assembly | 88 |
| 5.6.5 | Adjusting the valve stem lengths | 89 |
| 5.7 | Assembling the electrical parts | 90 |
| 5.7.1 | Assembling the distributor-cap-&cable assembly | 90 |
| 5.7.2 | Installing the on-off switch..... | 91 |
| 5.7.3 | Installing the spring clips | 92 |
| 5.7.4 | Installing the battery pack..... | 93 |
| 5.7.5 | Installing the back wire harness | 94 |
| 5.7.6 | Installing the LED holders | 97 |
| 5.7.7 | Installing the distributor-cap-&cable assembly | 98 |
| 5.7.8 | Installing the rotor-&contacts assembly..... | 99 |
| 5.7.9 | Installing the distributor cap | 101 |
| 5.7.10 | Setting the spark timing (Ref.) | 101 |
| 6 | Setting the timing | 102 |
| 6.1 | Four-stroke engine cycle..... | 102 |
| 6.2 | Setting the valve timing..... | 103 |
| 6.3 | Setting the spark timing | 104 |
| 7 | Troubleshooting | 106 |
| 7.1 | Troubleshooting: Gears | 106 |
| 7.2 | Troubleshooting: Pistons | 106 |
| 7.3 | Troubleshooting: Valves | 107 |

| | | |
|-----|-------------------------------------|-----|
| 7.4 | Troubleshooting: Timing | 108 |
| 7.5 | Troubleshooting: Electrical | 109 |
| 7.6 | Troubleshooting: Broken parts | 109 |

1 Introduction

1.1 Purpose of the radial engine model

The radial engine model is a hand-cranked transparent display model that demonstrates the operation of an airplane four-stroke radial engine.

1.2 Purpose of this manual

This **Assembly Manual** is for assemblers of the radial engine model (model 2). It lists tools, materials, and parts, describes all the parts and assemblies (section 4), and gives instructions for assembling the model (section 5).

Manuals. The model has a **User Manual**, an **Assembly Manual**, and a **Maker Manual**. Before reading this Assembly Manual, read the User Manual for a description of how the radial engine model works.

1.3 Assembly time and effort

Assembling and disassembling the radial engine model will take some time and effort. You will need to be patient and meticulous. You should first read through the Assembly Manual to see what is involved. Assembling the model involves assembling many parts and doing many fine adjustments. In addition to the parts (section 4), you will need some tools (section 2) and materials (section 3). Partially disassembling and re-assembling the model may take a couple of hours. Completely disassembling and re-assembling the entire model may take all day.

1.4 Conventions

1.4.1 Tables

Throughout this Assembly Manual are multiple lists of tools, materials, parts, and step-by-step instructions. For clarity, these lists are presented as tables with color-coded banners.

| Tools | Materials | Parts | Instructions |
|---|---|--|--|
| Lists of tools needed to assemble the model. | Lists of the materials needed to assemble the model. | Lists of the custom parts needed to assemble the model. Lists of the standard parts (ready-made, store-bought parts) needed to assemble the model. | Assembly sequences and step-by-step instructions for assembling the model. |

1.4.2 Measurement units

This model was designed using US customary units. Inches and fractions, for example $1\frac{3}{8}$ " = 1.375". UTS screw sizes, for example #10-24. AWG wire sizes, for example 24 AWG.

1.4.3 Abbreviations

- ID = inner diameter, OD = outer diameter.

1.5 Overview of the model



Radial engine model 2.

Wesley Moore conceived of this transparent cross-section radial engine model with these key features:

| Radial engine model | |
|--|--|
| Key feature | Description |
| Airplane radial engine model | The 24"×24" model demonstrates the operation of an airplane four-stroke nine-cylinder radial engine. The power, valve, and spark systems are synchronized by gears. |
| Power system | The pistons move in and out within the cylinders. The pistons are connected by one master rod and eight con rods to the crankshaft, which is directly connected to the driveshaft and propeller. |
| Valve system | The intake and exhaust valves open and close. The valves are opened by valve pushers on rocker arms, which are connected by pushrods to cam follower wheels, which ride the cam tracks on the big cam disk. |
| Spark system | The spark plugs are flashing LEDs. A distributor with a rotor controls the sparks. The firing order is every alternate cylinder. |
| Hands-on | You turn the propeller with the crank handle, which turns the driveshaft and crankshaft, which makes all the other parts move. The model is hand cranked, not motorized, because it is more engaging to crank it yourself. |
| Transparent, colorful, luminous | The model is made of colored transparent acrylic plastic. You can clearly see all the moving parts. The colors are delightfully luminous when backlit. |
| Cross-section | The model is a stack of flat layers, made from flat laser-cut parts. The engine cylinders, pistons, and valves are 2D cross sections. The model is a hybrid between a 3D model and a 2D cross-section illustration. |

WARNING: BREAKABLE. Do not turn the propeller hand crank too fast or too forcefully, especially if the machine is stuck, because you could break the plastic parts! The acrylic (plexiglass) plastic parts are brittle and breakable when overstressed. This model may be operated by children and teens under the supervision of a responsible adult.

1.6 Model photos



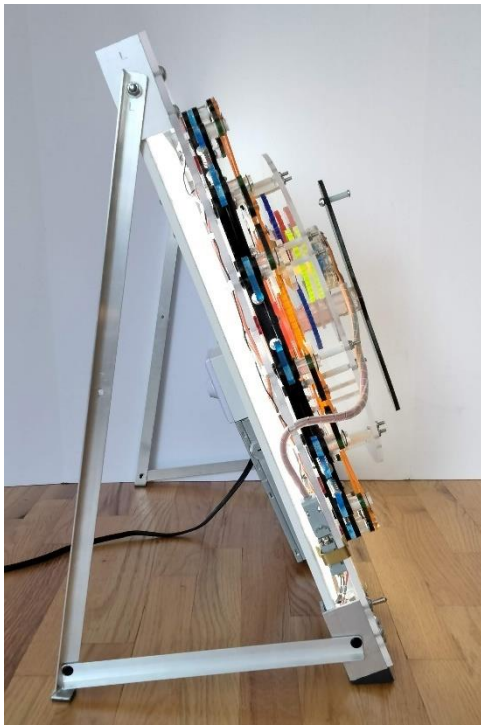
Radial engine model 2, with parts labeled.



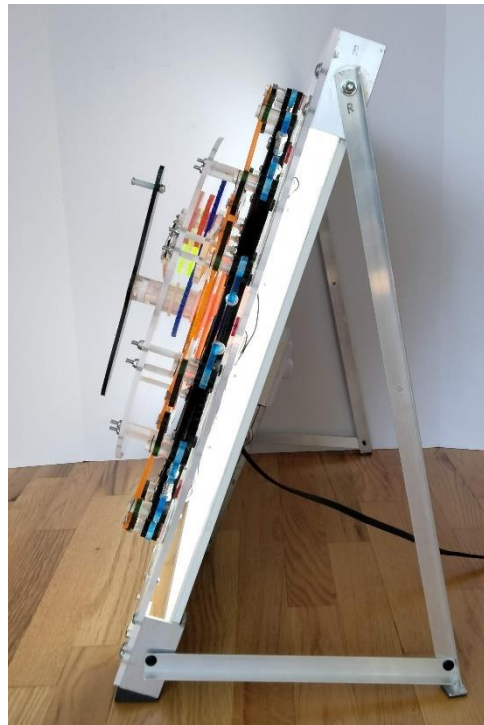
Model and stand, without the backlight.



Model and stand, with the backlight.



Model, left side view.

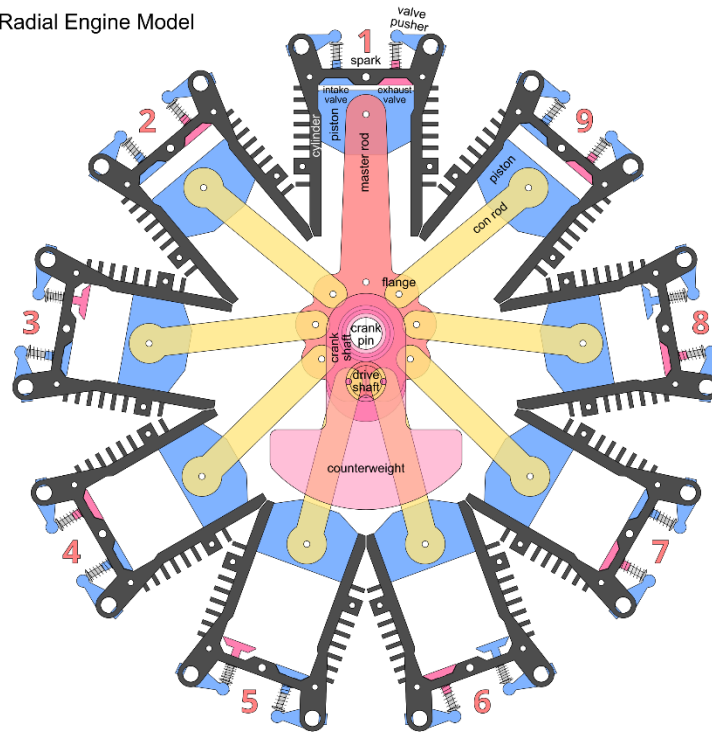


Model, right side view.

A photo of the back of the model is in the installation instructions for the back wire harness (5.7.5).

1.7 Model diagrams

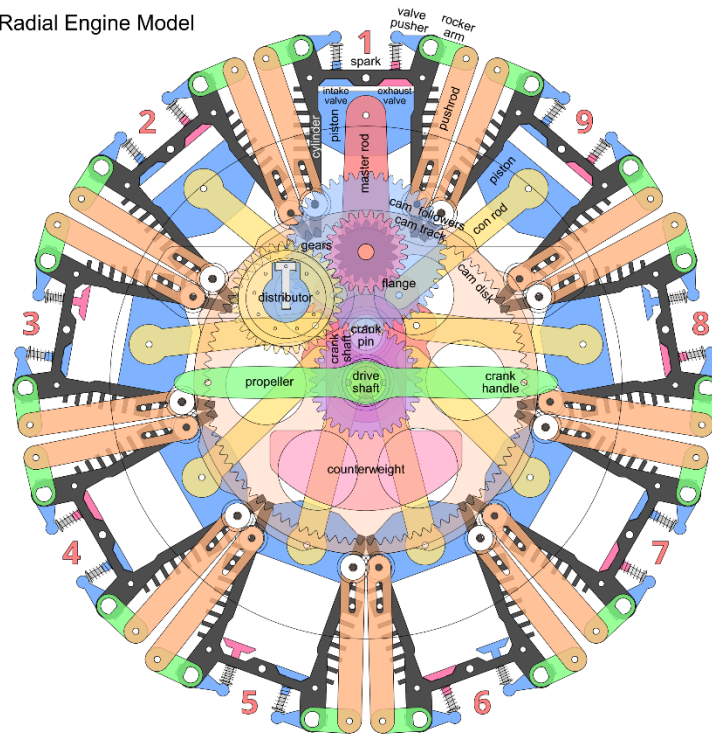
Radial Engine Model



Radial engine model by Wesley Moore 2018
Diagram by Keith Enevoldsen 2023

Radial engine model, back levels only (cylinder level).

Radial Engine Model



Radial engine model by Wesley Moore 2018
Diagram by Keith Enevoldsen 2023

Radial engine model, all mechanical parts. (Electrical wiring not shown.)

The assembly diagram (5.2) is a side/section view of the model.

2 Tools for assembly

The following tools are needed or useful for assembling and disassembling the model. (Tools for making the parts are listed in the Maker Manual.)

| Tools: Assembly tools | | |
|---|---|---|
| Screwdrivers and wrenches | | |
| Tool | Size | Usage |
| Hand screwdrivers, Phillips and flat-blade | For #4 to #10 screws | Screws. |
| Power screwdriver, Phillips (optional) | For #10 screws | Screws. Speeds up assembly and disassembly. |
| Short screwdriver with wide tip | Fits the wide shallow slot in a #8 binding screw. | Unscrewing thread-locked binding screws & posts. |
| Open-end wrenches | 3/8" (for #10 nuts) and 1/4" (for #4 nuts) | Nuts. |
| Box-end wrenches (optional) | 3/8" and 1/4" | Nuts. |
| Pair of open-end wrenches for jamming nuts, one thin | 3/8", one thin (1/8" thick) | To jam pairs of #10 nuts on the long main screws, use two open-end wrenches. One wrench should be thin, like a bicycle wrench, no thicker than a hex nut. Jamming nuts is described in the assembly instructions. |
| Box-end ratchet wrench (optional) | 3/8" | Nuts. Speeds up assembly and disassembly. |
| Socket wrench, manual or powered (optional) | 3/8" | Nuts. Speeds up assembly and disassembly. |
| Other assembly tools | | |
| Tool | Usage | |
| Pliers | General-purpose gripping. | |
| Needle-nose pliers | General-purpose gripping. | |
| Vise-grip pliers | General-purpose gripping. Unscrewing thread-locked binding screws & posts. | |
| Snap-ring pliers | Snap rings. | |
| Rubber mallet (optional) | Assembling or disassembling tight-fitting acrylic parts without damaging the acrylic. | |
| Depth gauge, manual or electronic, or a small ruler with a sliding marker (inches and mm) | Measuring the levels of parts (distances from the back plate). | |

3 Materials for assembly

3.1 Threadlocker



Primer and threadlocker.

Threadlocker prevents screws from loosening (and falling out) as the model operates. Threadlocker is critical for pivot pin joints that are made from binding screws & posts (4.2.3).

| Materials: Threadlocker | | |
|--|---|--|
| Material | Example product (in 2023) | Usage |
| Threadlocker, removable, low-strength for small screws | Loctite 222 threadlocker (PURPLE) | Removable low-strength threadlocker for small screws should be strong enough to keep the screws tight, but weak enough to allow you to unscrew the screws. |
| Threadlocker, removable, medium-strength (optional) | Loctite 242 or 243 threadlocker (BLUE) | If removable low-strength threadlocker is not strong enough, use removable medium-strength threadlocker. |
| Threadlocker primer | Loctite 7471 or 7649 primer | Threadlocker primer is required for aluminum or stainless-steel screws. |
| Cleaner/degreaser | Loctite SF 7070 cleaner or any degreaser, such as acetone | Cleaning screw threads. |

| Instructions: Applying threadlocker | | |
|-------------------------------------|---------------------|---|
| # | Step | Instructions |
| 1 | Clean the threads. | Clean the threads, even for new screws, to remove any oils or coatings. You can use any degreaser, such as acetone. |
| 2 | Apply primer. | You must apply a primer if the screws are aluminum or stainless steel. The anaerobic threadlocker is activated by the primer. Read the manufacturer's instructions. |
| 3 | Apply threadlocker. | Apply removable low-strength threadlocker for small screws (PURPLE). If that is not strong enough, apply removable medium-strength threadlocker (BLUE). |

Avoid unscrewing thread-locked screws. If you unscrew a thread-locked screw, you should clean the threads and reapply primer and threadlocker when you screw it in again.

3.2 Dry lubricant

| Materials: Dry lubricant | | |
|--------------------------|---|--|
| Material | Example product (in 2023) | Usage |
| Dry lubricant | DuPont non-stick dry-film lubricant with Teflon | Lubricate acrylic-on-acrylic interfaces. |

Lubrication is required in at least one location when you assemble this model. We recommend using a dry lubricant because it is less messy than oil lubricant. There are many kinds of dry lubricants that you can use. We recommend a Teflon dry-film lubricant that is applied as a liquid and then dries. Apply the lubricant to the contact surfaces only.

Lubrication is required for the 18 rocker-pusher shafts, and may be helpful in other places, wherever acrylic rubs against acrylic. Lubrication is NOT needed wherever low-friction spacers and bushings are used (such as the master rod hub around the crankpin, and the cam disk hub around the driveshaft).

| Locations for dry lubrication | | |
|---|----------|--------------------|
| Location | # places | Dry lube required? |
| Rocker-pusher shafts and shaft holes in the rocker-pusher supports. | 18 | Required |
| Gear shafts and shaft holes in the front and middle plates. | 4 | Optional |
| Back shaft and shaft hole in the back plate. | 1 | Optional |
| Piston edges and piston slots. | 18 | Optional |
| Gear teeth. | 6 | Optional |

3.3 Plastic cleaner

| Materials: Plastic cleaner | | |
|----------------------------|---|-------------------|
| Material | Example products | Usage |
| Plastic cleaner | Mild soap/detergent or plastic cleaner. | Cleaning acrylic. |

You can clean acrylic with mild soap or detergent and water, or you can use a special-purpose acrylic plastic cleaner. Use a clean, soft cloth or microfiber cloth to avoid scratching the surface. Avoid cleaners that contain abrasives, alcohol, ammonia, or aromatics. There are also products to restore scratched acrylic.

4 Parts and assemblies

This section describes all the parts and several key assemblies.

Assembly/installation instructions are in section 5.

4.1 General info about parts

4.1.1 Custom parts and standard parts

Custom parts are the parts that are made for this model, such as laser-cut acrylic parts and wire harnesses.

Standard parts are ready-made, store-bought parts, such as screws and nuts.

4.1.2 Acrylic parts

Most of the custom parts are made from acrylic plastic: laser-cut acrylic sheets and saw-cut acrylic rods and tubes. Acrylic parts are cemented (welded) together with acrylic solvent cement. See the Maker Manual.

WARNING: BREAKABLE. Do not turn the propeller hand crank too fast or too forcefully, especially if the machine is stuck, because you could break the plastic parts! The acrylic (plexiglass) plastic parts are brittle and breakable when overstressed. This model may be operated by children and teens under the supervision of a responsible adult.

4.2 Fasteners

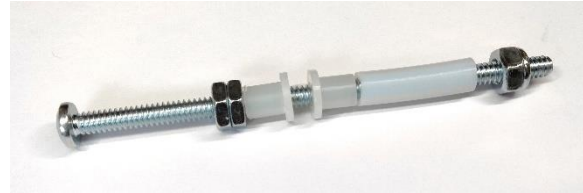
4.2.1 Screw sizes

| Preferred screw sizes | |
|------------------------|-------------------------------|
| #Diameter-thread (UTS) | Usage |
| #10-24 | Large machine screws and nuts |
| #8-32 | Medium screws & posts |
| #4-40 | Small machine screws and nuts |

4.2.2 Main screws



Main screw and short cylinder screw with nylock nuts.



Main screw with hex nuts, spacer sleeves, and a nylock nut.

The plates are held together by a circle of 18 main screws (#10-24 × 4", pan head, Phillips). The main screws extend forward from the back plate, supporting the cylinders, the pushrods, the middle plate, and the front plate. The main screws have nuts and sleeves to hold all the parts at the correct distance from the back plate. See the assembly diagram (5.2). Each cylinder is held to the back plate by two main screws (#10-24 × 4") and two short cylinder screws (#10-24 × 1.5"). We prefer Phillips cross slot over straight slot.

4.2.3 Pivot pins

The model has pivot pin joints on the con rods and pushrods.



Binding screws & posts (1/4" and 3/8") are used as pivot pins.

| Pivot pin joints | | | |
|------------------------------|--------------|--------------|----------|
| Location | Part | Size | Quantity |
| Con rod to master rod flange | Screw & post | #8-32 × 1/4" | 8 |
| Con rod to piston | Screw & post | #8-32 × 1/4" | 9 |
| Pushrod to cam follower | Screw & post | #8-32 × 3/8" | 18 |
| Pushrod to rocker arm | Screw & post | #8-32 × 3/8" | 18 |

Screws & posts (barrels). The pivot pins are common lightweight binding screws & posts. (Some other names for these fasteners are Chicago screws or barrel nuts.) The smooth posts (barrels) make them suitable for use as pivot pins. The screws & posts have a low profile (the heads are thin), so they do not require much clearance. (Alternative: Your model may use different fasteners as pivot pins. See the Design Alternatives document.)

Threadlocker for screws & posts. The rotation of the parts may loosen your screws & posts. Binding screws & posts have a loose fit. To solve this problem, you should apply primer and threadlocker (3.1). Avoid unscrewing thread-locked screws. If you unscrew a thread-locked screw, you should clean the threads and reapply primer and threadlocker when you screw it in again. (When shopping for new screws & posts, look for screws and posts that have a tighter fit. If they are tight enough, you may not need to apply threadlocker.)

Unscrewing tight screws & posts. It may be very difficult to unscrew thread-locked binding screws & posts. The low-profile head of the screw may have only a shallow drive slot in the head of the screw, so you may need to find a screwdriver that fits the slot perfectly. Furthermore, the low-profile head of the post (barrel) may have no drive slot or drive socket at all, so you cannot use a screwdriver. If the heads are round, you cannot use a wrench, so you may need to use vise-grip pliers! When shopping for screws & posts, you may want to try to find screws & posts that have low-profile heads that are made to be gripped with a screwdriver or a wrench (perhaps hex heads).

4.3 Plates

4.3.1 Parts list

| Plates: Custom parts | |
|----------------------|----------|
| Part | Quantity |
| Back plate | 1 |
| Front plate | 1 |
| Middle plate | 1 |

4.3.2 Back plate



Back plate with cylinder numbers and plaque.

The clear back plate supports the entire model. It holds the back end of the crankshaft, the 18 main screws, and the 18 short cylinder screws. It holds the back wire harness, the batteries, and the on-off switch. The brackets for the stand are mounted on the back plate.

Cylinder numbers are cemented to the back plate. The cylinder numbers are colored transparent acrylic so they are luminous when backlit. (Notice that the numbers are positioned at least 1" from the edge of the plate, so they will be backlit even if the backlight has a 1"-wide opaque frame.)

The plaque (4.15) is attached to the back plate.

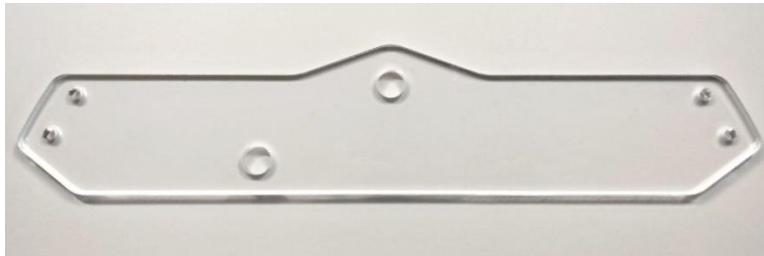
4.3.3 Front plate



Front plate.

The clear front plate supports the front ends of the driveshaft, the gears shaft, and the distributor shaft. The distributor cap is attached to the front plate. The front plate is supported by the 18 main screws.

4.3.4 Middle plate



Middle plate.

The clear middle plate supports the back ends of the gears shaft and the distributor shaft, because these shafts cannot reach to the back plate. The middle plate is supported by four of the main screws.

4.4 Rings

4.4.1 Parts list

Low-friction rings may be custom-made (by laser cutting) or ready-made (store-bought standard parts).

| Rings: Custom parts or standard parts | | | | | | |
|---------------------------------------|----------------------|-------|-------|-------------------------------------|--------------------------------------|--|
| Part | Material | ID | OD | 1/8" thick Quantity (approx.) | 1/16" thick Quantity (approx.) | Usage |
| Spacer rings | Low-friction plastic | 0.5" | 1" | 6 | 8 | Spacer rings on 0.5" shafts. |
| Spacer rings | Low-friction plastic | 1" | 1.25" | 2 | 2 | Spacer rings in-line with 1.25" OD shafts. |
| Bushing rings | Low-friction plastic | 1.25" | 1.5" | 8 | 0 | Bushing rings on 1.25" OD shafts, inside 1.5" ID hubs. |
| Spacer rings | Low-friction plastic | 1.25" | 1.75" | 6 | 2 | Spacer rings on 1.25" OD shafts. |

Low-friction plastics include nylon, PTFE (Teflon), and acetal (Delrin). For laser cutting, you can use acetal, but not nylon or PTFE.

4.4.2 Rings



Low-friction rings.

Low-friction plastic rings are used as spacers and bushings on the driveshaft, crankshaft, and the gear shafts.

Placement of the rings is shown in the assembly diagram (5.2) and described in the assembly instructions (section 5).

4.5 Sleeves

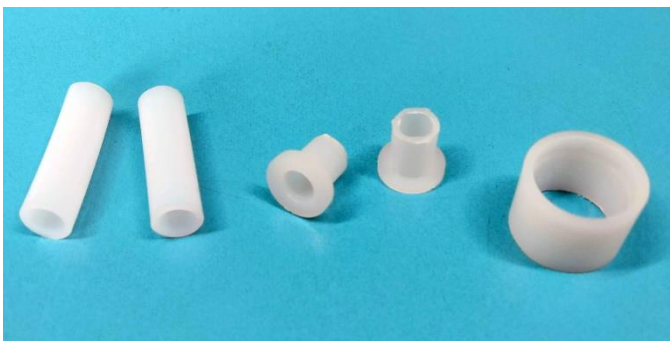
4.5.1 Parts list

Sleeves may be custom-made (by cutting tubes) or ready-made (store-bought standard parts).

| Sleeves: Custom parts or standard parts | | | | | | |
|---|---------------------------|------------------------------|------------------------------|----------------------------|----------|--|
| Part | Material | ID | OD | Length | Quantity | Usage |
| Screw sleeves | Plastic tube | ~3/16" (~0.2") (~5 mm) | ~9/32" (~0.3") (~7 mm) | 1" | 14 | Spacer sleeves on #10 main screws. |
| Screw sleeves | Plastic tube | ~3/16" | ~9/32" | 3/4" | 4 | Spacer sleeves on #10 main screws. |
| Screw sleeves | Plastic tube | ~3/16" | ~9/32" | 1" | 1 | Rotating sleeve on propeller crank handle. |
| Screw sleeves, wide or flanged | Low-friction plastic tube | ~3/16" | ~3/8" (~0.4") (~10 mm) | 3/8" (including flange) | 36 | Low-friction spacer sleeves on #10 main screws, wide or flanged where they touch the sliding pushrods. |
| Rod sleeve, narrow | Plastic tube (acrylic) | 1/2" | ≤5/8" | 7/16" | 1 | Sleeve on gear33_distributor shaft, must be narrow for clearance. |
| Rod sleeves | Plastic tube (acrylic) | 1/2" | ~5/8" | 3/8" | 18 | Spacer sleeves on rocker-pusher shafts. |
| Driveshaft sleeves | Plastic tube (acrylic) | 1.25" | ~1.5" | 3/8" | 2 | Spacer tube sleeves on middle driveshaft. |

Low-friction plastics include nylon, PTFE (Teflon), and acetal (Delrin).

4.5.2 Sleeves



Sleeves, cut from plastic tubes or ready-made.



Sleeves, cut from acrylic tubes.

Sleeves are used as spacers on screws and small and large shafts.

Placement of the sleeves is shown in the assembly diagram (5.2) and described in the assembly instructions (section 5).

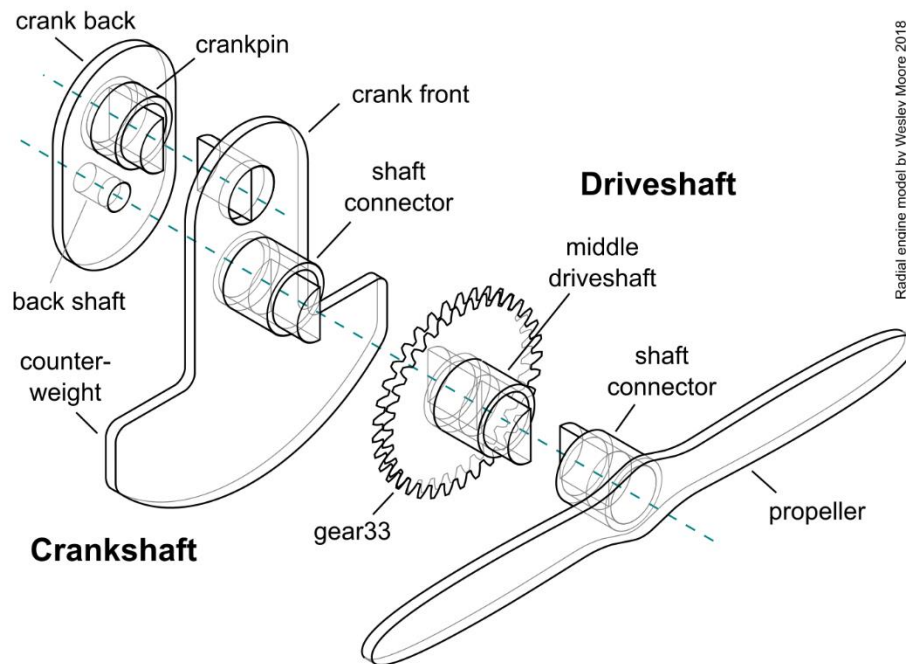
4.6 Power system: Crankshaft, driveshaft, propeller

4.6.1 Parts list

| Crankshaft, driveshaft, propeller: Custom parts | |
|---|----------|
| Part | Quantity |
| Crank back (with shafts) | 1 |
| Crank front (with shafts) | 1 |
| Middle driveshaft with gear33 | 1 |
| Propeller (with shaft) | 1 |

| Crankshaft, driveshaft, propeller: Standard parts | | | |
|---|---------------|----------|-------------------------|
| Part | Size | Quantity | Usage |
| Machine screw, pan head | #10-24 × 1.5" | 1 | Propeller crank handle. |
| Nylock nut | #10-24 | 1 | Propeller crank handle. |
| Sleeve | 3/16" ID × 1" | 1 | Propeller crank handle. |

4.6.2 Crankshaft-driveshaft-propeller assembly



Crankshaft-driveshaft-propeller assembly.

The crankshaft-driveshaft-propeller assembly has four segments: crank back, crank front, middle driveshaft, and propeller. The driveshaft and crankpin shaft are made from acrylic tubes (1" ID, 1.25" OD).

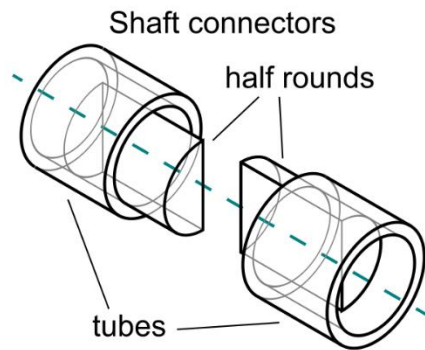
In a real radial engine, the driving force goes in this direction:

Combustion pushes piston → con rod → master rod flange → crankshaft → driveshaft → propeller.

In this model, the driving force goes in the opposite direction:

User turns propeller → driveshaft → crankshaft → master rod flange → con rod → piston.

4.6.3 Shaft connectors



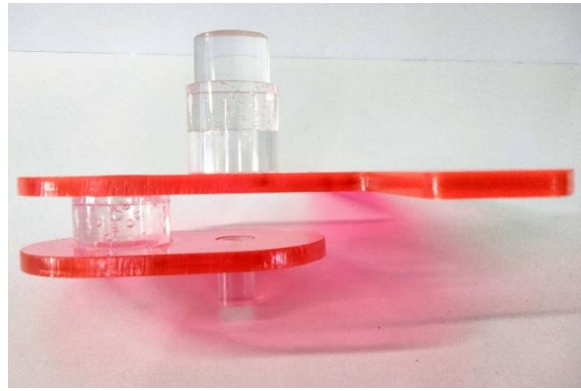
Shaft connectors.

Shaft connectors connect the segments rigidly, but they are easy to push together and pull apart. The end of the shaft tube has a protruding half-round rod, cemented to the inside of the tube on one side, leaving the other side hollow. Each connector is half plug and half socket, so two identical connectors will fit together.

4.6.4 Crankshaft assembly



Crankshaft.



Crankshaft.

The crankshaft has the driveshaft in the center and the crankpin offset from the center. The master rod hub is mounted on the crankpin. The crankshaft is assembled from the crank back and the crank front.

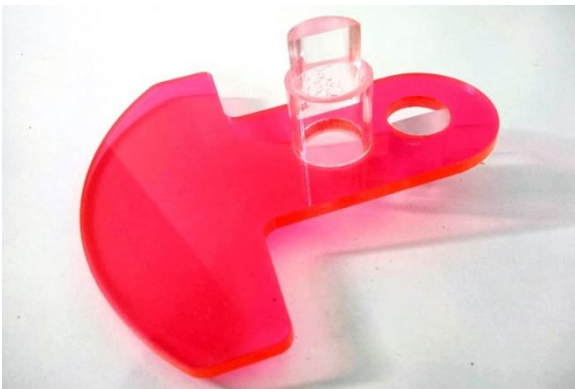


Crank back (front side).



Crank front (back side).

The crank back is the smaller back half of the crank. The back side has a small back shaft. The front side has the crankpin, which has a push-in shaft connector.



Crank front (front side).



Crank front (back side).

The crank front is the bigger front half of the crank, with the counterweight lobe. The back side connects to the crankpin with a push-in shaft connector. The front side connects to the driveshaft with a push-in shaft connector. Installation instructions are in 5.4.4.

4.6.5 Middle driveshaft with gear33



Middle driveshaft with gear33.

The middle segment of the driveshaft is connected to the crankshaft behind and the propeller in front, using push-in shaft connectors. The middle driveshaft is cemented to gear33, which drives the entire gear train.

Installation instructions are in 5.5.4.

4.6.6 Propeller assembly



Propeller assembly.

The propeller assembly consists of the propeller, the shaft connector, and the crank handle.

Shaft connector. The propeller connects to the driveshaft with a push-in shaft connector. The propeller hub is cemented to the shaft connector. The built-in screws in the hub are for added strength, not for disassembly.

Crank handle. You will manually turn the propeller COUNTERCLOCKWISE to turn the driveshaft and all the other moving parts. Counterclockwise is the normal propeller direction for single-engine airplanes.

Hand cranked, not motorized. The model is hand cranked, not motorized, for two reasons. Firstly, it is more fun, more engaging, and more instructional, if you turn the crank yourself and watch the effect of your actions. Secondly, a motor would cause the model to undergo many more machine cycles, and the acrylic plastic parts would wear out and break sooner.

Propeller shape. The propeller is built to be strong and durable because it is used as a hand crank. The propeller blades and hub are made from a single piece of thick acrylic. The blades are flat, not pitched like a real propeller. The propeller outline is roughly based on 1920s-1940s-era propellers. The propeller is very small compared to the size of the engine — if it were to scale, its length would be about three times the diameter of the engine!

Assembly and installation instructions are in 5.6.3 and 5.6.4.

4.7 Power system: Cylinders, pistons, con rods

4.7.1 Parts list

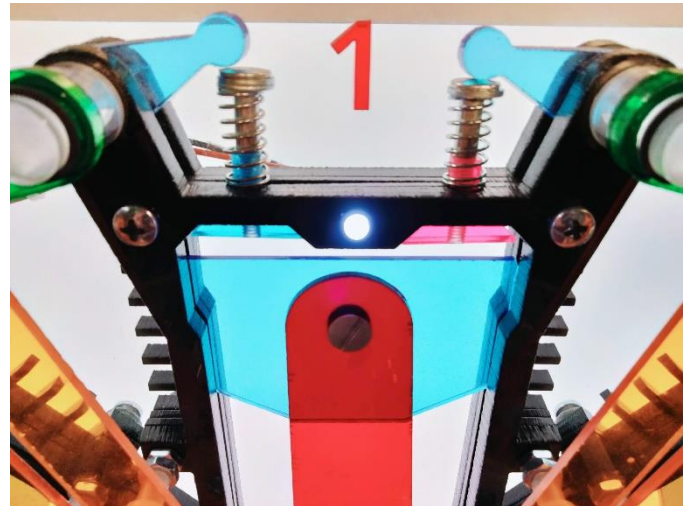
| Cylinders, pistons, rods: Custom parts | |
|---|----------|
| Part | Quantity |
| Cylinder backs | 9 |
| Cylinder fronts | 9 |
| Pistons | 9 |
| Master rod | 1 |
| Con rods | 8 |

| Cylinders, pistons, rods: Standard parts | | | |
|---|---------------|----------|--|
| Part | Size | Quantity | Usage |
| Machine screws, pan head, Phillips | #10-24 × 4" | 18 | Main screws for cylinders, pushrods, and plates. |
| Machine screws, pan head, Phillips | #10-24 × 1.5" | 18 | Short cylinder screws. |
| Nylock nuts | #10-24 | 36 | Main screws and short cylinder screws. |
| Hex nuts | #10-24 | 36 | Each main screw has two hex nuts (jammed) to hold the cylinder. (We use two standard hex nuts, not thin jam nuts.) |
| Pivot pins (binding screws & posts) | #8-32 × 1/4" | 18 pairs | Con rods. |

4.7.2 Cylinders



Cylinder, two parts: cylinder back and cylinder front.



Cylinder, assembled. The piston slot is on the middle-front layer. The valve holes go through both middle layers. The valve pushers are between the rocker supports on the front and back layers.

Nine cylinders are attached to the back plate. These roughly rectangular parts represent 2D cross sections of the 3D cylinders in a real engine. The cylinders are numbered 1 to 9, counterclockwise, starting with the top cylinder #1.

Each assembled cylinder has piston slots to hold the piston and let it slide, valve holes to hold the valves and let them slide, rocker supports to hold the rocker-pusher shafts and let them turn, a spark plug hole to hold the LED, and holes for the screws that hold the cylinder to the back plate.

Each cylinder is assembled from two parts: the cylinder back and the cylinder front. The cylinder back is made of four layers (layers 0 to 3) cemented together. The cylinder front is a single layer (layer 4). This table lists the features of each layer:

| Cylinder layers | | | | | | | | | | | |
|-----------------|---------|--------------|------|----------------|--------------|-------------|-----------------|-------------|----------|--------------|--------------|
| Part | Layer # | Layer | Thk. | Cylinder walls | Piston slots | Valve holes | Rocker supports | Screw holes | LED hole | Cooling fins | Spacer rings |
| Cylinder front | 4 | Front | 1/4" | ✓ | | | ✓ | ✓ | ✓ | | |
| Cylinder back | 3 | Middle-front | 1/8" | ✓ | ✓ | ✓ | | ✓ | ✓ | | |
| | 2 | Middle-back | 1/8" | ✓ | | ✓ | | ✓ | ✓ | | |
| | 1 | Back | 1/4" | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| | 0 | Spacers | 1/4" | | | | | ✓ | | | ✓ |

Installation instructions are in 5.4.2 and 5.4.6.

4.7.3 Pistons

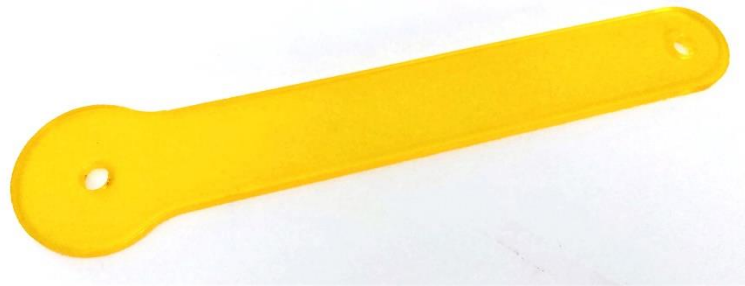


Piston.

The nine pistons slide in the piston slots in the cylinders. These roughly rectangular pistons represent 2D cross sections of the 3D cylindrical pistons in a real engine.

Pistons are parts of the rods-&-pistons assembly (4.7.6).

4.7.4 Con rods



Con rod.

Eight con rods (connecting rods) connect pistons to the flange on the master rod. The connections at both ends are pivot pins.

Con rods are parts of the rods-&-pistons assembly (4.7.6).

4.7.5 Master rod

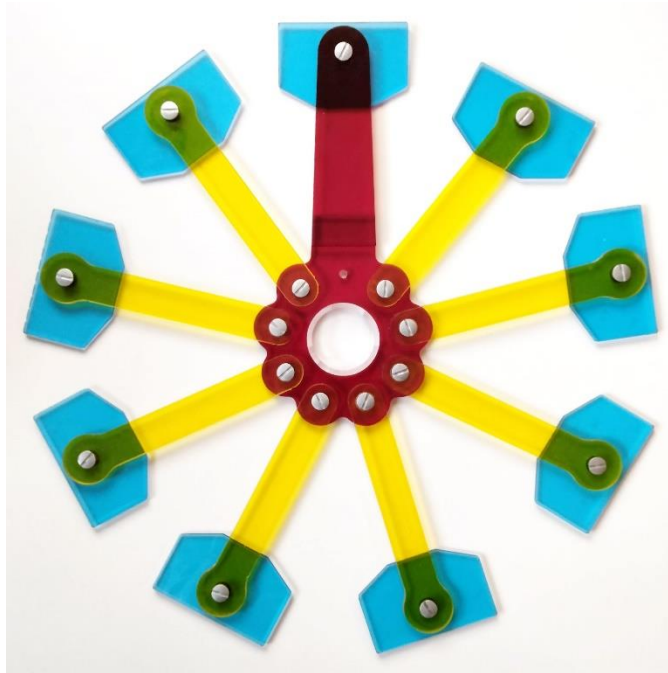


Master rod (and flange).

There is one master rod, which connects to piston #1. The master rod's big end has a flange (collar) with holes to connect to the other eight con rods with pivot pins. The master rod (and flange) has a front and back: the master rod is on the front side and the flange is on the back side. The eight con rods will be attached with pivot pins to the front side of the flange, so all nine rods are at the same level. The master rod hub will fit around the crankpin shaft. The hub is made from a short, wide tube that is big enough to accommodate bushing rings inside.

The master rod is part of the rods-&-pistons assembly (4.7.6).

4.7.6 Rods-&-pistons assembly

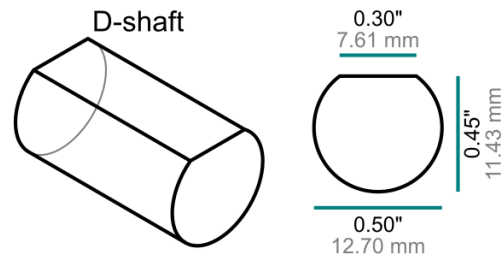


Rods-&-pistons assembly.

The rods-&-pistons assembly consists of the master rod (and flange), eight con rods, and nine pistons, all connected with pivot pins.

Assembly and installation instructions are in 5.4.1 and 5.4.4.

4.8 Small shafts for gears and rocker-pushers



*D-shaft profile: diameter=0.50",
flat diameter=0.45", flat width=0.30".*

The model has 20 small shafts (smaller than the driveshaft): the gears shaft (4.9), the distributor shaft (4.11.3), and 18 rocker-pusher shafts (4.10.4).

All small shafts are 1/2"-diameter acrylic D-shafts connected to D-holes in the acrylic parts. (Alternative: Your model may use different kinds of shafts. See the Design Alternatives document.)

4.9 Gears

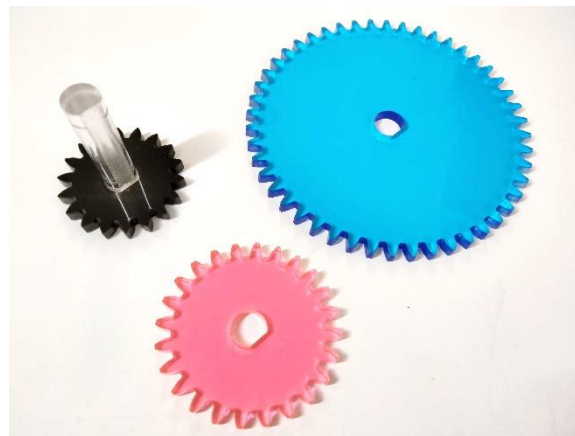
4.9.1 Parts list

| Spur gears: Custom parts | |
|--|----------|
| Part | Quantity |
| Gear33_driveshaft (on middle driveshaft) | 1 |
| Gear18 (with D-shaft) | 1 |
| Gear24 | 1 |
| Gear48 | 1 |
| Gear33_distributor | 1 |

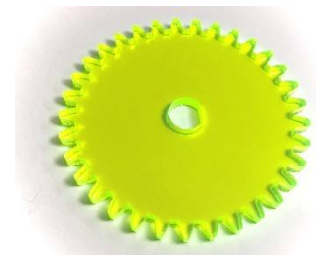
4.9.2 Gears



Gear33_driveshaft will be cemented onto the middle driveshaft.



Gear18 (with D-shaft), gear48, and gear24.



Gear33_distributor.

The model has six gears: five spur gears and one internal gear. When the driveshaft rotates, the gear train (4.9.3) drives the cam disk and the distributor rotor.

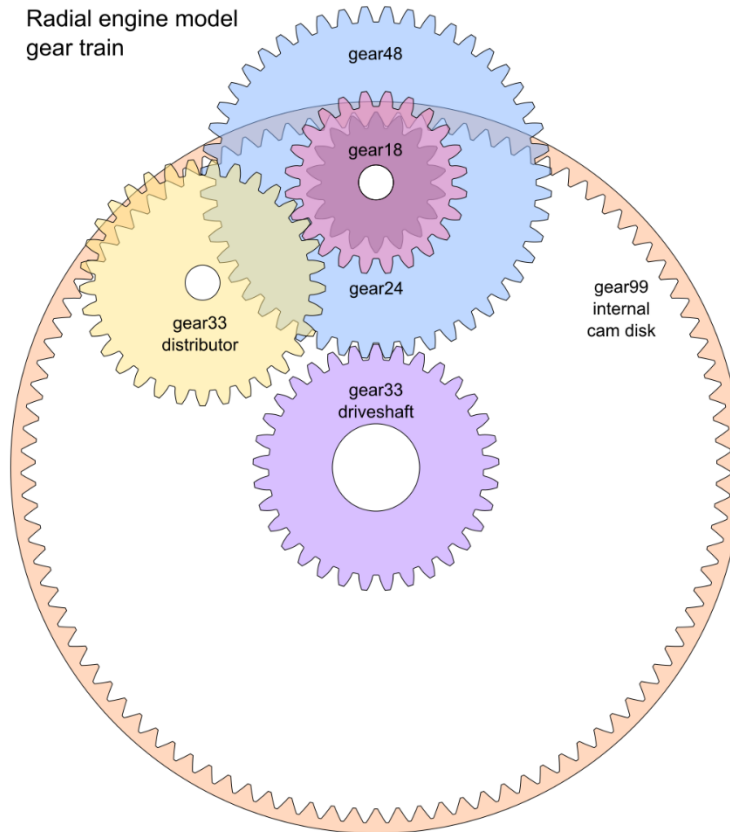
Gear33_driveshaft is cemented to the middle driveshaft (4.6.5). (Installation instructions are in 5.5.4.)

Gear18, gear24, and gear48 are on the gears shaft. (Assembly instructions are in 5.5.5.)

Gear33_distributor is on the distributor shaft. (Assembly instructions are in 5.6.1.)

Gear99_internal is built into the cam disk (4.10.10). (Installation instructions are in 5.5.1.)

4.9.3 Gear train



Gear train design by Wesley Moore 2016
Diagram by Keith Enevoldsen 2022

Gear train.

The gear train has six gears: gear33_driveshaft, gear18, gear24, gear48, gear33_distributor, and gear99_internal_cam_disk. The numbers indicate the number of teeth.

How it works:

- Two turns of the crankshaft-driveshaft = one four-stroke cycle.
- Cam disk gear train: 33 → 48 → 18 → 99.
 - The cam disk turns at $(33/48) \times (18/99) = 1/8$ the rotation rate of the driveshaft.
- Distributor gear train: 33 → 48 → 24 → 33.
 - The distributor gear turns at $(33/48) \times (24/33) = 1/2$ the rotation rate of the driveshaft.

| Gear ratios | | | |
|--------------------------|---------|------------------|--------------------------|
| Gear | # teeth | Gear speed ratio | Gear speed calculation |
| gear33_driveshaft | 33 | 1 | 1 |
| gear18 | 18 | 11/16 | 33/48 |
| gear24 | 24 | 11/16 | 33/48 |
| gear48 | 48 | 11/16 | 33/48 |
| gear33_distributor | 33 | 1/2 | $(33/48) \times (24/33)$ |
| gear99_internal_cam_disk | 99 | 1/8 | $(33/48) \times (18/99)$ |

The gear parameters for this model are described in the Maker Manual.

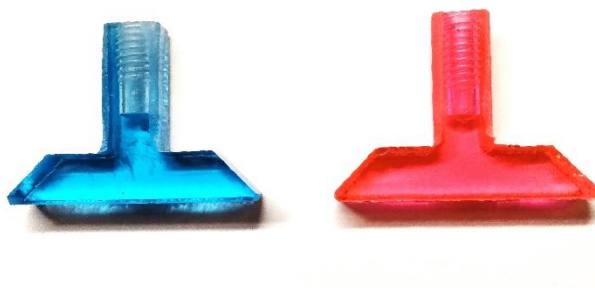
4.10 Valve system: Valves, rocker-pushers, pushrods, cam disk

4.10.1 Parts list

| Valve system: Custom parts | |
|-------------------------------|----------|
| Part | Quantity |
| Cam disk | 1 |
| Pushrods | 18 |
| Rocker arms | 18 |
| Valve pushers (with D-shafts) | 18 |
| Valves | 18 |

| Valve system: Standard parts | | | |
|-------------------------------------|---|----------|--|
| Part | Size | Quantity | Usage |
| Grooved wheels (nylon) | ~1" (25 mm) flange OD, ~0.8" (20 mm) roller OD, ~1/4" (6 mm) ID, ~1/8" (3 mm) roller thk., ~1/4" (6 mm) total thk. (Example product in 2023: Prime-Line sliding door wheel.) | 18 | Cam followers. |
| Pivot pins (binding screws & posts) | #8-32 × 3/8" | 36 pairs | Pushrods. |
| Binding screws & post extensions | #8-32 × 1/4" with 1/2" post extension (1/4" threaded end) | 18 pairs | Valve stems. |
| Washers | #8 | ~ 60 | Valve stems. Stem length adjustment washers. |
| Compression springs | 3/8" diameter, 3/4" long | 18 | Valve stems. |
| Snap rings | For 1/2"-diameter rod | 19 | Rocker-pusher shafts, gears shaft. |

4.10.2 Valves

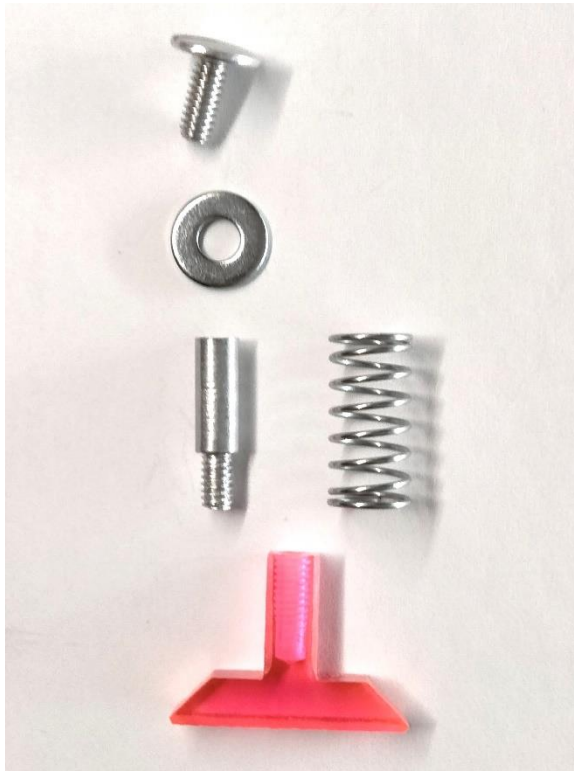


Valves, intake (blue) and exhaust (red or pink).

Each cylinder has two valves, an intake valve colored blue (a cool color), on the left side (looking at cylinder #1), and an exhaust valve colored red or pink (a warm color), on the right side.

Valves are parts of the valve assemblies (4.10.3).

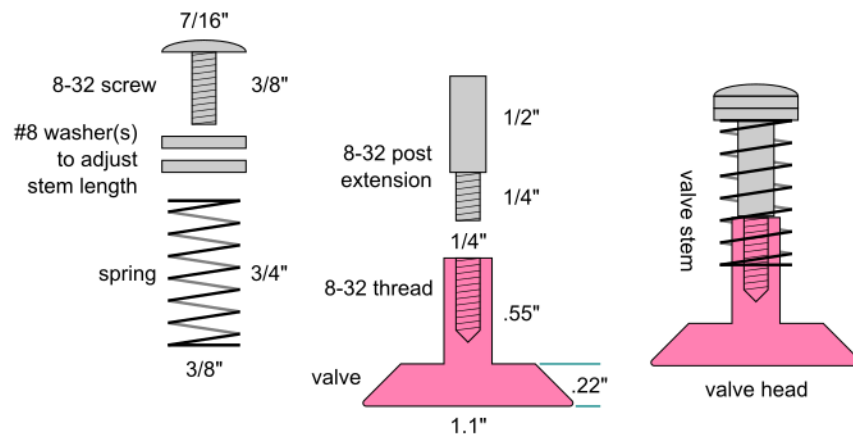
4.10.3 Valve assemblies



Valve, disassembled.



Valve assembly.



Valve assembly.

Each valve assembly consists of a valve, a screw, a post extension, a valve spring, and some washers. The spring on the valve stem returns the valve to its closed position and pushes (by means of the rocker arm and pushrod) the cam follower onto the cam track. The washers are used to adjust the valve stem length.

Installation instructions are in 5.4.5. Valve stem length adjustment instructions are in 5.6.5.

4.10.4 Valve pushers



Valve pusher with D-shaft.

The valve pushers push the valves open. Each valve pusher is rigidly connected to a rocker-pusher shaft.

The valve pushers are cemented to the shafts. (Alternative: The valve pusher may be fastened to the shaft with a screw. See the Design Alternatives document.)

Valve pushers are parts of the rocker-pusher assemblies (4.10.6).

4.10.5 Rocker arms

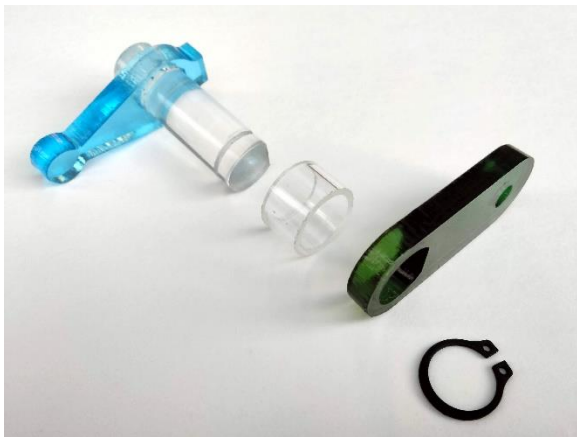


Rocker arm.

The rocker arms turn the rocker-pusher shafts. Each rocker arm is rigidly connected to a rocker-pusher shaft and is connected to a pushrod with a pivot pin.

Rocker arms are parts of the rocker-pusher assemblies (4.10.6) and the pushrod assemblies (4.10.9).

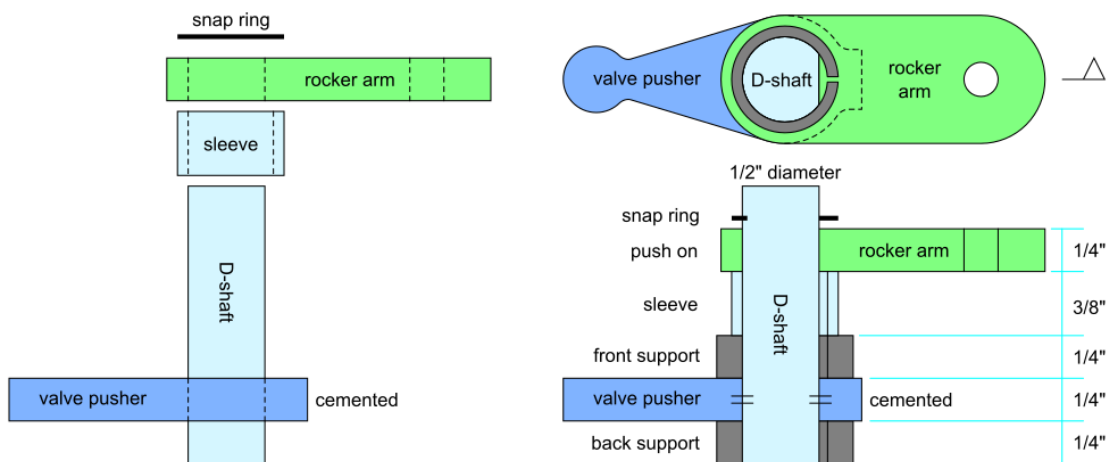
4.10.6 Rocker-pusher assemblies



Rocker-pusher disassembled.



Rocker-pusher assembly.



Rocker-pusher assembly with cemented valve pusher and push-on rocker arm.

Each rocker-pusher assembly consists of a rocker arm and a valve pusher, both rigidly connected to a rocker-pusher D-shaft. When a pushrod pushes the rocker arm, it makes the valve pusher push the valve open.

The valve pusher is cemented to the shaft, and the rocker arm is pushed onto the D-shaft and held at the correct level by a sleeve and a snap ring. (Alternative: The valve pusher may be fastened to the shaft with a screw, and the rocker arm may be cemented to the shaft. See the Design Alternatives document.)

Each rocker-pusher functions as a single rigid assembly, but you will not assemble it as a stand-alone assembly. Instead, you will first install the valve pushers (5.4.3), then fasten the rocker arm to a pushrod assembly (5.5.2), and finally push the rocker arm onto the rocker-pusher D-shaft (5.5.3).

The rocker-pusher assemblies may be somewhat irregular. The angle between the valve pusher and the rocker arm may vary from the ideal (180°). You will compensate for these irregularities by adjusting the valve stem lengths (5.6.5).

4.10.7 Pushrods



Pushrod.

The 18 pushrods are connected to the cam follower wheels on one end and to the rocker arms on the other end. The connections at both ends are pivot pins. The slot goes on a main screw, between two low-friction sleeves, allowing the pushrod to slide in and out.

Pushrods are parts of the pushrod assemblies (4.10.9).

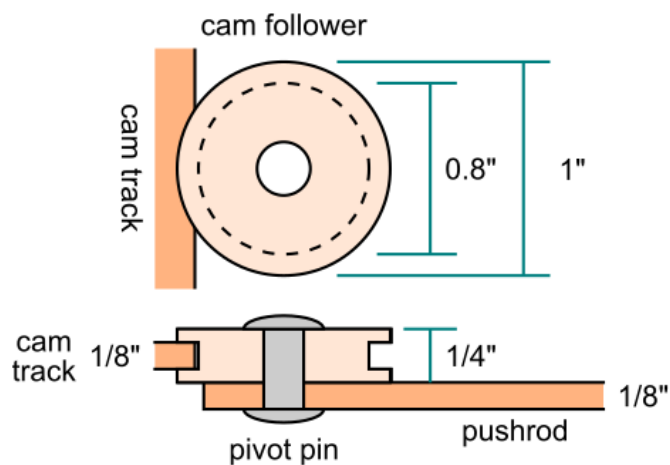
4.10.8 Cam followers



Cam follower (grooved wheel).



Cam follower (grooved wheel) on cam track.



Cam follower.

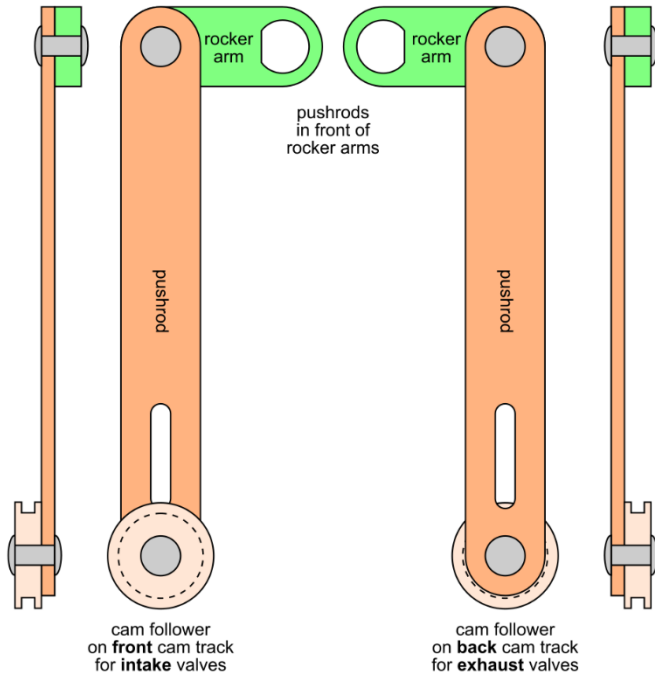
The cam followers are store-bought nylon grooved wheels, like sliding door wheels. The flanges on the wheels keep the cam followers on the cam tracks. Dimensions are shown in the diagram and the parts list (4.10.1).

Cam followers are part of the pushrod assemblies (4.10.9).

4.10.9 Pushrod assemblies



Pushrod assemblies.



Pushrod assemblies for intake and exhaust valves.

Each pushrod assembly consists of a pushrod, a rocker arm, and a cam follower, all connected with pivot pins. The intake valve cam followers are on the front side of the pushrod to run on the front cam track, whereas the exhaust valve cam followers are on the back side of the pushrod to run on the back cam track.

Assembly and installation instructions are in 5.5.2 and 5.5.3.

4.10.10 Cam disk



Cam disk with intake cam track (front) and exhaust cam track (back).

The cam disk controls the intake and exhaust valves. The cam disk has three layers: back cam disk (exhaust cam track), front cam ring (intake cam track), and middle ring. This table lists the features of each layer:

| Cam disk layers | | | | | |
|-----------------|----------------|------|-----------|-----------------|-----|
| Part | Layer | Thk. | Cam track | Gear99_internal | Hub |
| Cam disk | Front cam ring | 1/8" | Intake | ✓ | |
| Cam disk | Middle ring | 1/4" | | ✓ | |
| Cam disk | Back cam disk | 1/8" | Exhaust | | ✓ |

The cam followers, flanged wheels, run along the cam tracks.

The cam disk hub will fit around the driveshaft. The hub is made from a short, wide tube that is big enough to accommodate bushing rings inside.

Cam disk geometry. Each engine cycle has four strokes: intake, compress, power, and exhaust. In a four-stroke radial engine, each valve opens once for every two rotations of the crankshaft-driveshaft. In this model, one turn of the cam disk makes four engine cycles (a quarter turn = one engine cycle), so each cam track has four lobes to open the valves. The cam disk rotates at one eighth the rotation rate of the driveshaft. The combination of four lobes per track and one eighth the rotation rate makes the valve period be half the driveshaft period. For a more detailed description of the cam disk geometry, see the Maker Manual.

Installation instructions are in 5.5.1.

4.11 Electrical system: Distributor

4.11.1 Parts list

| Distributor: Custom parts | |
|---|----------|
| Part | Quantity |
| Distributor cap | 1 |
| Distributor spline connector (with D-shaft) | 1 |
| Distributor rotor (with springs) | 1 |
| Distributor rotor contacts strip | 1 |

| Distributor: Standard parts | | | |
|---------------------------------------|--------------|----------|--|
| Part | Size | Quantity | Usage |
| Machine screws, flat/countersunk head | #4-40 × 3/8" | 10 | Distributor contact screws. |
| Nylock nuts | #4-40 | 10 | Distributor contact screws. |
| Machine screw, pan head (optional) | #4-40 × 3/8" | 1 | Distributor cap lock screw (optional). |
| Split pin (cotter pin) (optional) | 3/64" × 3/8" | 1 | Distributor cap lock pin (optional). |

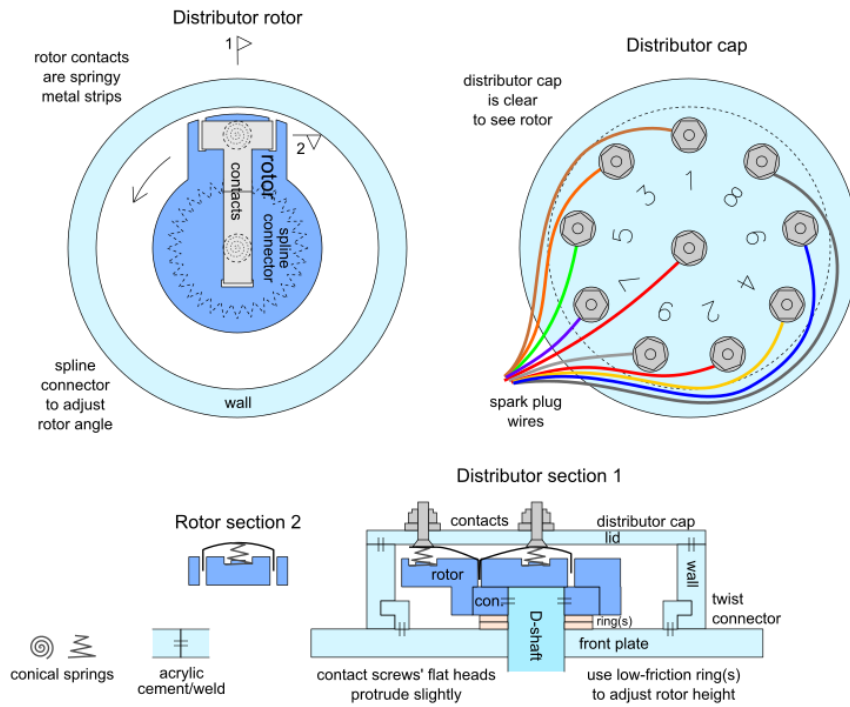
Note: The distributor cap may be locked with a screw or a pin.

4.11.2 Distributor



Distributor cap and rotor.

The distributor has a cap and a rotor, very similar to old airplanes and cars. The distributor has mechanical and electrical parts. The distributor gear turns the rotor. As the rotor turns, it contacts each of the spark plug contacts in the distributor cap, causing the LEDs to flash in the correct firing order.



Distributor cap and rotor diagram.

4.11.3 Rotor spline connector



Spline connector with D-shaft.

The rotor is connected to the distributor shaft by a spline connector shaped like a 32-pointed star. The spline connector allows you to easily change the angle of the rotor when you are setting the spark timing. The shaft goes through the front plate to connect to the distributor gear.

The spline connector is part of the front-plate-&-gear assembly (5.6.1).

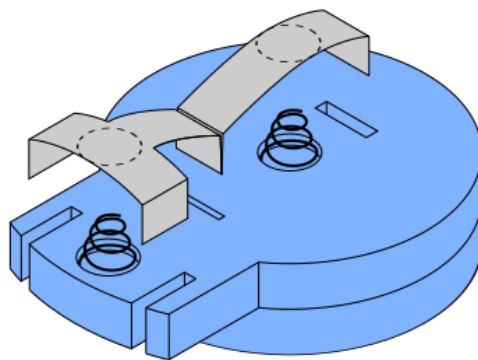
4.11.4 Rotor-&-contacts assembly



Rotor with springs and contacts strip.



Rotor-&-contacts assembly.



Rotor with springs and contacts strip.

The rotor turns inside the distributor cap. The rotor has two conical springs (glued) and a contacts strip (inserted). The contacts strip is a bent T-shaped metal sheet with two contact points, one in the center of the rotor and one near the tip of the rotor. The springs push the contacts strip against the contact points (flat-head screws) that are inside the lid of the distributor cap.

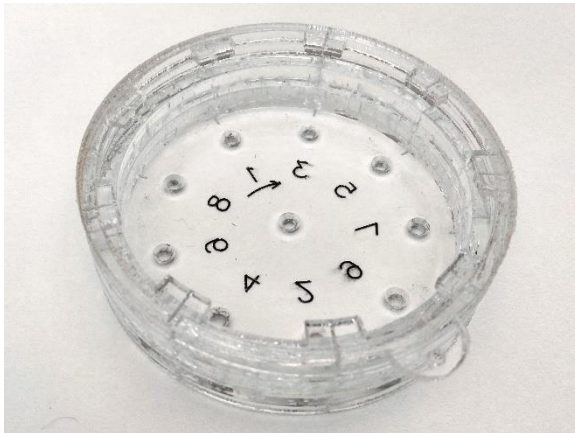
Assembly and installation instructions are in 5.7.8 and 6.3.

4.11.5 Distributor cap

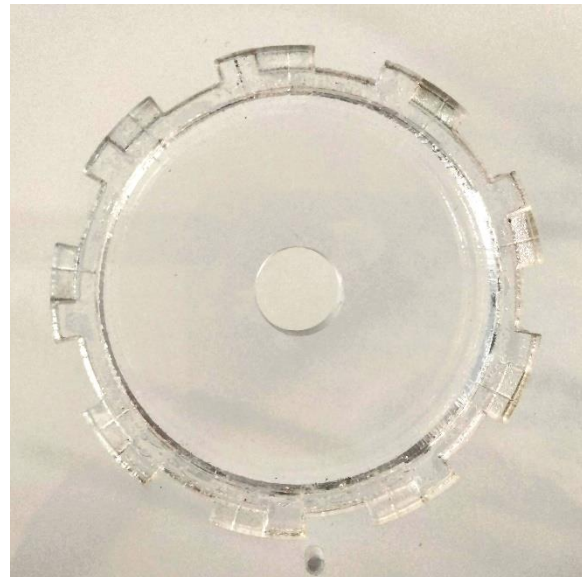


Distributor cap.

The distributor cap has a circle of nine countersunk holes for the spark plug contact points, and a center hole for the center positive contact point. The contact points are flat-head screws to be installed into the countersunk holes. The spark plug points are numbered with the cylinder numbers in the correct firing order, 1-3-5-7-9-2-4-6-8, counterclockwise, with 1 at the top. The distributor cap is transparent so you can see the rotor turning inside.



Distributor cap, back side (inside), showing the twist connector outer ring cemented to the base.



Twist connector inner ring, cemented to the front plate.

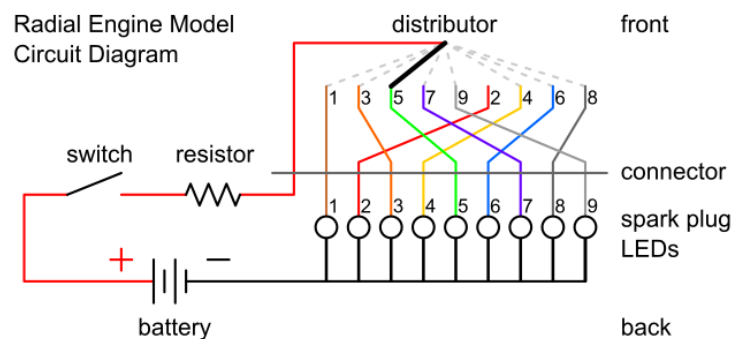
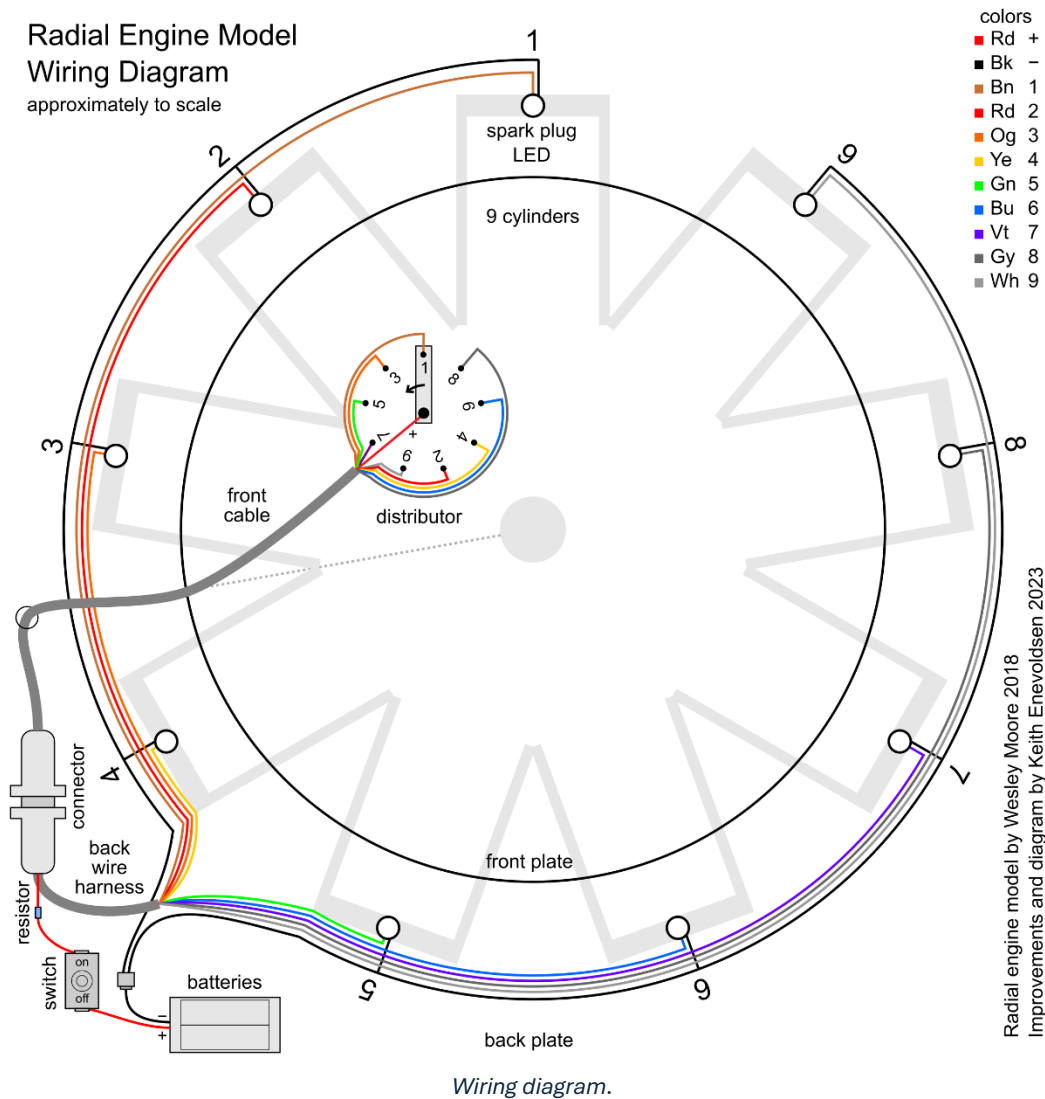
The distributor cap is attached to the front plate with a twist connector. The outer ring of the twist connector is cemented to the base of the distributor cap. The inner ring of the twist connector is cemented to the front plate, around the distributor shaft.

To tighten the distributor cap, you will turn it counterclockwise (same as the rotor direction). The counterclockwise turning of the rotor will tend to tighten, rather than loosen, the cap. (Notice that this is the opposite of normal screw caps, which are tightened by turning clockwise.)

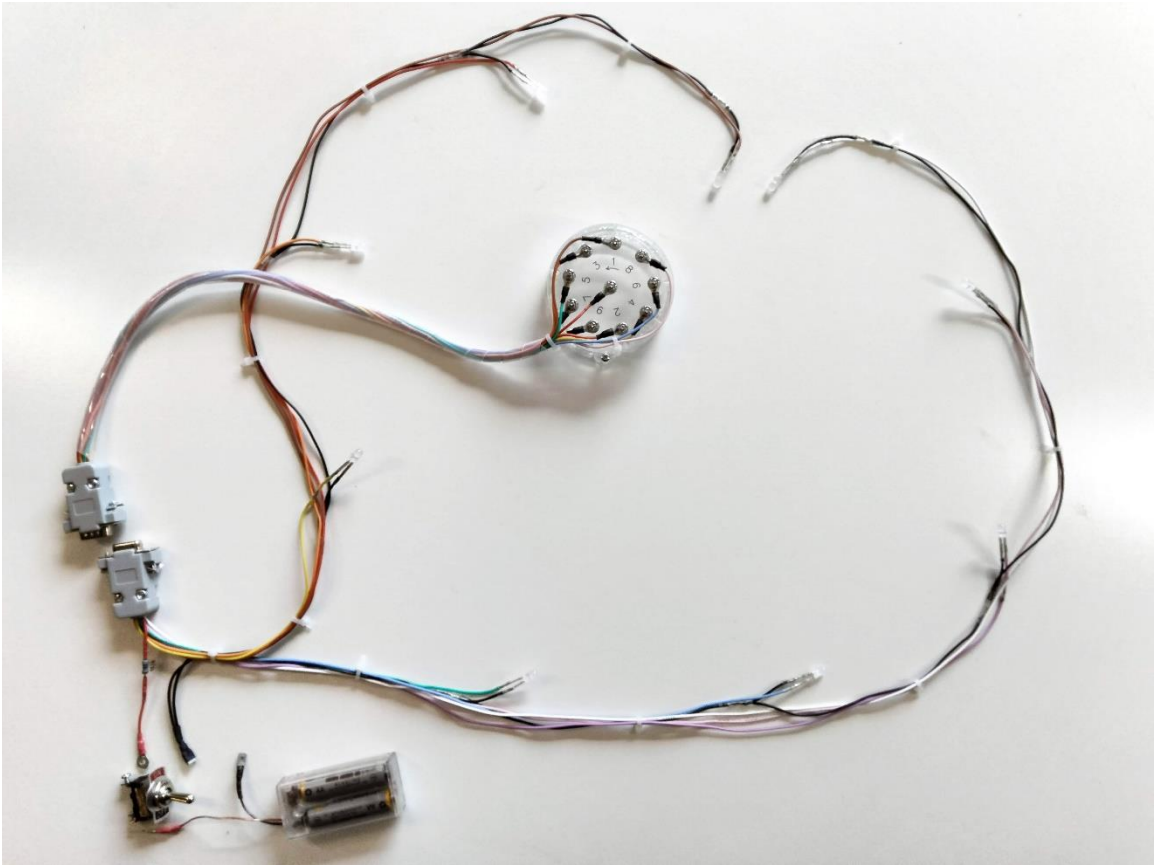
The distributor cap is part of the distributor-cap-&-cable assembly (4.12.5). Assembly and installation instructions are in 5.7.1 and 5.7.9.

4.12 Electrical system: Wiring, LEDs

4.12.1 Wiring diagram



The wiring consists of a distributor and front cable on the front plate, a back wire harness with nine spark plug LEDs (and one resistor) on the back plate, an on-off switch, and a battery pack.



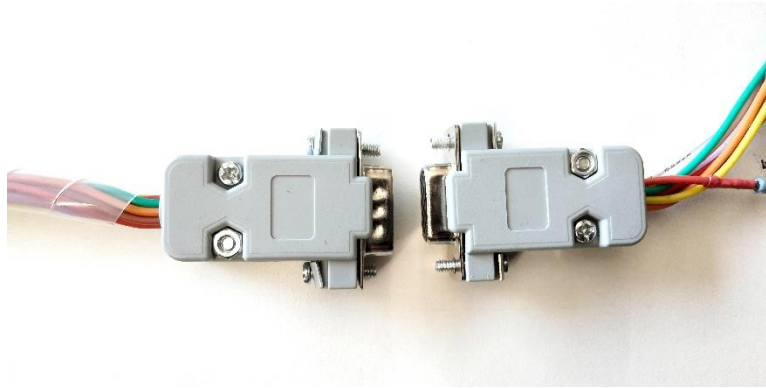
All the wiring parts: distributor-cap-&-cable assembly, back wire harness with nine LEDs (and one resistor), on-off switch, and battery pack.

4.12.2 Parts list

| Wiring: Custom parts | |
|---|----------|
| Part | Quantity |
| Front cable | 1 |
| Back wire harness (with LEDs) | 1 |
| Battery pack (with wires and terminals) | 1 |
| Spring clip for cable connector | 1 |
| Spring clip for battery pack | 1 |

| Wiring: Standard parts | | | |
|--|--|----------|---|
| Part | Size | Quantity | Usage |
| Cable clips (open or closed) | #10 screw hole (~3/16" diam.), holds 2 to 6 wires (~3/16" diam.) | 18 | Holding the wires in the back wire harness. |
| Cable clip or strap (optional) | #10 screw hole (~3/16" diam.), holds cable (~3/8" diam.) | 1 | Holding the front cable (optional). |
| LED holders, plastic, panel-mount | Sized for 5mm LEDs | 9 | LEDs in cylinders. (LED holders may be slightly modified to fit.) |
| Toggle switch, panel mount (with label plate, nut, and screws) | Mounted in 12 mm (15/32") panel hole | 1 | Toggle switch includes an on-off label plate, a mounting nut, and two screws for the wires. |
| Batteries | 1.5V AA alkaline | 2 | Battery pack. |
| Machine screws, pan head | #4-40 × 1/4" | 2 | Spring clips. |

4.12.3 Cable connectors



*Cable connectors (D-Sub DE-15)
on front cable (left) and back wire harness (right).*

A pair of cable connectors (plug and socket) connect the front cable to the back wire harness.

The connectors make it easy to join and separate the front and back wiring during assembly and disassembly of the model. (Also, the separation makes it possible for the maker to rebuild either the front or back wiring without needing to rebuild both.)

The cable connectors have 10 conductors for the nine spark plug wires and the one center positive (red) wire. Our model uses a D-Sub DE-15 connector with 15 pins, but only 10 pins are used. Your model may use a different cable connector.

Cable connectors are parts of the front cable (4.12.4) and the back wire harness (4.12.10).

4.12.4 Front cable



Front cable.

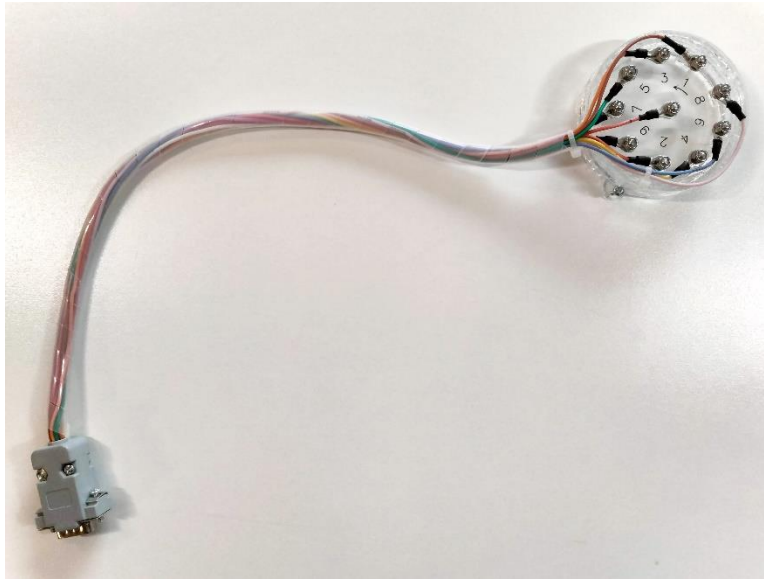
The front cable has all the wiring that is on the front plate. See the wiring diagram (4.12.1).

The front cable has 10 wires: nine spark plug wires and one center positive (red) wire. The harness is in the form of a tree with a long trunk, rooted at the cable connector, and 10 short branches with ring terminals to connect to the distributor cap contact screws. The spark plug wires have multiple colors based on the standard electronic color code, as shown in the wiring diagram (4.12.1).

The trunk has removable (spiral) cable wrap, and a zip tie at the end of the trunk where the 10 wires branch out.

The front cable is part of the distributor-cap-&-cable assembly (4.12.5).

4.12.5 Distributor-cap-&-cable assembly



Distributor-cap-&-cable assembly.

The front cable is connected to the distributor cap. The nine spark plug wires connect to the circle of nine contact screws. The center positive (red) wire connects to the center contact screw.

Assembly and installation instructions are in 5.7.1, 5.7.7, and 5.7.9.

4.12.6 On-off switch



Toggle switch.



Toggle switch parts.

A panel-mount on-off toggle switch is used to turn on the battery-powered LEDs. Remember to switch off the battery power when the model is not in use. We used an old-fashioned metal toggle switch that is reminiscent of an old radial-engine airplane control panel.

Installation instructions are in 5.7.2.

4.12.7 Spring clips



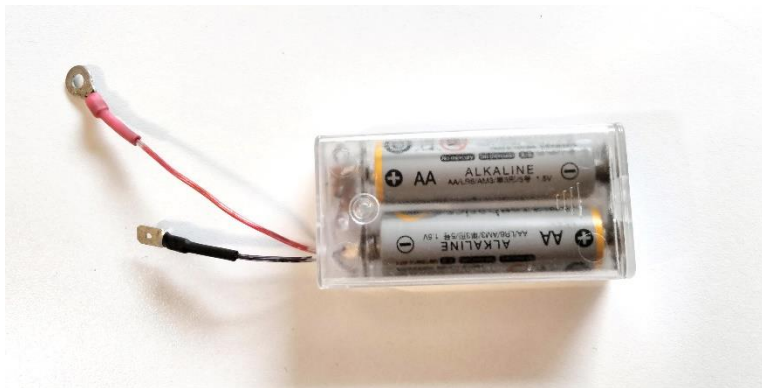
Spring clips for battery pack and cable connector.

The model has two spring clips: the battery pack clip and the cable connector clip. Each spring clip holds its part to the back side of the back plate, along the edge of the plate, with the front of the clip on the front side of the plate. The spring clips can hold the parts to the plate without any fastener, but each can be fastened to the plate with a screw at its preferred location.

The spring clips should be made to fit your battery pack and cable connector. Our two clips are the same size because our battery pack and our cable connector happen to be the same thickness (about 5/8”).

Installation instructions are in 5.7.3.

4.12.8 Battery pack



Battery pack, with short wires and wire terminals.

The battery pack holds two 1.5V AA batteries to supply 3V for the LEDs. Use alkaline batteries that deliver the full 1.5V rather than rechargeable batteries that deliver less voltage. The LEDs will be dim if the battery voltage is low.

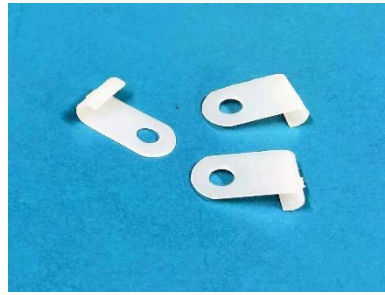
The battery pack’s positive (red) wire connects to the on-off switch. The battery pack’s negative (black) wire connects to the back wire harness.

Installation instructions are in 5.7.4.

4.12.9 Cable clips



Loop cable clips.



Half-loop cable clips.

Back cable clips. The wires of the back wire harness are routed around the back side of the back plate and are held in place by plastic cable clips behind the cylinders. The cable clips are on the short cylinder screws, held by the nuts. Each cable clip is large enough to hold 2 to 6 wires.

You can use loop clips or half-loop clips. If you use loop clips, you must remove the nuts to install or uninstall the wires. If you use flexible half-loop clips, you do not need to remove the nuts to install or uninstall the wires. (We used flexible half-loop clips.)

Installation instructions are in 5.7.5.



*Cable clip or strap for front cable (optional).
The strap shown here is a flexible nylon loop clip
bent wide open to act as a strap.*

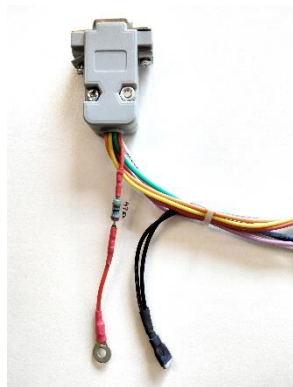
Front cable clip. If necessary, you may put one cable clip (attached to one screw) or strap (attached to two screws) on the front plate to hold the front cable between the main screws for cylinders 3 and 4. (Our model did not require a front cable clip or strap, because our front cable was taut enough to stay in place by itself.)

Installation instructions are in 5.7.7.

4.12.10 Back wire harness, LEDs



Back wire harness with two main branches and nine LEDs.



The back wire harness has three electrical connections: the cable connector, the positive terminal, and the negative terminal.



LED soldered to the back wire harness.

The back wire harness has almost all the wiring that is on the back plate, including the LEDs. The back wire harness is routed around and behind the periphery of the circle of cylinders. See the wiring diagram (4.12.1).

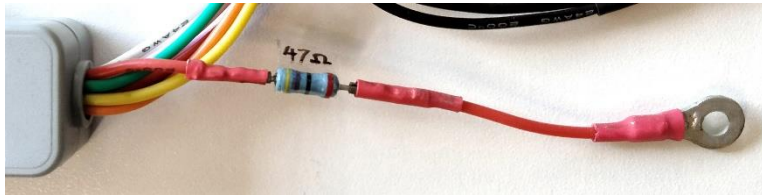
LEDs. The back wire harness has nine LEDs representing the nine spark plugs. The LEDs should be bright enough to be eye-catching, even in a daylight room, or with the backlight on. The LEDs are white to represent the color of an electrical spark (a real spark is blue-white). The LEDs should have a wide viewing angle so viewers can see the flashes from all nine LEDs even if they are not standing directly in front of the model.

Wire tree. The back wire harness has the general form of a tree with a short trunk, rooted at the cable connector and the negative (black) wire terminal, and two main branches. Branch 1 goes to LEDs 1 to 4, and branch 2 goes to LEDs 5 to 9. The main branches each have short branches terminating in the LEDs for each cylinder. The main wire tree is actually made of two parallel wire trees, the positive wire tree and the negative wire tree. The two trees have separate roots and are connected at the tips of their branches where they are soldered to the LEDs.

Positive wire tree. The nine spark plug wires are soldered to the positive leads of the LEDs. The root of the positive wire tree is the cable connector. The spark plug wires have multiple colors based on the standard electronic color code, as shown in the wiring diagram (4.12.1).

Negative wire tree. The negative (black) wires are soldered to the negative leads of the LEDs. The root of the negative wire tree is a single tab socket terminal that connects to the battery negative wire.

Short positive (red) wire. The back wire harness has a short positive (red) wire from the cable connector to a ring terminal that connects to the on-off switch. This wire is part of the path from the battery pack's positive lead to the distributor's center contact.



In-line plug-in resistor, in the short positive (red) wire.

In-line resistor. The short positive (red) wire has an in-line resistor. The purpose of the resistor is to prevent burnout of the LEDs and increase the lifetime of the batteries and the LEDs. The resistor is always in the circuit (in series) with whichever LED is currently lit. The Maker Manual explains how to determine the resistance (ohms) of this resistor. (We used a 47-Ω resistor.)

The resistor in your model may be simply soldered into the wire.

Alternative: The resistor may be plugged into the wire with two single-pin sockets — the two resistor leads are the pins. (Our model has a plug-in resistor.) If your model has a plug-in resistor, you should keep it plugged in, so you do not lose it. The resistor should never need to be unplugged unless the model maker decides to change the resistance value (ohms).

Installation instructions are in 5.7.5.

4.12.11 LED holders



LEDs and holders.

The LED holders are store-bought black plastic sleeves that hold the LEDs snugly in the LED holes in the cylinders. The LED holders are store-bought parts, but they may be slightly modified. See the Maker Manual.

Installation instructions are in 5.7.6.

4.13 Stand

4.13.1 Parts list

| Stand: Custom parts | |
|---------------------|----------|
| Part | Quantity |
| Stand brackets | 6 |
| Stand legs | 2 |
| Stand crossbars | 2 |

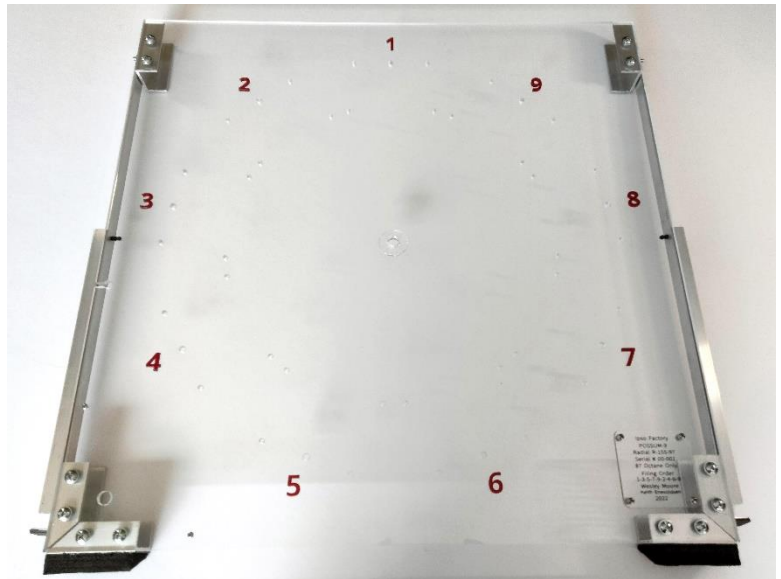
| Stand: Standard parts | | | |
|---|----------------------------|----------|--------------------|
| Part | Size | Quantity | Usage |
| Machine screws, pan head, Phillips | #10-24 × 5/8" | 14 | Brackets and legs. |
| Nylock nuts | #10-24 | 14 | Brackets and legs. |
| Washers | #10 | 16 | Brackets and legs. |
| Push-in rivets, plastic | Fits 3/16" hole, 1/2" long | 4 | Crossbars. |
| Machine screws, pan head, Phillips (optional) | #10-24 × 5/8" | 4 | Crossbars. |
| Hex nuts or knurled nuts (optional) | #10-24 | 4 | Crossbars. |

The crossbars are attached with push-in rivets. (Alternative: The crossbars may be attached with screws and nuts.)

4.13.2 Stand



Stand, upright.



Stand, lying face up with legs stowed.



Legs and crossbars, stowed.



Model and stand, upright, without the backlight.

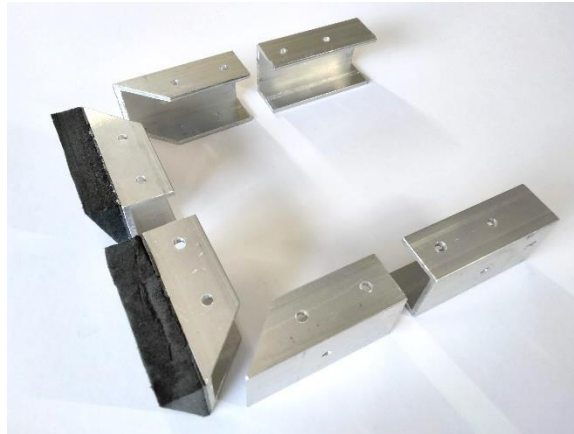


Model and stand, lying face up with legs stowed.

The stand can stand up on a tabletop. The model can be displayed with or without the backlight. Users will operate the model in the upright position. The stand's metal structure is on the sides of the model, so the opaque structure does not interfere with the transparency of the model (without the backlight), when viewed or photographed from the front.

The stand can be folded flat for storage. The legs and crossbars are stowed parallel to the left and right sides of the model. The model may be operated in the stowed configuration, lying face up on a table.

4.13.3 Brackets



The six U-brackets. The two bottom brackets have footpads.

The stand is built on six U-brackets that are fastened to the back plate with screws and nuts. There are two upper side brackets, two lower side brackets, and two bottom brackets. The bottom brackets have big rubbery footpads.

4.13.4 Legs and crossbars



*Legs and crossbars. The legs have small footpads.
Also shown are screws, nylock nuts, washers, and plastic push-in rivets.*

The legs and crossbars are made from L-angles. The legs have feet with rubbery footpads. The legs are fastened at the upper side brackets with screws and nylock nuts. The crossbars are fastened with plastic push-in rivets. (Alternative: The crossbars may be fastened with screws and hand-tightened hex nuts or knurled nuts. Wing nuts may be too big for the L-angles.)

4.13.5 Assembling the stand

We recommend that you assemble the stand first, before you assemble the rest of the model. The stand is very helpful during assembly of the model.



Upper side U-bracket, attached behind the back plate with screws, washers, and nylock nuts.



Bottom and lower side U-brackets, attached behind the back plate with screws, washers, and nylock nuts.

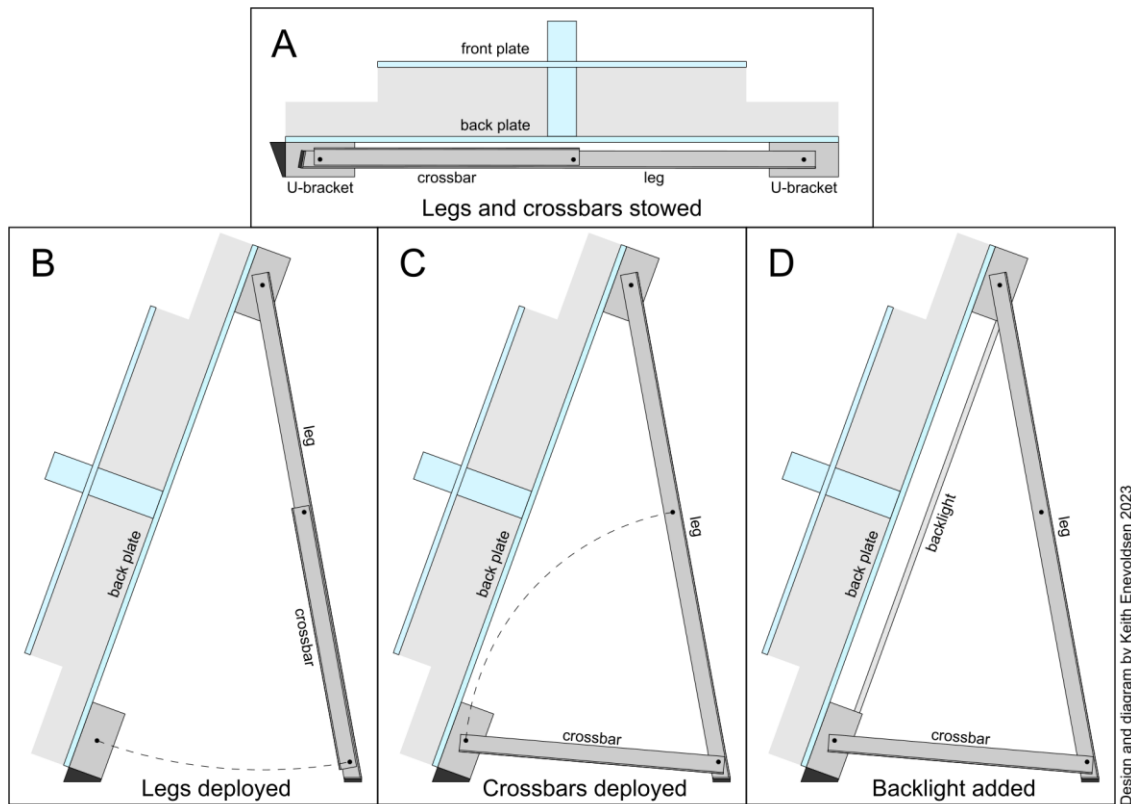


*Legs are attached to the upper side brackets with screws, washers, and nylock nuts.
Crossbars are attached to the legs with push-in rivets.*

Instructions: Assembling the stand

| # | Step | Instructions |
|---|---|--|
| 1 | Install the brackets on the back plate. | Install the six U-brackets behind the back plate. Use #10-24 × 5/8" pan head screws, with the heads on the front side. Put #10 washers between the front of the plate and the screw heads (these washers distribute the load on the acrylic to prevent stress cracks). Install and tighten nylock nuts on the back side. |
| 2 | Install the legs on the upper brackets. | Attach the tops of the legs to the upper side brackets (with the L-angle oriented as shown). Use #10-24 × 5/8" pan head screws, with the heads (and no washers) on the inside (to give maximum clearance for the backlight). Put #10 washers between the brackets and the legs, and between the legs and the nylock nuts (these washers serve as spacers). Install and moderately tighten nylock nuts on the outside, holding the legs firmly, but allowing the legs to pivot. |
| 3 | Install the crossbars on the legs. | Attach the crossbars, in the stowed position, to the legs (with the L-angle oriented as shown). Use plastic push-in rivets (fits 3/16" hole, 1/2" long), two per crossbar. (Alternative: You can use screws and hand-tightened hex nuts or knurled nuts.) |
| 4 | Stow the legs and crossbars onto the lower side brackets. | Stow the legs and crossbars onto the lower side brackets. Use the same push-in rivets (or the alternative screws and nuts) that were used to attach the crossbars to the legs. |

4.13.6 Setting up the stand



Setting up the stand.

| Instructions: Setting up the stand | | |
|------------------------------------|----------------------------------|---|
| # | Step | Instructions |
| 1 | Unstow the legs. | Starting from the stowed configuration (figure A), detach each leg from the bottom bracket, keeping it attached to the top bracket. |
| 2 | Deploy the legs. | Hold the model upright while you unfold each leg toward the back, then let the model stand up by itself (figure B). |
| 3 | Unstow the crossbars. | Detach each crossbar from the middle of the leg, keeping it attached at the foot. |
| 4 | Deploy the crossbars. | Fold each crossbar down and attach it to the bottom bracket, making a sturdy A-frame (figure C). |
| 5 | Insert the backlight (optional). | Slide the LED backlight panel into the U-brackets that are attached behind the back plate of the model (figure D). The backlight panel should sit directly behind the transparent back plate, separated by a gap of about 1 inch. |

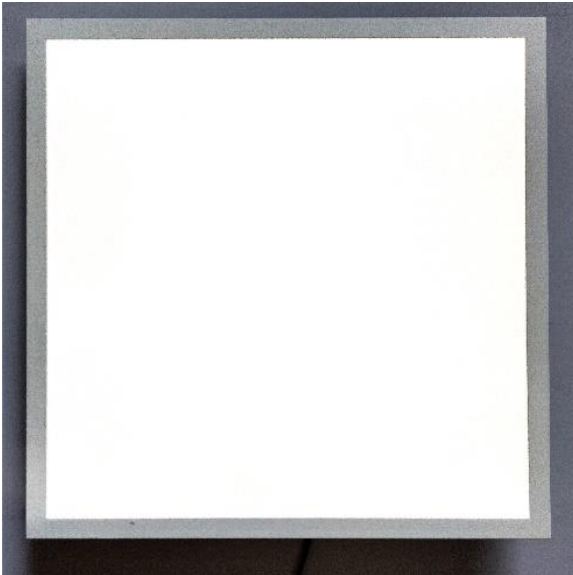
To stow the stand, reverse the steps.

4.14 Backlight

4.14.1 Parts list

| Backlight: Custom parts | |
|--|----------|
| Parts | Quantity |
| Backlight (with dimmer control and power cord) | 1 |

4.14.2 Backlight



Backlight, front.



Backlight, back.



Model on stand with backlight.



Stand with backlight, back view.

This colorful transparent model looks beautiful when backlit. You can install the backlight panel in the stand to provide bright and uniform backlighting. If you do not install the backlight panel, the model will be backlit by the ambient room lighting or daylight.

Our model's backlight is custom-made from a 24"×24" ceiling light panel with the addition of an on-off-dimmer control and a power cord. Your model's backlight may be different.

WARNING: ELECTRICAL. Take precautions with the backlight panel and power cord, as you would with any other appliance that is plugged into a (grounded) wall socket. Ensure that the custom-made electrical wiring connections are safely enclosed in an electrical box (on the back of the panel) and that the power cord is safely secured to the electrical box. (See the Maker Manual.)

4.14.3 Installing the backlight

| Instructions: Installing the backlight | | |
|--|-----------------------|--|
| # | Step | Instructions |
| 1 | Insert the backlight. | Slide the LED backlight panel into the U-brackets that are attached behind the back plate of the model. The backlight panel should sit directly behind the transparent back plate, separated by a gap of about 1 inch. |

4.15 Plaque

4.15.1 Parts list

| Plaque: Custom parts | |
|----------------------|----------|
| Part | Quantity |
| Plaque | 1 |

| Plaque: Standard parts | | | |
|--------------------------|--------------|----------|---------|
| Part | Size | Quantity | Usage |
| Machine screws, pan head | #4-40 × 3/8" | 4 | Plaque. |
| Nylock nuts | #4-40 | 4 | Plaque. |

4.15.2 Plaque



Plaque for model 2.

The model has a laser-scored plaque mounted on the front of the back plate. Our model 2 plaque has this text:

| Text | Notes |
|-----------------------------------|---|
| Ipso Factory | Ipso Factory was Wes's name for his one-person shop. Ipso Factory means "self factory". It is a pun on the Latin "ipso facto", meaning "by the fact itself". |
| POSSUM-9 | Possum-9 is Wes's whimsical name for this nine-cylinder engine. |
| Radial R-155-97 | Radial, 155 cubic inches displacement, model 97. This style of piston engine designation was used by the US military from the 1920s to the 1940s. 155 cubic inches displacement is roughly correct for the size of this model. I don't know why the model number is 97. |
| Serial # 00-002 | Wes's model 1 had serial # 00-001. Keith's model 2 has serial # 00-002. Wes used five digits as a joke, as if he were planning to make thousands of these models. |
| 87 Octane Only | This is Wes's joke that this toy model requires gasoline. |
| Firing order 1-3-5-7-9-2-4-6-8 | A four-stroke radial engine has an odd number of cylinders, and the firing order is every alternate cylinder. |
| Wesley Moore | Wes designed and built the radial engine model in 2016-20. |
| Keith Enevoldsen 2022 | Keith renovated and improved the model in 2022-23. |

4.15.3 Installing the plaque

| Instructions: Installing the plaque | | |
|--|---------------------|---|
| # | Step | Instructions |
| 1 | Install the plaque. | Install the plaque onto the back plate with #4-40 screws, and nylock nuts on the back side of the back plate. |

4.16 Storage box



Storage box containing the model.

You can store the model in a box that is at least 27" × 27" × 7", big enough to hold the model when the backlight is removed, the stand is stowed, and the propeller hand crank is detached.

We stored the backlight in a separate box. We stored the spare parts and manuals in additional boxes.

5 Assembly instructions

This section gives detailed instructions for assembling the entire model. This includes assembling the subassemblies, installing the parts and assemblies onto the plates, and making final adjustments.

Descriptions of the parts and assemblies are in section 4.

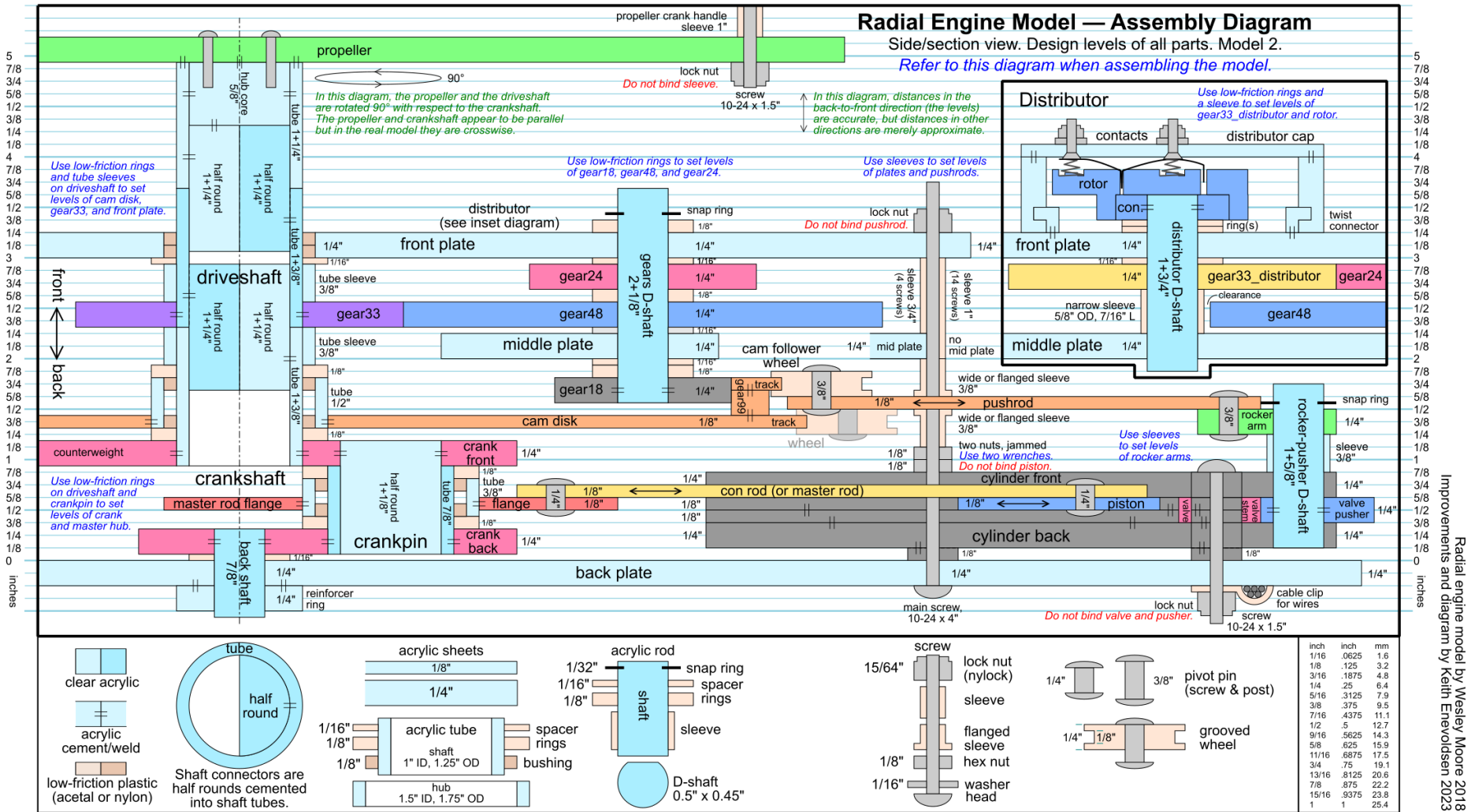
5.1 Assembly sequence

The assembly sequence generally goes from back to front, with the electrical parts installed last.

| Assembly sequence | | |
|-------------------|--|--------------|
| # | Assembly/installation stage | Section # |
| Stand | | 5.3 |
| 1 | Installing the stand | 5.3 → 4.13.5 |
| 2 | Setting up the stand | 5.3 → 4.13.6 |
| Back levels | | 5.4 |
| 1 | Assembling the rods-&-pistons assembly | 5.4.1 |
| 2 | Preliminary placement of the cylinders | 5.4.2 |
| 3 | Installing the valve pushers | 5.4.3 |
| 4 | Installing the crank and rods-&-pistons assembly | 5.4.4 |
| 5 | Installing the valve assemblies | 5.4.5 |
| 6 | Tightening the cylinders | 5.4.6 |
| Middle levels | | 5.5 |
| 1 | Installing the cam disk | 5.5.1 |
| 2 | Assembling the pushrod assemblies | 5.5.2 |
| 3 | Installing the pushrod assemblies | 5.5.3 |
| 4 | Installing the middle driveshaft | 5.5.4 |
| 5 | Assembling the middle-plate-&-gears assembly | 5.5.5 |
| 6 | Installing the middle-plate-&-gears assembly | 5.5.6 |
| 7 | Setting the valve timing | 5.5.7 → 6.2 |
| Front levels | | 5.6 |
| 1 | Assembling the front-plate-&-gear assembly | 5.6.1 |
| 2 | Installing the front-plate-&-gear assembly | 5.6.2 |
| 3 | Assembling the propeller assembly | 5.6.3 |
| 4 | Installing the propeller assembly | 5.6.4 |
| 5 | Adjusting the valve stem lengths | 5.6.5 |
| Electrical | | 5.7 |
| 1 | Assembling the distributor-cap-&-cable assembly | 5.7.1 |
| 2 | Installing the on-off switch | 5.7.2 |
| 3 | Installing the spring clips | 5.7.3 |
| 4 | Installing the battery pack | 5.7.4 |
| 5 | Installing the back wire harness | 5.7.5 |
| 6 | Installing the LED holders | 5.7.6 |
| 7 | Installing the distributor-cap-&-cable assembly | 5.7.7 |
| 8 | Installing the rotor-&-contacts assembly | 5.7.8 |
| 9 | Installing the distributor cap | 5.7.9 |
| 10 | Setting the spark timing | 5.7.10 → 6.3 |

To disassemble the entire model or parts of the model, reverse the steps.

5.2 Assembly diagram



Radial engine model 2 assembly diagram, side/section view, showing design levels of all parts. Refer to this diagram when assembling the model.

5.3 Assembling the stand (Ref.)

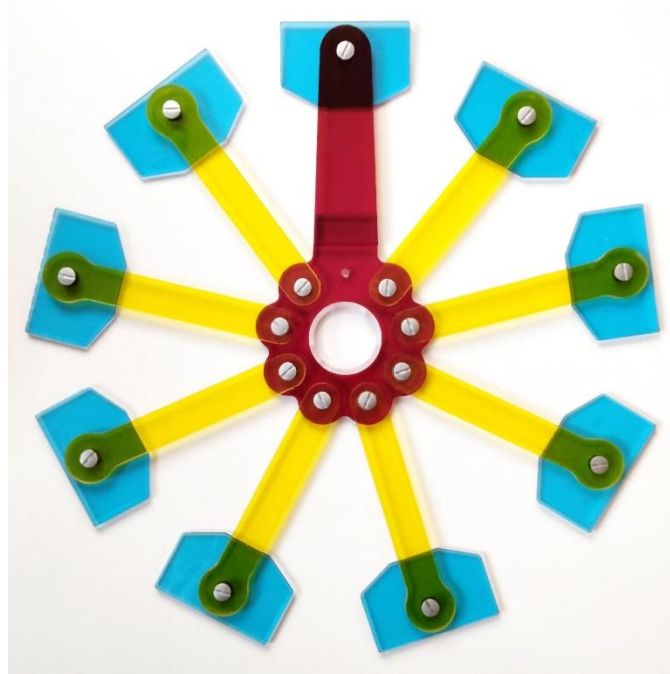


Stand.

The stand is described in 4.13. Assembly instructions are in 4.13.5. Setup instructions are in 4.13.6.

5.4 Assembling the back levels

5.4.1 Assembling the rods-&-pistons assembly



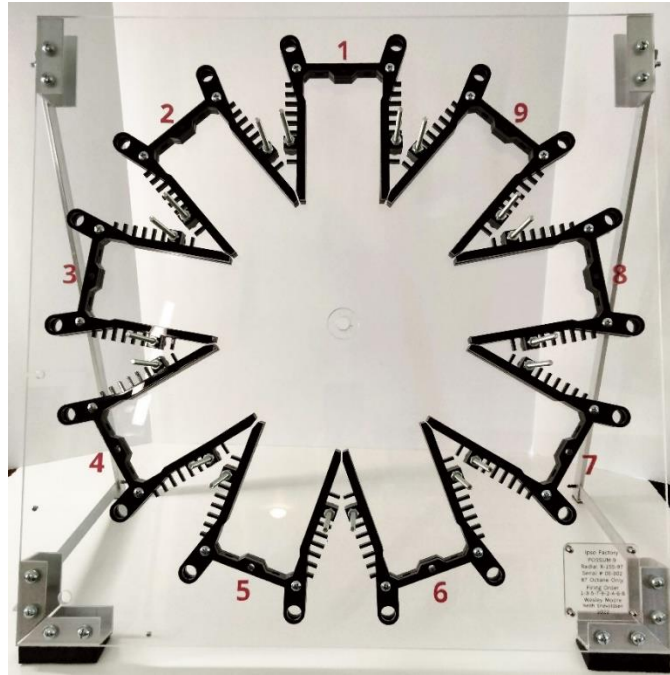
Rods-&-pistons assembly.

The rods-&-pistons assembly is described in 4.7.6.

| Instructions: Assembling the rods-&-pistons assembly | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Fasten the con rods to the master rod flange. | Find the front side of the master rod and flange. The master rod is on the front side and the flange (collar) is on the back side. Put the front side up. |
| | | If your pivot pins are screws & posts that require threadlocker, apply primer and threadlocker (3.1). |
| | | Fasten the small ends of eight con rods to the flange with 1/4"-long pivot pins. Fasten the rods to the front side of the flange, so the eight con rods are at the same level as the master rod. |
| 2 | Fasten the pistons to the rods. | If your pivot pins are screws & posts that require threadlocker, apply primer and threadlocker (3.1). |
| | | Fasten nine pistons to the con rods with 1/4"-long pivot pins. Fasten the pistons to the back side of the rods, so the pistons are at the same level as the flange. |
| 3 | Check all fastened joints. | Check that all the joints turn freely. |
| | | After the threadlocker has set, check that the screws & posts are thread-locked and will not come loose. |

Keep the rods-&-pistons assembly intact if they use threadlocker. Avoid unscrewing thread-locked screws. To install or remove the entire rods-&-pistons assembly intact, the cylinder backs and fronts must be separated (by at least 1").

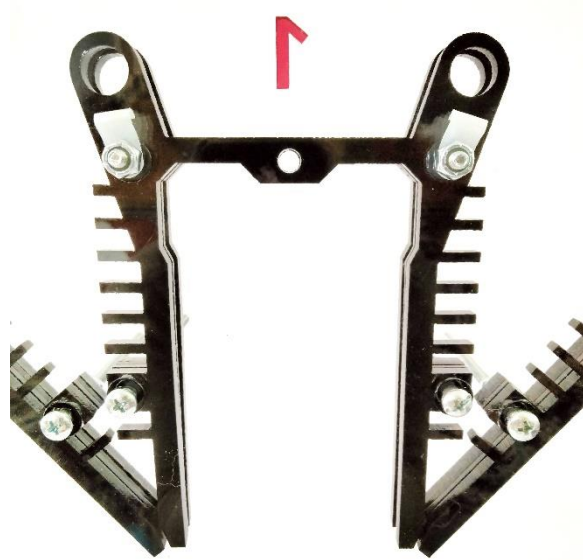
5.4.2 Preliminary placement of the cylinders



Cylinders installed on back plate, without the pistons, valve pushers, and valves.



*Cylinder back and front parts, front view.
Installed on the long main screws (middle), and
the short cylinder screws (top).*



*Cylinder back and front parts, back view.
The short cylinder screws (top) also hold
the cable clips on the back side.*

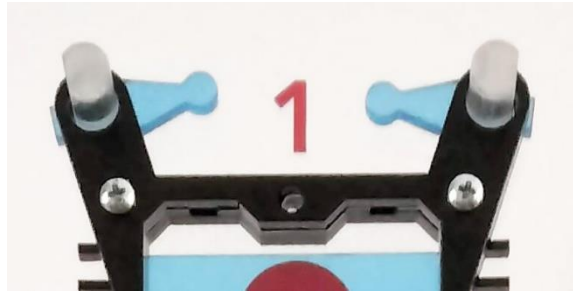
The cylinders are described in 4.7.2.

Instructions: Preliminary placement of the cylinders

| # | Step | Instructions |
|---|--|--|
| 1 | Stand the model upright. | Stand the model upright on the stand. This allows you to access both the front and back of the model. |
| 2 | Install the main screws in the back plate. | Insert the 18 long main screws (#10-24 × 4", pan head, Phillips) through the back plate, with the screw heads on the back side of the plate (see photos). |
| 3 | Apply dry lube to the rocker-pusher shaft holes (required). | Apply dry lube (3.2) to the rocker-pusher shaft holes in the cylinder backs and fronts (required). |
| 4 | Apply dry lube to the piston slots (optional). | Apply dry lube (3.2) to the piston slots in the cylinder backs (optional). |
| 5 | Install the cylinder backs on the main screws and push them onto the back plate. | Install the cylinder backs on the main screws and push them all the way onto the back plate. |
| 6 | Put the cylinder fronts on the main screws and push them halfway back. | Put the cylinder fronts on the main screws and push them halfway down the screws, not yet all the way onto the cylinder backs. (The cylinders need to stay partway open to install the valve pushers and the rods-&-pistons assembly.) |
| 7 | Put the hex nuts on the main screws and spin them halfway down. | Put a pair of standard hex nuts on each main screw and spin them halfway down the screws, to keep the cylinder fronts halfway back. (Later we will jam these pairs of hex nuts.) |

Initially, to check the fit of the cylinders, you may skip ahead and tighten the cylinder fronts onto the backs, without first installing the parts that go between in between them. But then you will need to reopen the cylinders to install the valve pushers and the rods-&-pistons assembly.

5.4.3 Installing the valve pushers

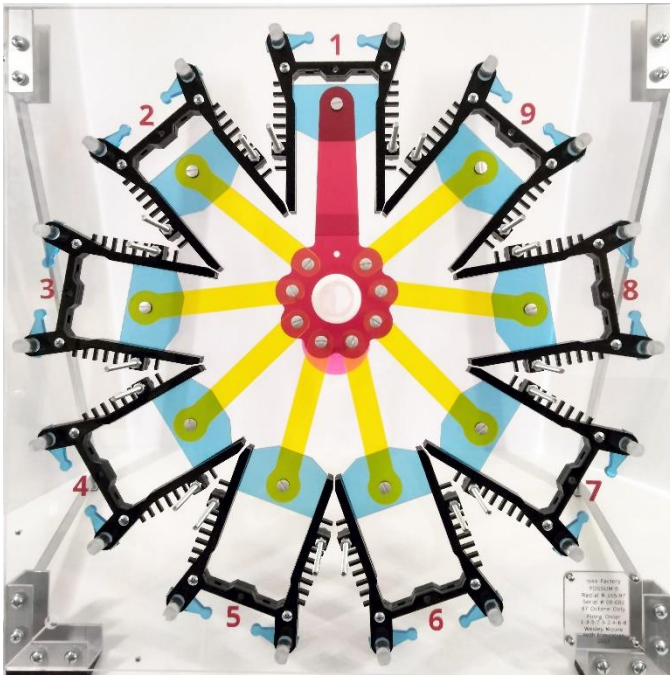


Valve pushers installed, but valves not yet installed.

The valve pushers are described in 4.10.4.

| Instructions: Installing the valves pushers | | |
|--|--|---|
| # | Step | Instructions |
| 1 | Apply dry lube to the rocker-pusher shafts (required). | Apply dry lube (3.2) to the rocker-pusher D-shafts, where they will touch the shaft holes in the cylinder backs and fronts (required). |
| 2 | Install the valve pushers in the cylinder backs. | Put the valve pushers' shafts into the shaft holes in the cylinder backs. The valve pushers are cemented to the rocker-pusher shafts, so they must be installed while the cylinders are separated. Alternative: If your valve pushers are fastened with screws rather than cemented to the shafts, you can install them later. |
| 3 | Push the cylinder fronts partway back. | After you install each pair of valve pushers, you can push that cylinder's front partway back onto the front ends of the rocker-pusher D-shafts. But leave the cylinder front separated from the cylinder back so you can install the rods-&-pistons assembly. |

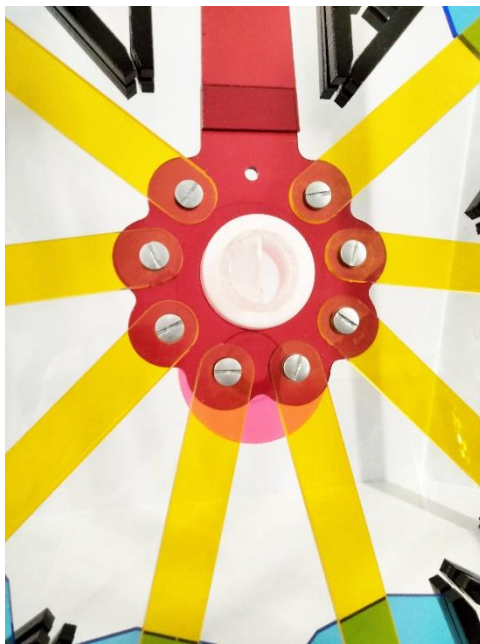
5.4.4 Installing the crank and rods-&-pistons assembly



Model with crank back and rods-&-pistons assembly installed.



Model with crank front installed.



Master rod crank hub. The hub goes around the low-friction bushing rings on the crankpin.

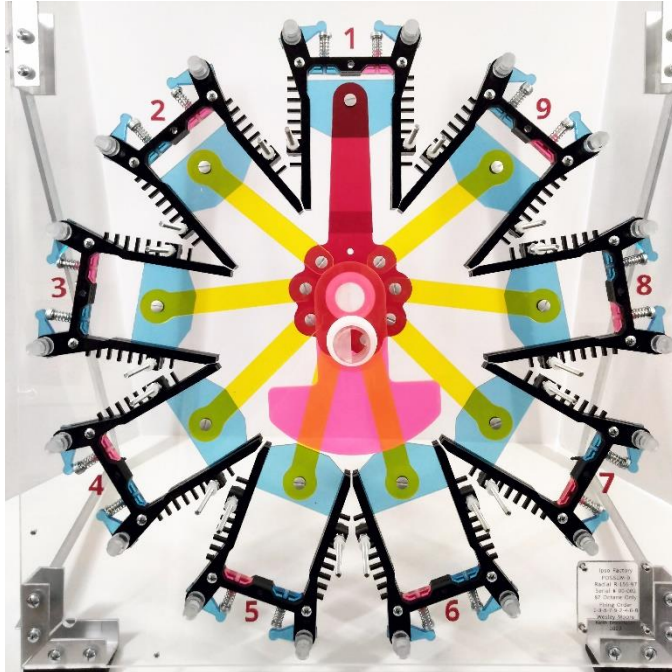


Crank front, installed.

The crankshaft assembly is described in 4.6.4. The rods-&-pistons assembly is described in 4.7.6. Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the crank, rods, and pistons | | |
|---|---|--|
| # | Step | Instructions |
| 1 | Apply dry lube to the back shaft hole or shaft (optional). | Apply dry lube (3.2) to the back shaft hole in the back plate (optional). Apply dry lube to the back shaft on the crank back (optional). |
| 2 | Install the crank back. | Put a low-friction spacer ring (1/16" thick) on the back shaft. |
| | | Install the crank back's back shaft into the center hole on the back plate. |
| 3 | Apply dry lube to piston edges (optional). | Apply dry lube (3.2) to piston edges (optional). |
| 4 | Install the rods-&-pistons assembly. | Put a low-friction spacer ring (1/8" thick, 1.75" OD) onto the crankpin, to go behind the master rod hub. |
| | | Put two low-friction bushing rings (1/8" thick, 1.5" OD) on the crankpin, to go inside the master rod hub. |
| | | Install the rods-&-pistons assembly. Put the master rod's hub around the bushing rings. Put the master rod into cylinder #1. Put all the pistons into the piston slots in the cylinder backs. |
| | | After you install each piston, you can push that cylinder's front all the way back onto the cylinder back, to hold that piston in place. |
| | | Put a low-friction spacer ring (1/8" thick, 1.75" OD) onto the crankpin, in front of the master rod hub. |
| 5 | Install the crank front. | Install the crank front into the crank back, using the crankpin push-in shaft connector. |
| 6 | Push the cylinder fronts onto the backs and slightly tighten the nuts on the main screws. | Push the cylinder fronts all the way back onto the cylinder backs. |
| | | Slightly tighten (hand tight) the pairs of hex nuts on each of the main screws, to hold the cylinder fronts onto the cylinder backs. |
| 7 | Install the short cylinder screws, cable clips, and nuts. | Insert 18 short cylinder screws (#10-24 x 1.5", pan head, Phillips) through the cylinders and the back plate, with the screw heads on the front side of the cylinders. |
| | | Install 18 cable clips on the short cylinder screws, behind the back plate, to be held by the nylock nuts. The cable clips should be positioned to hold the wires around the outside of the circle of screws (see photo). See the installation of the back wire harness (5.7.5). |
| | | Install and slightly tighten nylock nuts on the short cylinder screws, on the back side of the plate. |

5.4.5 Installing the valve assemblies



Model with valves installed.



Cylinder with piston, valves, and valve pushers installed.

The valve assemblies are described in 4.10.3.

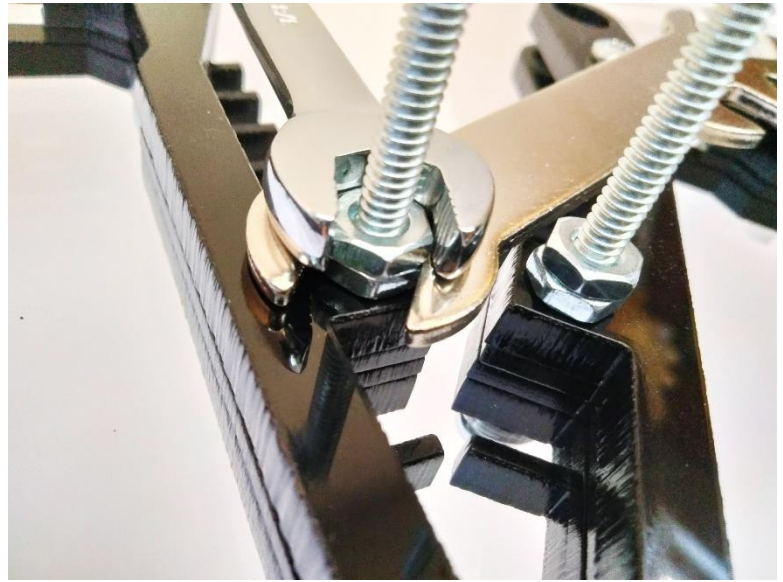
| Instructions: Installing the valve assemblies | | |
|---|---|--|
| # | Step | Instructions |
| 1 | Install the valves into the cylinders (with no adjustment washers). | Screw the post extenders into the plastic valve stems. Do not over-tighten (do not strip the plastic threads). |
| | | Insert the plastic valves (with post extenders) into the square valve holes in the cylinder heads. |
| | | Put the springs over the post extenders and the plastic valve stems. |
| | | Screw the valve stem screws onto the post extenders. |
| | | Initially, do not install any valve stem adjustment washers. |

Fit. The square valve stem should slide easily in the square valve hole in the cylinder, and the spring should slide easily over the square valve stem. If the valve does not slide easily, try loosening the screws that squeeze the cylinder front and back. You can also try swapping the valve with another valve (of the same color). If the valve still sticks, you may need to sand the valve stems or the valve holes (see the Maker Manual).

5.4.6 Tightening the cylinders



Cylinder with piston, valves, and valve pushers installed.



Jamming a pair of hex nuts with two open-end wrenches.
The first wrench is thin, no thicker than a nut.

The cylinders are described in 4.7.2.

After the pistons, valve pushers, and valves have been installed in the cylinders, you will tighten the hex nuts that hold the cylinders, but not too tight.

| Instructions: Tightening the cylinders main screws and short cylinder screws | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Tighten (jam) the hex nuts on the main screws, but do not bind the pistons. | Use two wrenches to jam (see instructions below) the pairs of hex nuts on each main screw to hold the cylinders moderately tightly, but do not over-tighten and bind the pistons (or break the acrylic). |
| 2 | Tighten the nylock nuts on the short cylinder screws, but do not bind the valves and valve pushers. | Moderately tighten the nylock nuts on the short cylinder screws, but do not over-tighten and bind the valves and valve pushers (or break the acrylic). |

Cylinder fronts with laser-etched slots. If your cylinder fronts are laser etched to have slightly roomier slots (see the Maker Manual), you can tighten the screws and nuts without binding the moving parts (pistons, valves, and valve pushers), but you still must avoid over-tightening the screws and nuts, so you do not break the acrylic.

Here is how to jam the two hex nuts with two wrenches:

| Instructions: Jamming hex nuts with two wrenches | | |
|--|--|--|
| # | Step | Instructions |
| 1 | Hold the first hex nut in position, using the first wrench. | Initially, finger-tighten the first hex nut onto the cylinder. |
| | | Use a thin open-end wrench, no thicker than a nut, to hold the first hex nut. Use a (Phillips) screwdriver to hold the screw head. Tighten the first hex nut until it holds the cylinder at the desired tightness. |
| 2 | Jam the second hex nut against the first hex nut, using the second wrench. | While holding the first hex nut stationary with the first wrench, finger-tighten the second hex nut against the first hex nut. |
| | | While firmly holding the first hex nut stationary with the thin open-end wrench, use the second open-end wrench to jam the second hex nut tightly against the first hex nut, locking the pair of nuts in place. |

Rationale for using jammed hex nuts. The cylinders are held by jammed pairs of standard hex nuts rather than using nylock nuts, lock nuts with serrations or teeth, toothed lock washers, or split lock washers. The standard hex nuts can be jammed together at any distance along the screw, so they can be locked in place where they hold the cylinder moderately tightly, but not too tightly. In contrast, lock nuts with serrations or teeth, toothed lock washers, or split lock washers would hold the cylinders too tightly. During assembly and disassembly, you can quickly spin standard hex nuts down and up the long main screws. In contrast, nylock nuts are always tight and would be very slow to install or uninstall on the long main screws. The jammed hex nuts are needed to hold the cylinders only until the front plate is installed and tightened. After the front plate is installed and tightened, the nylock nuts on the ends of the main screws and the sleeves on the main screws will hold the cylinders, even if some of the jammed hex nuts loosen.

Reopening the cylinders. After the model is fully assembled, it will be a big job to reopen the cylinders.

| Instructions: Reopening the cylinders after the model is assembled | | |
|--|---|---|
| # | Step | Instructions |
| 1 | Uninstall everything in front of the cylinders. | Uninstall the all the parts that are in front of the cylinders, including the front plate, the middle plate, the gears, the pushrod assemblies, and the cam disk. |
| 2 | Remove the LED holders. | If the LEDs have been installed in the cylinders, remove the LED holders (because the LED holders also restrict the movement of the cylinder fronts). |
| 3 | Remove or loosen the cylinder screws and nuts. | Remove the nylock nuts from the short cylinder screws. Remove the short cylinder screws. |
| | | Loosen the pairs of jammed hex nuts on the main screws. Spin the nuts forward halfway on the main screws. |
| 4 | Pull the cylinder fronts forward. | Pull the cylinder fronts forward halfway on the main screws. |

5.5 Assembling the middle levels

5.5.1 Installing the cam disk



Model with cam disk installed.



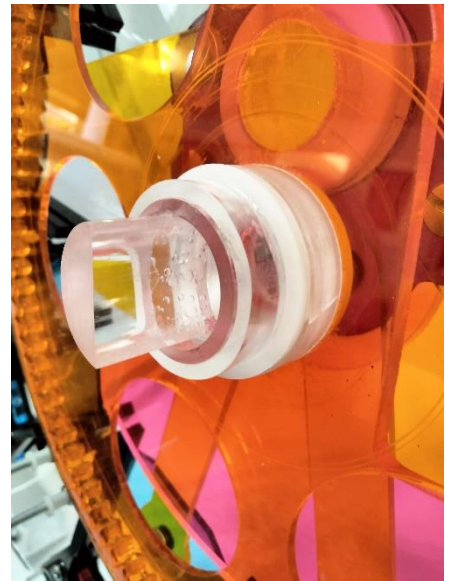
Cam disk.



Spacer ring and bushing rings installed in front of the crank front, in preparation for installing the cam disk.



Cam disk installed, with the hub around the bushing rings.



Spacer ring and shaft sleeve installed in front of the cam disk, in preparation for installing the middle driveshaft.

The cam disk is described in 4.10.10.

Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the cam disk | | |
|---------------------------------------|---|--|
| # | Step | Instructions |
| 1 | Install a spacer ring and bushing rings. | Install a low-friction spacer ring (1/8" thick, 1.75" OD) on the driveshaft, in front of the crank front, to go behind the cam disk hub. |
| | | Install two low-friction bushing rings (each 1/8" thick, 1.5" OD) on the driveshaft, to go inside the cam disk hub. |
| 2 | Apply dry lube to the cam disk gear teeth (optional). | Apply dry lube (3.2) to the cam disk gear teeth (optional). |
| 3 | Install the cam disk. | Install the cam disk on the driveshaft, with the bushing rings inside the cam disk hub. |
| 4 | Install a spacer ring and a shaft sleeve. | Install a low-friction spacer ring (1/8" thick, 1.75" OD) on the driveshaft, in front of the cam disk hub. |
| | | Install a shaft sleeve (3/8" long) on the driveshaft, to go behind gear 33 on the middle driveshaft. |

5.5.2 Assembling the pushrod assemblies



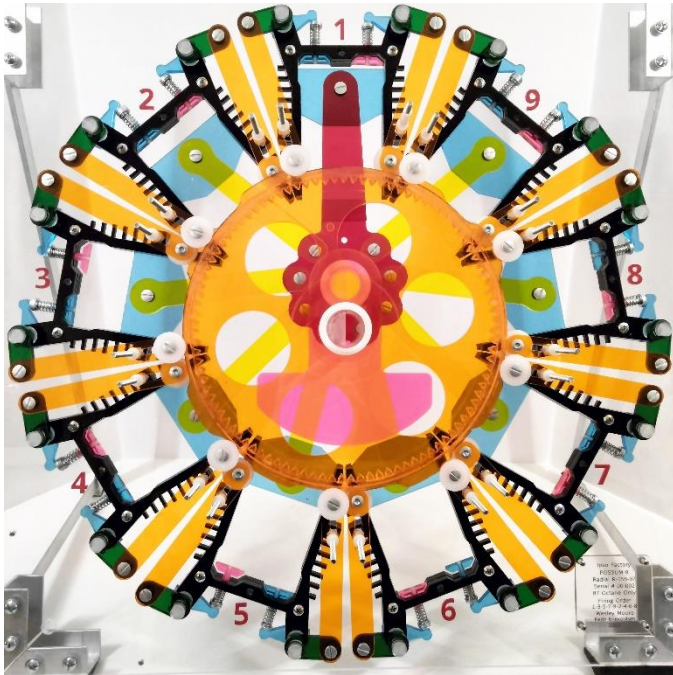
Pushrod assemblies.

The pushrod assemblies are described in 4.10.9.

| Instructions: Assembling the pushrod assemblies | | |
|---|--|---|
| # | Step | Instructions |
| 1 | Notice that the intake and exhaust pushrod assemblies are different. | You will assemble nine intake pushrod assemblies and nine exhaust pushrod assemblies. |
| | | Each intake pushrod assembly has a rocker arm on the back and a cam follower on the front (opposite side), whereas each exhaust pushrod assembly has a rocker arm on the back and a cam follower on the back (same side) (see photo). |
| 2 | Fasten the cam followers to the pushrods. | If your pivot pins are screws & posts that require threadlocker, apply primer and threadlocker (3.1). |
| | | Fasten the cam followers (grooved wheels) to the pushrods with 3/8"-long pivot pins. |
| 3 | Fasten the rocker arms to the pushrods. | If your pivot pins are screws & posts that require threadlocker, apply primer and threadlocker (3.1). |
| | | Fasten the rocker arms to the pushrods with 3/8"-long pivot pins. |
| 4 | Check all fastened joints. | Check that all the joints turn freely. |
| | | After the threadlocker has set, check that the screws & posts are thread-locked and will not come loose. |

Keep the pushrod assemblies intact if they use threadlocker. Avoid unscrewing thread-locked screws. To install or remove a pushrod assembly intact, you merely need to remove the snap ring from the rocker-pusher D-shaft.

5.5.3 Installing the pushrod assemblies



Model with pushrod assemblies installed



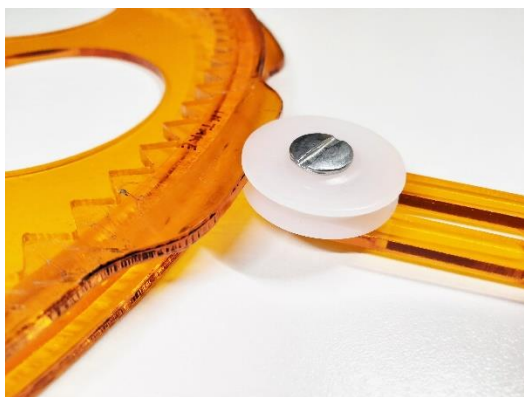
Pushrod assemblies, installed.



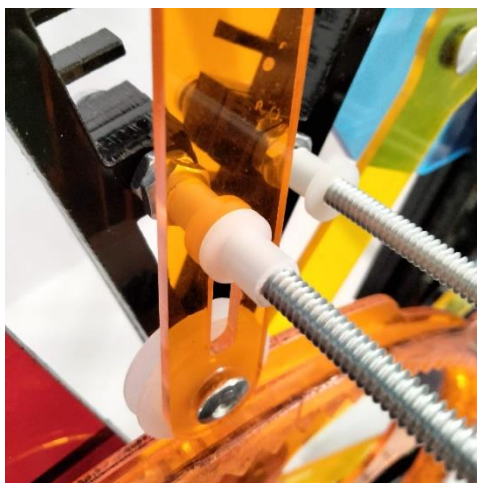
*Rocker arm, spacer sleeve, and snap ring, installed.
(Installing the rocker arm completes the rocker-pusher assembly.)*



Snap-ring pliers.



Cam follower (grooved wheel) on cam track.



Wide or flanged low-friction sleeves on the main screws, next to the pushrod slots.

The pushrod assemblies are described in 4.10.9.

Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the pushrod assemblies | | |
|--|--|---|
| # | Step | Instructions |
| 1 | Install sleeves on the main screws. | Put 18 wide or flanged low-friction sleeves (3/8" long) on the main screws, to hold the back sides of the sliding pushrods. If flanged, the wider ends should be in front, where they touch the pushrods. |
| 2 | Install sleeves on the rocker-pusher D-shafts. | Put 18 sleeves (3/8" long) on the rocker-pusher D-shafts, to support the rocker arms. |
| 3 | Install the pushrod assemblies on the main screws. | Remember that the intake and exhaust pushrod assemblies are not interchangeable. The intake cam followers are on the front side, and the exhaust cam followers are on the back side (see photo). |
| | | Put the 18 pushrods assemblies onto the main screws — the screws go through the slots. Push the assemblies back. |
| 4 | Install the rocker arms on the rocker-pusher shafts. | Push the rocker arms onto the rocker-pusher D-shafts. |
| | | Install 18 snap rings (use snap-ring pliers) into the snap-ring grooves on the rocker-pusher shafts, in front of the rocker arms. If you prefer, you may wait until later to install the rocker snap rings. The model will work without these snap rings. |
| 5 | Put the cam followers on the cam tracks. | Put the cam followers (grooved wheels) onto the cam tracks on the cam disk. The intake cam followers go on the front track, and the exhaust cam followers go on the back track. You may turn the cam disk if that helps. |
| | | For now, try to keep the cam disk pushed back against the crank. Later, the front plate will push the cam disk back. |
| | | For now, it is OK if some of the cam followers do not stay on the tracks. Later, after the valve stems are adjusted, all of the cam followers will stay on the tracks. |
| 6 | Install more sleeves on the main screws. | Put 18 wide or flanged low-friction sleeves (3/8" long) on the main screws, to hold the front sides of the sliding pushrods. If flanged, the wider ends should be in back, where they touch the pushrods. |

5.5.4 Installing the middle driveshaft



Middle driveshaft with gear33.



*Middle driveshaft with gear33.
A shaft sleeve (clear), a spacer ring, and
bushing rings are installed.*



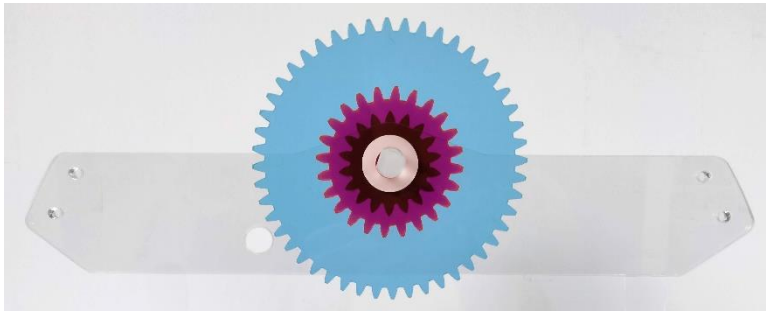
*Middle driveshaft with gear33 installed.
A shaft sleeve (clear), a spacer ring, and
bushing rings are installed in preparation
for installing the front plate.*

The middle driveshaft is described in 4.6.5.

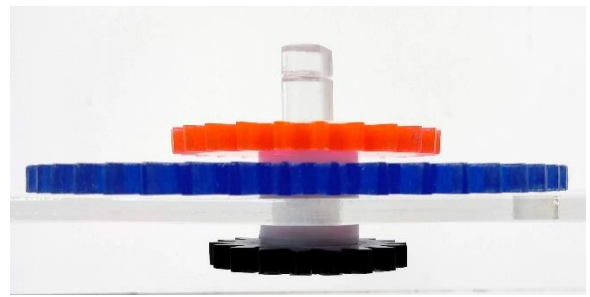
Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the middle driveshaft with gear33 | | |
|---|---|---|
| # | Step | Instructions |
| 1 | Apply dry lube to the gear teeth (optional). | Apply dry lube (3.2) to the gear teeth (optional). |
| 2 | Install the middle driveshaft with gear33. | Install the middle driveshaft with the built-in gear33 on the back side. Simply push the driveshaft connectors together. |
| 3 | Install a shaft sleeve, a spacer ring, and bushing rings. | Install a shaft sleeve (3/8" long) on the middle driveshaft. |
| | | Install a low-friction spacer ring (1/8" thick, 1.75" OD) on the middle driveshaft, to go behind the front plate. |
| | | Install two low-friction bushing rings (each 1/8" thick, 1.5" OD) on the middle driveshaft, to go inside the shaft hole in the front plate. |

5.5.5 Assembling the middle-plate-&-gears assembly



Middle-plate-&-gears assembly with gear18, gear48, and gear24.



Middle-plate-&-gears assembly with gear18, gear48, and gear24, side view.

Gear18, gear48, and gear24 are installed onto the middle plate before the middle plate is installed into the model. The middle plate is described in 4.3.4. The gears are described in 4.9.2.

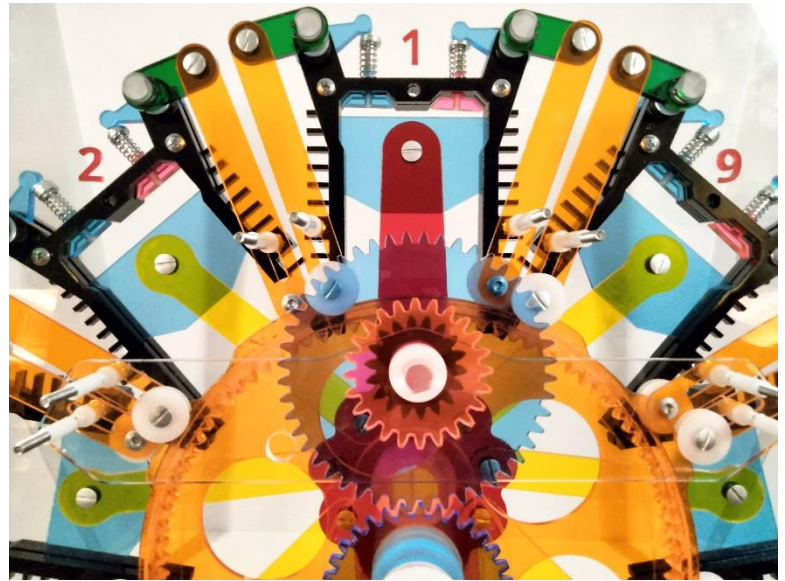
Refer to the assembly diagram (5.2) when assembling these parts.

| Instructions: Assembling the middle-plate-&-gears assembly | | |
|---|--|---|
| # | Step | Instructions |
| 1 | Apply dry lube to the shaft holes or shaft (optional). | Apply dry lube (3.2) to the two shaft holes in the middle plate (optional). Apply dry lube to the gears shaft, where it will touch the shaft holes in the middle plate and front plate (optional). |
| 2 | Install gear18 with D-shaft onto the middle plate. | Put one or more low-friction spacer rings (1/8" + 1/16" thick) onto the D-shaft that is cemented to gear18. Insert gear18's D-shaft into the gears shaft hole in the middle plate, with gear18 on the back side. |
| 3 | Install gear48 onto the D-shaft. | Put a low-friction spacer ring (1/16" thick) onto the D-shaft. Install gear48 onto the D-shaft, front side. |
| 4 | Install gear24 onto the D-shaft. | Put a low-friction spacer ring (1/8" thick) onto the D-shaft. Install gear48 onto the D-shaft, front side. Put a low-friction spacer ring (1/16" thick) onto the D-shaft. |

5.5.6 Installing the middle-plate-&-gears assembly



Model with middle plate (clear) and gears installed.



Middle plate (clear) and gears (gear18, gear48, and gear24), installed.

The middle-plate-&-gears assembly is described in 5.5.5.

Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the middle-plate-&-gears assembly | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Apply dry lube to the gear teeth (optional). | Apply dry lube (3.2) to the gear teeth (optional). |
| 2 | Install the middle-plate-&-gears assembly. | Install the middle-plate-&-gears assembly on four main screws: two main screws between cylinders 2 and 3, and two main screws between cylinders 8 and 9 (see photos and diagrams). |
| | | Push the middle plate all the way back to engage the gears. Gear18 engages gear99 on the cam disk. Gear48 engages gear33 on the driveshaft. You must engage the gears at a particular position. See the instructions for setting the valve timing (6.2). |
| 3 | Install long spacer sleeves on the main screws. | Install spacer sleeves on the 18 main screws to hold the front plate at the correct level. |
| | | Put four shorter spacer sleeves (3/4" long) on the four main screws that hold the middle plate. |
| | | Put 14 longer spacer sleeves (1" long) on the other 14 main screws. |

5.5.7 Setting the valve timing (Ref.)

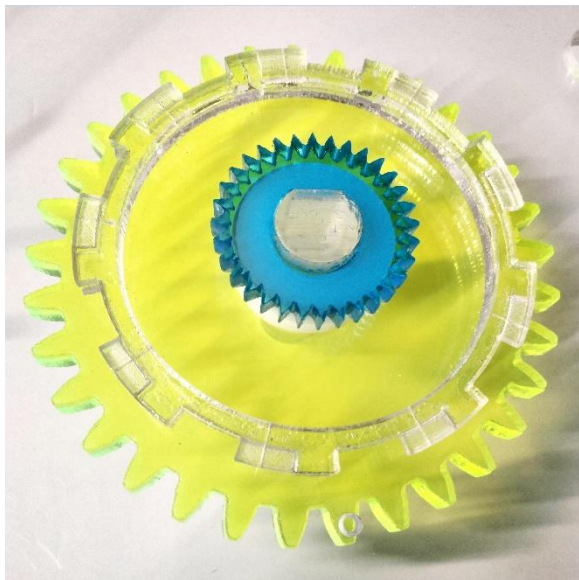
Valve timing instructions are in 6.2.

5.6 Assembling the front levels

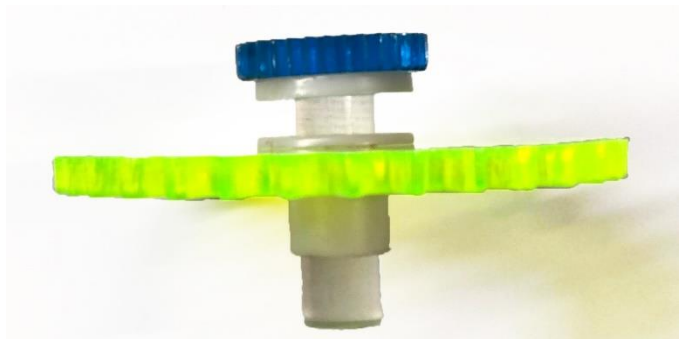
5.6.1 Assembling the front-plate-&-gear assembly



Front-plate-&-gear assembly.



Distributor gear and rotor spline connector installed on the front plate.



Distributor gear and rotor spline connector, side view (front plate not shown).

The distributor gear and rotor spline connector are installed onto the front plate before the front plate is installed into the model.

The front plate is described in 4.3.3. The gears are described in 4.9.2. The rotor spline connector is described in 4.11.3.

Refer to the assembly diagram (5.2) when assembling these parts.

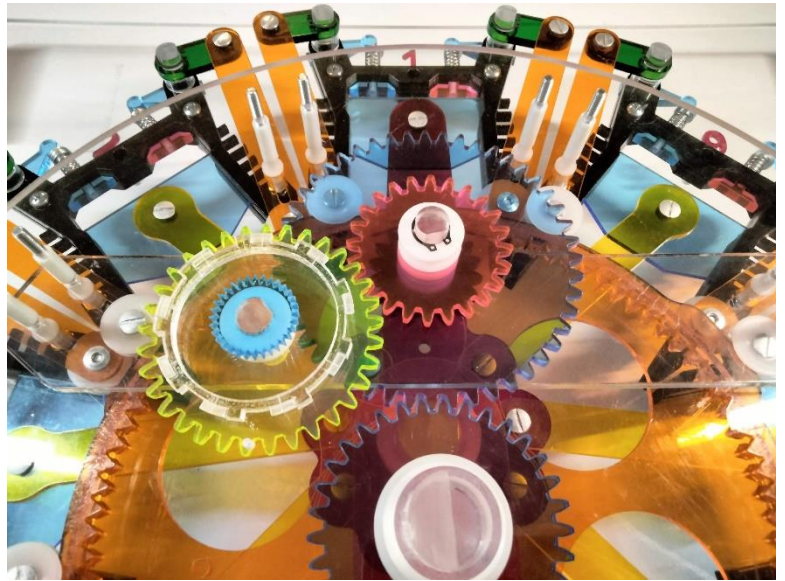
Instructions: Assembling the front-plate-&-gear assembly

| # | Step | Instructions |
|---|---|---|
| 1 | Apply dry lube to the shaft holes or shaft (optional) | Apply dry lube (3.2) to the gears shaft hole and the distributor gear shaft hole in the front plate (optional). Apply dry lube to the distributor shaft, where it will touch the shaft holes in the front plate and middle plate (optional). |
| 2 | Install the rotor spline connector with D-shaft onto the front plate. | <p>Put a low-friction spacer ring (1/8" thick) onto the D-shaft that is cemented to the rotor spline connector. You may need to adjust the number and thickness of spacer rings so the rotor makes good electrical contact with the distributor cap.</p> <p>Insert the rotor spline connector D-shaft into the distributor hole in the front plate, with the connector on the front side.</p> |
| 3 | Install the distributor gear onto the D-shaft. | <p>Put a low-friction spacer ring (1/16" thick) onto the D-shaft.</p> <p>Install gear33_distributor onto the D-shaft, back side.</p> <p>Put a narrow spacer sleeve ($\leq 5/8$" OD \times 7/16" long) onto the D-shaft. The sleeve must have thin walls to have clearance from gear48.</p> |

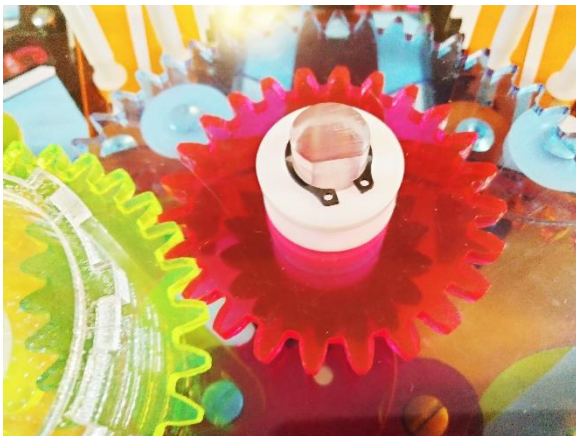
5.6.2 Installing the front-plate-&-gear assembly



Model with front plate (clear) and distributor gear installed.



Front plate (clear) and distributor gear, installed.



Gears shaft held at correct level by a spacer ring and a snap ring



Snap-ring pliers.

The front-plate-&-gear assembly is described in 5.6.1.
Refer to the assembly diagram (5.2) when installing these parts.

| Instructions: Installing the front-plate-&-gear assembly | | |
|--|---|---|
| # | Step | Instructions |
| 1 | Check that the required spacers have been installed. | Check that the shaft sleeve, spacer ring, and bushing rings have been installed on the middle driveshaft (5.5.4). |
| | | Check that the spacer sleeves have been installed on the main screws (5.5.6). |
| 2 | Apply dry lube to the gear teeth (optional). | Apply dry lube (3.2) to the distributor gear teeth (optional). |
| 3 | Lay the model face up. | Fold up the stand and lay the model face up on the worktable. |
| 4 | Install the front-plate-&-gear assembly. | Lay the front plate lightly on top the main screws and carefully align the 18 main screws to go into the 18 close-fit screw holes. It may be tricky to get all the screws in all the holes simultaneously. It may be easier with two people and four hands. Try to avoid scratching the plate. |
| | | Push the front plate down onto all 18 main screws, slowly and evenly, not tilted. If it is tight, you may tap the plate (down or up) with a rubber mallet. Keep pushing the plate down, slowly and evenly, until the shafts meet the shaft holes. |
| | | Align all three shafts. The front end of the driveshaft should go through the driveshaft hole in the front plate, with the bushing rings inside the hole. The front end of the gears shaft should go through the gears shaft hole in the front plate. The back end of the distributor shaft should go through the distributor shaft hole in the middle plate, and Gear33_distributor should mesh with gear24. |
| | | Continue pushing the front plate down until it meets the spacer sleeves on the main screws, with all three shafts in the shaft holes, and all gears meshed. |
| 5 | Install a spacer ring and snap ring onto the gears shaft. | Put a low-friction spacer ring (1/8" thick) onto the gears shaft, in front of the front plate. Adjust the number and/or thickness of the spacer ring(s) so the meshing gears will be aligned after the snap ring is installed. See the assembly diagram (5.2). |
| | | Install a snap ring (use snap-ring pliers) into the snap-ring groove on the gears shaft, in front of the spacer ring(s). You may need to pull the gears shaft toward the front, to align the meshing gears, while you are installing the snap ring. |
| 6 | Stand the model upright. | Stand the model upright on the stand. This allows you to access both the front and back of the model. |
| 7 | Install and tighten the nylock nuts on the main screws, but do not bind the pushrods. | Install and moderately tighten the nylock nuts on the 18 main screws, but do not over-tighten and bind the pushrods. |
| | | Use a wrench to turn the nuts. We recommend using a socket wrench or a box-end ratchet wrench because it is faster than using a standard open-end or box-end wrench. |
| | | Use a (Phillips) screwdriver to hold the screw heads stationary. Do not turn the screw heads because that may dislocate the jammed hex nuts. We recommend using a short screwdriver. |
| | | For a temporary installation of the front plate, install only three nylock nuts on three main screws, evenly spaced at 120°. The model will work quite well with only three nylock nuts. For the final installation, install all 18 nylock nuts. |

5.6.3 Assembling the propeller assembly



Propeller assembly with crank handle parts.

The propeller assembly is described in 4.6.6.

The shaft connector is cemented to the propeller, so the only thing to assemble is the crank handle.

| Instructions: Assembling the propeller assembly | | |
|---|--------------------------------------|---|
| # | Step | Instructions |
| 1 | Assemble the propeller crank handle. | Slide the sleeve (3/16" ID × 1") onto the screw (#10-24 × 1.5"). |
| | | Insert the end of the screw through the hole near the tip of the blade. |
| | | Attach and moderately tighten the nylock nut, but do not over-tighten and bind the sleeve. The sleeve should be free to rotate. |

5.6.4 Installing the propeller assembly



Model with propeller installed.

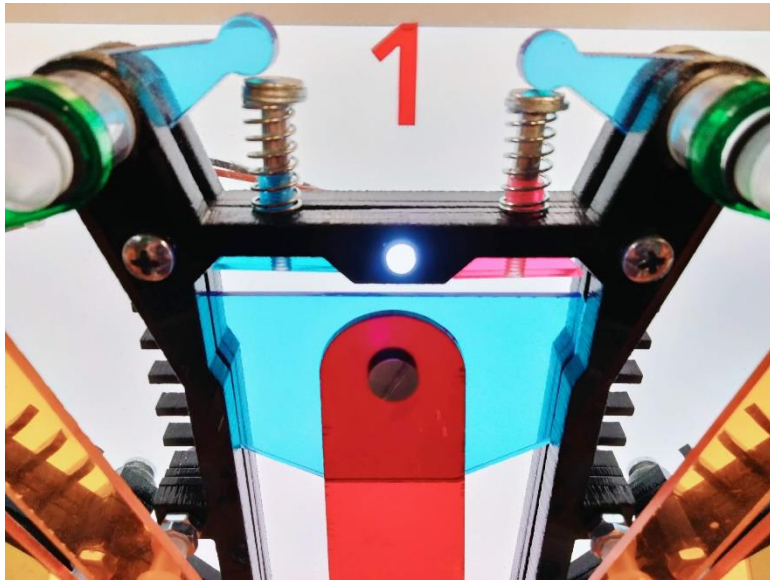
The propeller assembly is described in 4.6.6.

| Instructions: Installing the propeller | | |
|--|------------------------|--|
| # | Step | Instructions |
| 1 | Install the propeller. | Install the propeller onto the driveshaft. Simply push the driveshaft connectors together. |

5.6.5 Adjusting the valve stem lengths



Valve assembly with stem length adjustment washers.



Valves assemblies with stem-length adjustment washers.

The valve assemblies are described in 4.10.3. Installation instructions are in 5.4.5.

After installing the entire valve system (valves, cam disk, pushrods, rocker arms, and valve pushers), you must adjust the length of each valve stem to make the valves operate correctly. Adjust the valve stem length by adding zero or more washers below the head of the screw and above the post and valve spring.

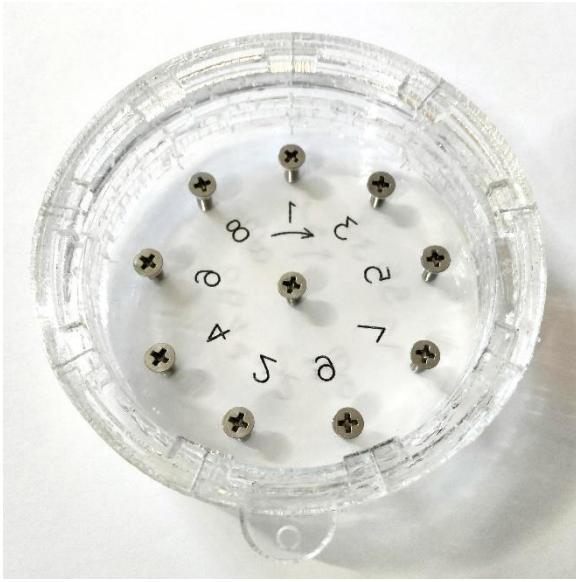
| Instructions: Adjusting the valve stem lengths | | |
|---|--|---|
| # | Step | Instructions |
| 1 | Start with no washers. | When you first install a valve assembly, start with no washers on the valve stem. |
| 2 | Check the operation of the valve. | Turn the crank and check the following things: <ul style="list-style-type: none"> • The valve should fully open and close. The valve pusher should push the valve fully open. The valve spring should return the valve to fully closed. • The valve spring should push (by means of the rocker arm and pushrod) the grooved cam follower wheel onto the cam track so it should never derail. • The cam disk should turn with moderate force applied. |
| 3 | If it does not work, add or remove a washer. | If it does not work, add or remove a washer: <ul style="list-style-type: none"> • Add a washer if the valve does not fully open. • Remove a washer if the valve does not fully close. • Add a washer if the cam follower is not always pressed onto the cam track. • Remove a washer if the cam follower is pressed too strongly onto the cam track. |
| Repeat checking the operation of the valves (step 2) and adding or removing washers (steps 3) until it works. | | |

These individual valve-stem-length adjustments are necessary mainly because the rocker-pusher assemblies are imperfect, so the angle between the valve pusher and the rocker arm varies from the ideal (180°).

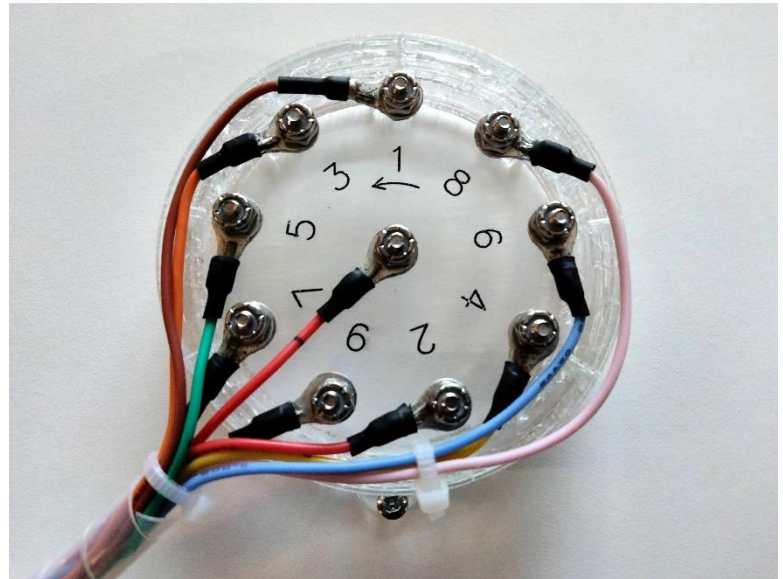
If you need to use more washers than will fit on the valve stem screw, then the rocker-pusher assembly is probably bad and you will need to make a new rocker-pusher assembly (or install a spare, if you have a spare).

5.7 Assembling the electrical parts

5.7.1 Assembling the distributor-cap-&-cable assembly



Distributor cap, back side (inside), with flat-head contact screws in countersunk screw holes, almost flush, but slightly protruding.

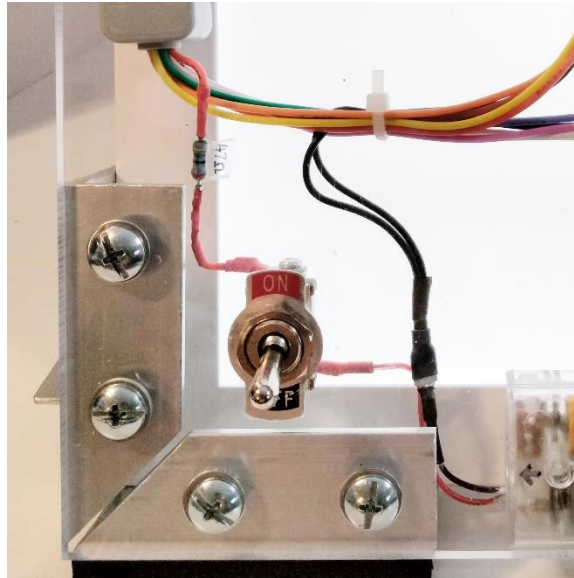


The ring terminals on the front cable are connected to the contact screws in the distributor cap with nylock nuts.

The distributor-cap-&-cable assembly is described in 4.12.5.

| Instructions: Assembling the distributor-cap-&-cable assembly | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Put the contact screws into the distributor cap. | Put the flat-head contact screws (#4-40 × 3/8") into the countersunk holes in the lid of the distributor cap. The screw heads are on the back side (inside the cap). |
| | | The flat heads of the contact screws should be almost flush with the surface but should protrude slightly to make contact. |
| 2 | Fasten the harness's 10 wires to the distributor cap. | Fasten the harness's 10 wires to the 10 contact screws on front side (topside) of the lid of the distributor cap. Put the ring terminals onto the screws and fasten them with nylock nuts (#4-40). |
| | | The nine spark plug wires connect to the circle of nine contact screws. Route the wires around the outside of the circle so they do not obstruct the view of the rotor turning. |
| | | The center positive (red) wire connects to the center contact screw. |
| 3 | Attach the lock screw or pin (optional). | Attach the lock screw or pin, if possible. For example, if the lock tab has a threaded hole, it can store the lock screw even when the distributor cap is unattached to the plate. |

5.7.2 Installing the on-off switch

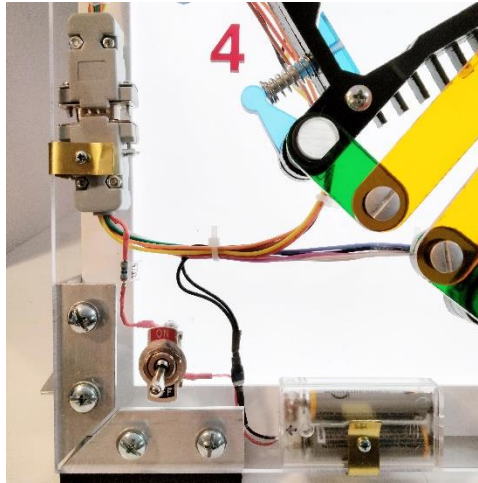


Toggle switch, installed.

The switch is described in 4.12.6.

| Instructions: Installing the on-off switch | | |
|---|---------------------------------------|---|
| # | Step | Instructions |
| 1 | Install the switch on the back plate. | Mount the toggle switch through the back side of the switch hole in the back plate. Put the ON-OFF label plate and the hex nut on the front side. Install and tighten the nut. Make sure the terminal screws on back side are oriented so they are accessible by a screwdriver to connect and disconnect the wires. |

5.7.3 Installing the spring clips

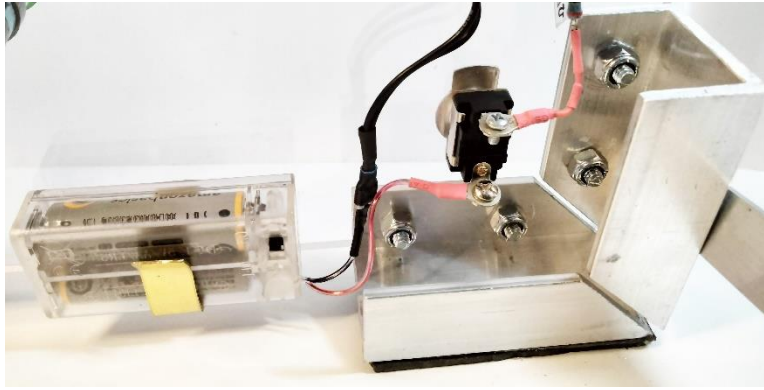


Electrical corner, with spring clips holding battery pack (bottom edge) and cable connector (left edge).

The spring clips are described in 4.12.7.

| Instructions: Installing the spring clips | | |
|--|--|--|
| # | Step | Instructions |
| 1 | Install the battery pack spring clip. | Put the battery pack clip on the bottom edge of the back plate, with the front of the clip on the front side of the plate, over the screw hole. |
| | | Fasten the clip to the plate with a screw (#4-40 × 1/4"). Do not over-tighten (do not strip the plastic threads). |
| 2 | Install the cable connector spring clip. | Put the cable connector clip on the left edge of the back plate, with the front of the clip on the front side of the plate, over the screw hole. |
| | | Fasten the clip to the plate with a screw (#4-40 × 1/4"). Do not over-tighten (do not strip the plastic threads). |

5.7.4 Installing the battery pack

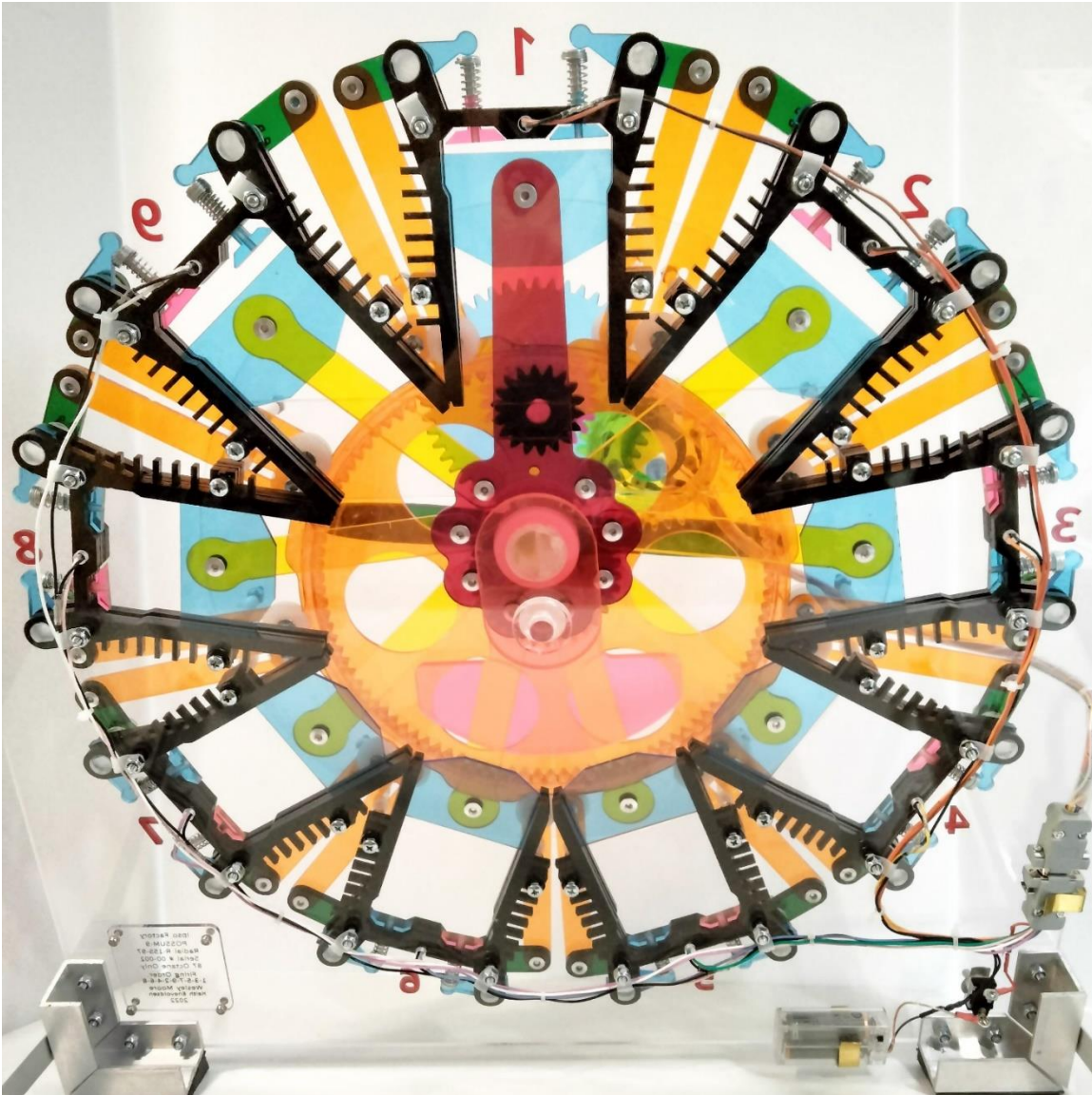


Electrical corner, back side, showing the battery pack's connections.

The battery pack is described in 4.12.8.

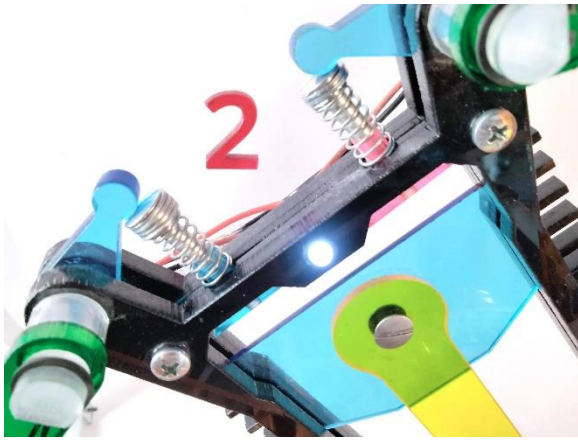
| Instructions: Installing the battery pack | | |
|--|---|---|
| # | Step | Instructions |
| 1 | Install batteries. | Install two new 1.5V AA alkaline batteries. Use alkaline batteries that deliver the full 1.5V rather than rechargeable batteries that deliver less voltage. The LEDs will be dim if the battery voltage is low. |
| | | If the battery holder has its own built-in on-off switch, make sure that switch is on. |
| 2 | Put the battery pack into the spring clip. | Put the battery pack behind into the spring clip, behind the bottom edge of the back plate (see photo). |
| 3 | Connect the positive wire to the on-off switch. | Connect the battery pack's positive (red) wire's ring terminal to the screw terminal on the on-off switch (see photo). |
| 4 | Connect the negative wire to the back wire harness. | Connect the battery pack's negative (black) wire's tab terminal to the tab socket terminal on the negative wire of the back wire harness (see photo). |

5.7.5 Installing the back wire harness

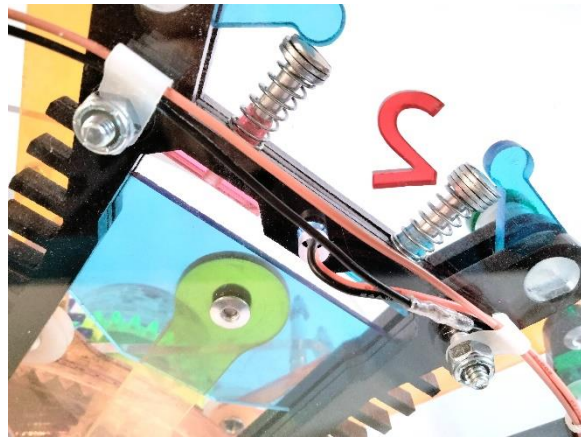


*Back side of the model, showing the back wire harness routed around and behind the periphery of the circle of cylinders.
Branch 1 goes to LEDs 1 to 4, and branch 2 goes to LEDs 5 to 9.*

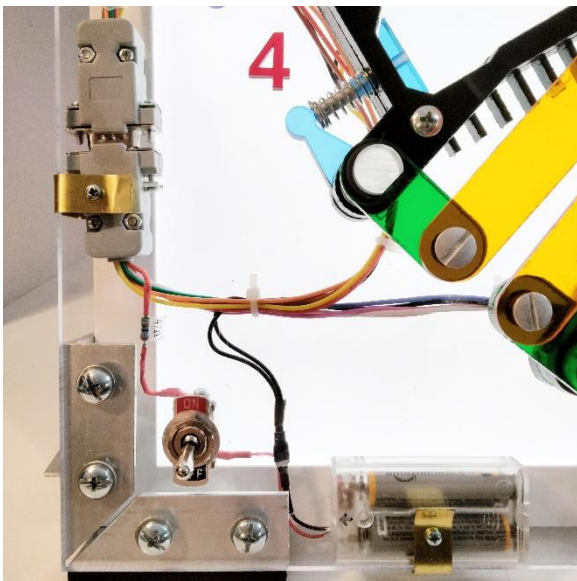
The back wire harness is described in 4.12.10. See the wiring diagram (4.12.1).



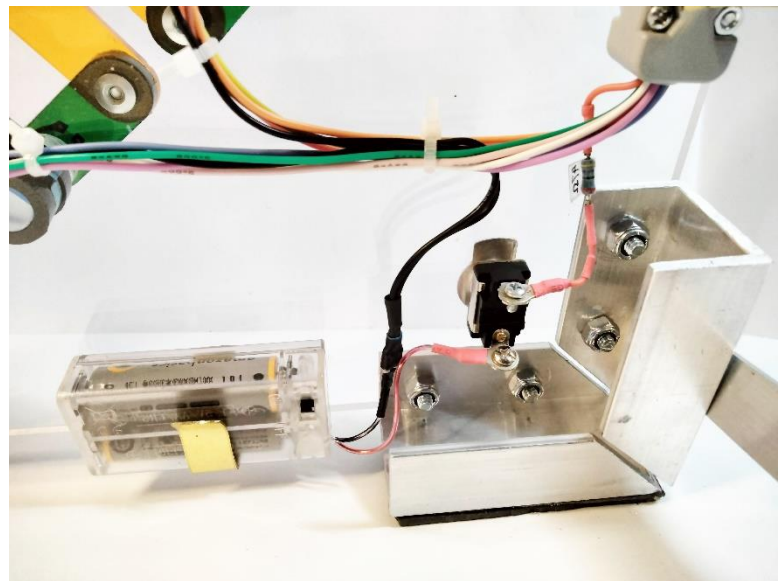
Front view of a cylinder, with a lit LED, showing that the back wires are partially hidden behind the head of the cylinder.



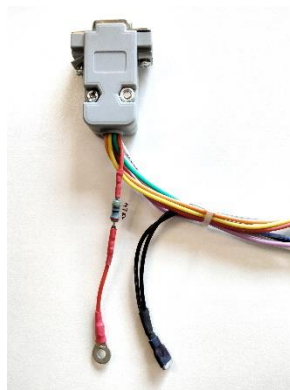
Back view of a cylinder, showing the back wires routed through the cable clips, and leading to the LED.



Electrical corner, front side, showing the back wire harness connections.



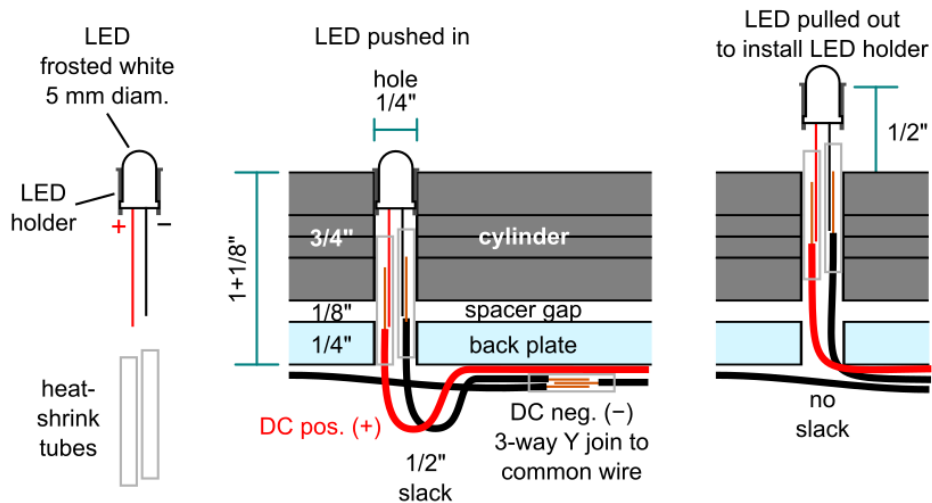
Electrical corner, back side, showing the back wire harness connections.



The back wire harness has three electrical connections: the cable connector, the positive terminal, and the negative terminal.

| Instructions: Installing the back wire harness | | |
|--|---|---|
| # | Step | Instructions |
| 1 | Stand the model upright. | Stand the model upright on the stand. This allows you to access the front and back. |
| 2 | Install the cable clips. | Install 18 cable clips (if not already installed) on the short cylinder screws, behind the back plate, held by the nylock nuts. The cable clips should be positioned to hold the wires around the outside of the circle of screws (see photo and note about hidden wires below). |
| | | There are 18 cable clips: 16 will hold wires, two are unused (spares). |
| | | If you use flexible half-loop clips, you can first install all the clips, then install the wires into the clips without removing the nuts. If you are using loop clips, you will need to remove and replace nuts and clips as you route the wires. |
| 3 | Stand the model upright or lay the model face down. | Stand the model upright on the stand or lay the model face down on blocks on the worktable. This allows you to access the back. |
| 4 | Check that the resistor is plugged in. | The harness's short positive (red) wire has an in-line resistor. If your model has a plug-in resistor, keep it always plugged in. |
| 5 | Put the cable connector into the spring clip. | Put the multi-pin cable connector behind the back plate, in the spring clip on the lower left edge of the back plate (see photo). |
| 6 | Connect the short positive (red) wire to the on-off switch. | Connect the harness's short positive (red) wire's ring terminal to the screw terminal on the on-off switch (see photo). |
| 7 | Connect the negative (black) wire to the battery pack. | Connect the harness's negative (black) wire's tab socket terminal to the tab terminal on the negative wire of the battery pack (see photo). |
| 8 | Route the wires around the circle of cylinders. | Route the back wire harness through the cable clips, around the outside of the circle of short cylinder screws. Branch 1 goes to cylinders 1 to 4, and branch 2 goes to cylinders 5 to 9 (see photos). See the wiring diagram (4.12.1). |
| 9 | Put the LEDs in the holes. | From behind the back plate, push each wired LED through the LED hole in the cylinder until the entire LED protrudes 1/2" forward of the hole. There should be no slack in the wire when the LED is pulled forward 1/2". There should be 1/2" slack in the wire when the LED is pushed back in. See the LED wires diagram (below). |
| 10 | Tidy up the wire bundling. | After the entire wire harness is installed, tidy up the wire bundling by moving or adding zip ties. The positive and negative wires should be bundled together with at least 10 zip ties: at the trunk (1 tie), at the main branches (2 ties), and on the smaller branches between adjacent cylinders (7 ties). |

Hidden wires. The back wire harness is routed through the cable clips around the outside of the circle of short cylinder screws, so the wires are partially hidden behind the heads of the cylinders. There should be no clutter of wires visible directly behind the pistons and valve heads when the model is viewed or photographed from the front. Since the model demonstrates a four-stroke engine cycle, there should be a clear view of the pistons, valves, and sparks.



LED wires, section view. LED wires need 1/2" slack so LEDs can be pulled forward.

5.7.6 Installing the LED holders



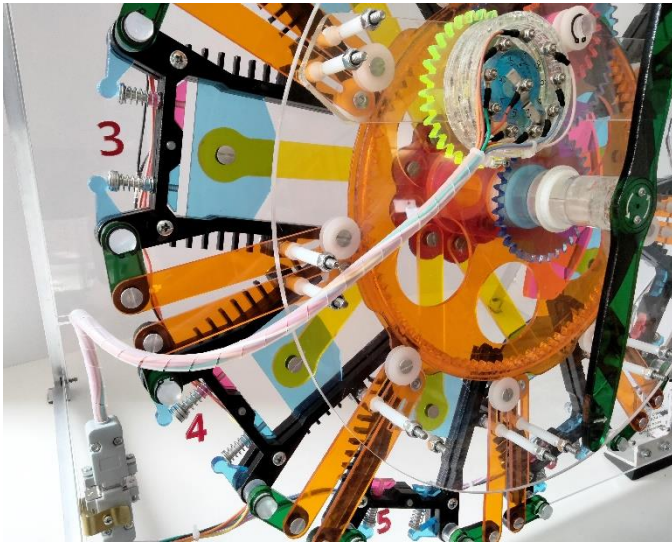
LED pulled forward to install the plastic LED holder.

LED and holder pushed back into cylinder.

The LED holders are described in 4.12.11.

| Instructions: Installing the LED holders | | |
|--|-------------------------------|---|
| # | Step | Instructions |
| 1 | Pull the LED forward. | From behind the back plate, push the wired LED through the LED hole in the cylinder until the LED protrudes about 1/2" forward of the hole. To push the LED forward, the LED wires must have some slack (see the LED wires diagram in the previous section). |
| 2 | Put the holder on the LED. | From the front, slide the plastic LED holder over the LED until the LED snaps into the holder. |
| 3 | Push the LED and holder back. | From the front, push the LED and LED holder back into the hole until it is fully seated. |

5.7.7 Installing the distributor-cap-&-cable assembly



Distributor-cap-&-cable assembly, installed.

The front cable runs from the distributor, between the main screws for cylinders 3 and 4, back to the back plate, through the cable slot, and down to the cable connectors.



Distributor-cap-&-cable assembly, installed.

An optional cable clip or strap holds the cable between the two main screws for cylinders 3 and 4.

The distributor-cap-&-cable assembly is described in 4.12.5.

| Instructions: Installing the distributor-cap-&-cable assembly | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Connect the cable connector. | Connect the front cable connector to the back wire harness cable connector. Put the back wire harness cable connector into the spring clip, behind the lower left edge of the back plate (see photos). |
| 2 | Install the distributor cap. | Instructions are in 5.7.9. |
| 3 | Put the cable into the cable slot. | Hold the front cable so it runs from the distributor, between the protruding ends of the main screws for cylinders 3 and 4, and back to the cable slot on the back plate. The cable should be moderately taut on the front plate, so the cable naturally stays between the main screws for cylinders 3 and 4, but with enough slack to allow the distributor cap to be installed and uninstalled. Insert the cable into the cable slot on the lower left edge of the back plate, adjusting the tautness of the cable as needed. |
| 4 | Install a cable clip or strap (optional). | If necessary, install a cable clip (attached to one screw) or strap (attached to two screws) to hold the front cable between the main screws for cylinders 3 and 4. The clip or strap may be installed with hex nut(s) on top of the nylock nut(s) holding the front plate. This allows you to remove the cable clip or strap without loosening the nylock nuts. |

5.7.8 Installing the rotor-&-contacts assembly



Rotor with springs and contacts strip.



Rotor-&-contacts assembly.



Rotor spline connector.



Distributor rotor, installed.

The rotor-&-contacts assembly is described in 4.11.4.

| Instructions: Installing the rotor-&-contacts assembly | | |
|---|---|---|
| # | Step | Instructions |
| 1 | Insert the contacts strip into the rotor. | Insert the contacts strip into the rotor. The middle tab of the strip should fit snugly into the middle slot (between the two contact points), but the other ends of the strip should be free to move up and down on the springs. |
| 2 | Push the rotor onto the spline connector. | Push the rotor onto the spline connector. The spline connector allows you to install the rotor at the required angle. See the instructions for setting the spark timing (6.3). |

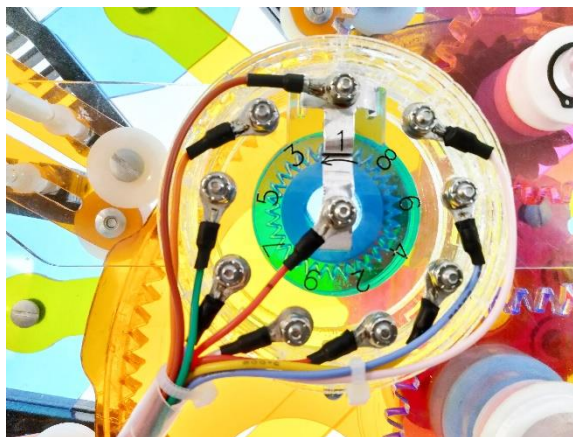
Instructions: Adjusting the rotor contacts strip

| # | Step | Instructions |
|---|----------------------------|---|
| 1 | Check the fit. | Insert the contacts strip into the rotor. The middle tab of the strip should fit snugly into the middle slot (between the two contact points), but the other ends of the strip should be free to move up and down on the springs. The contacts strip should have slight contact bumps or buttons at the two contact points. |
| 2 | Check the operation. | When the distributor is assembled and the rotor turns, all nine spark plug LEDs should flash at the appropriate times. |
| 3 | Adjust the contacts strip. | <p>If the contacts strip does not fit or operate properly, adjust it by slightly bending it with your fingers or needle-nose pliers. Then check the fit and operation again.</p> <p>If you cannot make it work by bending the contacts strip, you may need to change the rotor level or do something else. See troubleshooting (7.5).</p> |

5.7.9 Installing the distributor cap



Distributor rotor, before distributor cap is installed.



Distributor cap, installed.

The distributor cap is described in 4.11.5. The distributor-cap-&-cable assembly is described in 4.12.5.

| Instructions: Installing the distributor cap. | | |
|--|--------------------------|--|
| # | Step | Instructions |
| 1 | Align. | Put the cap over the twist connector ring on the front plate, with contact point 1 about 15° clockwise of straight up, so the tabs and slots align. The tabs and slots are inside the cap, but you can look through the clear plastic to align them. |
| 2 | Push. | Push the cap onto the twist connector ring on the front plate. |
| 3 | Twist counter-clockwise. | Twist the cap COUNTERCLOCKWISE (same as the rotor direction) about 15° until it stops. Contact point 1 should be straight up (12 o'clock position). |
| 4 | Lock. | If necessary, lock the cap with the lock screw or lock pin. |

| Instructions: Removing the distributor cap. | | |
|--|------------------|--|
| # | Step | Instructions |
| 1 | Unlock. | Unlock the cap by undoing the lock screw or lock pin. |
| 2 | Twist clockwise. | Twist the cap CLOCKWISE (opposite the rotor direction) about 15° until it stops. |
| 3 | Pull. | Pull the cap off the twist connector ring on the front plate. |

You can lock the cap in place with a lock screw or lock pin in the lock tab at the bottom of the cap. The lock may not be needed if the cap fits tightly, but it is needed if the cap fits loosely.



Distributor cap lock screw or lock pin.

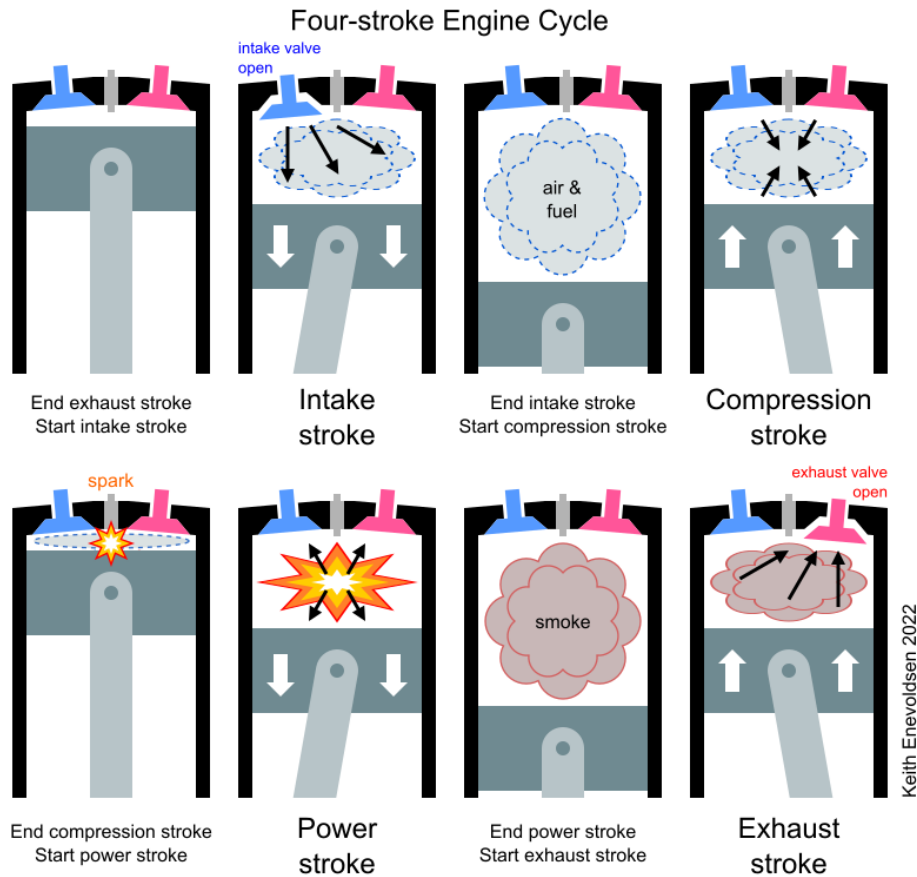
5.7.10 Setting the spark timing (Ref.)

Spark timing instructions are in 6.3.

6 Setting the timing

First, understand the four-stroke engine cycle (6.1). Then set the valve timing (6.2) and the spark timing (6.3).

6.1 Four-stroke engine cycle



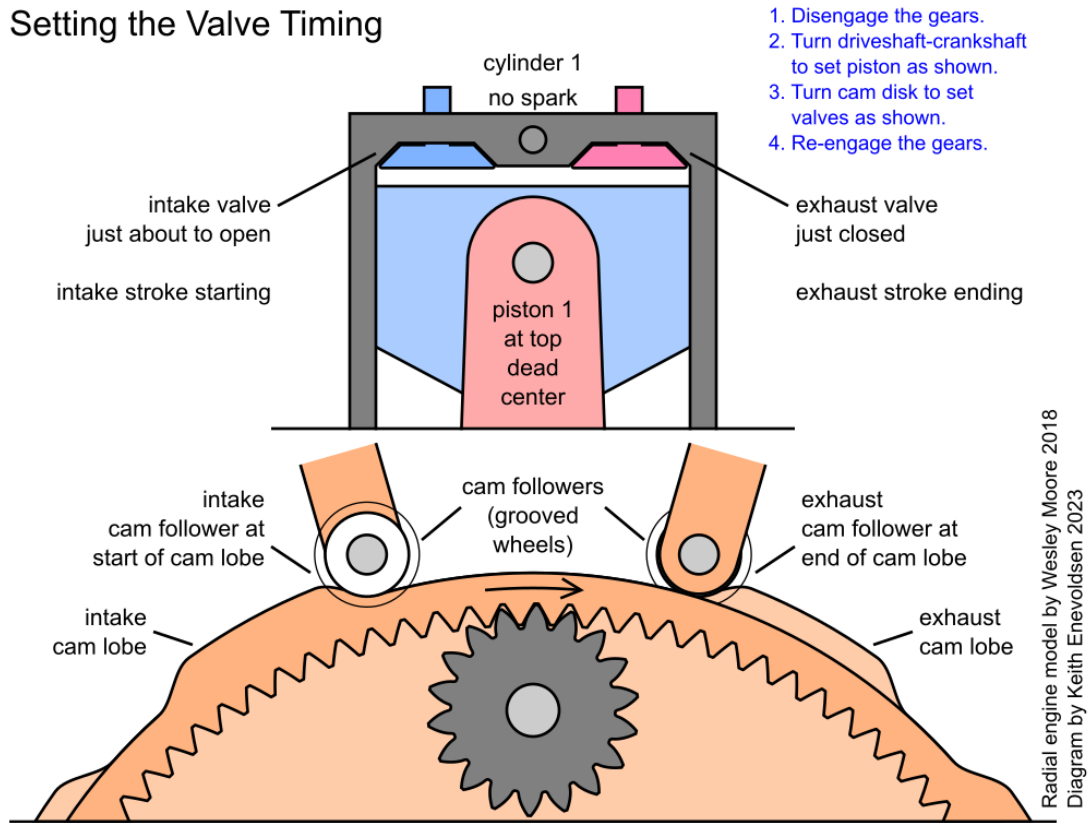
Four-stroke engine cycle.

| Four-stroke engine cycle | | | | |
|---------------------------|-------------|--------------|---------------|---|
| Stroke or event | Piston | Intake valve | Exhaust valve | Action |
| Intake stroke | expanding | open | closed | Only the intake valve is open. The piston pulls air and fuel into the cylinder. |
| Compression stroke | compressing | closed | closed | The valves are closed. The piston compresses the air/fuel mixture. |
| Ignition | compressed | closed | closed | The spark ignites the air/fuel mixture. The spark is at the end of the compression stroke. |
| Power stroke | expanding | closed | closed | The valves are closed. Combustion of the air/fuel mixture pushes the piston, driving the crankshaft, driveshaft, and propeller. |
| Exhaust stroke | compressing | closed | open | Only the exhaust valve is open. The piston pushes the exhaust gases out of the cylinder. |

6.2 Setting the valve timing

You must set the valve timing before you can set the spark timing (6.3). Setting the valve timing means synchronizing the valves with the pistons. You do this by engaging the gears at a set position.

Setting the Valve Timing



Valve timing diagram.

| Instructions: Setting the valve timing | | |
|--|---|---|
| # | Step | Instructions |
| 1 | Disengage the gears that synchronize the cam disk with the crankshaft-driveshaft. | Remove the nylock nuts from the main screws. |
| | | Remove the front plate (or pull it forward 1/2"). |
| | | Remove the middle driveshaft (pull it out or pull it forward 1/2"). This will disengage gear33_driveshaft from gear48. |
| 2 | Turn the driveshaft to put piston 1 at the top dead center. | Turn the driveshaft-crankshaft to put piston 1 at the top dead center (TDC) (see the diagram). |
| 3 | Turn the cam disk to put the valves at the set position. | Turn the cam disk to put the valves at the set position, at the end of the exhaust stroke and the beginning of the intake stroke (see the diagram). |
| 4 | Re-engage the gears. | Reinstall the middle driveshaft (push it in). This will re-engage gear33_driveshaft with gear48. |
| | | Reinstall the front plate. |
| | | Reinstall the nylock nuts on the main screws. |

Finer adjustments. Using the procedure above, you can set the valve timing closely enough for this toy model. If you want finer control, you can turn the cam disk an extra half (or quarter) turn to shift gear99 by a half (or quarter) tooth width.

6.3 Setting the spark timing

Before you can set the spark timing, you must first set the valve timing (6.2). Setting the spark timing means synchronizing the spark with the valves and pistons. You do this by setting the distributor rotor angle.



Rotor spline connector.

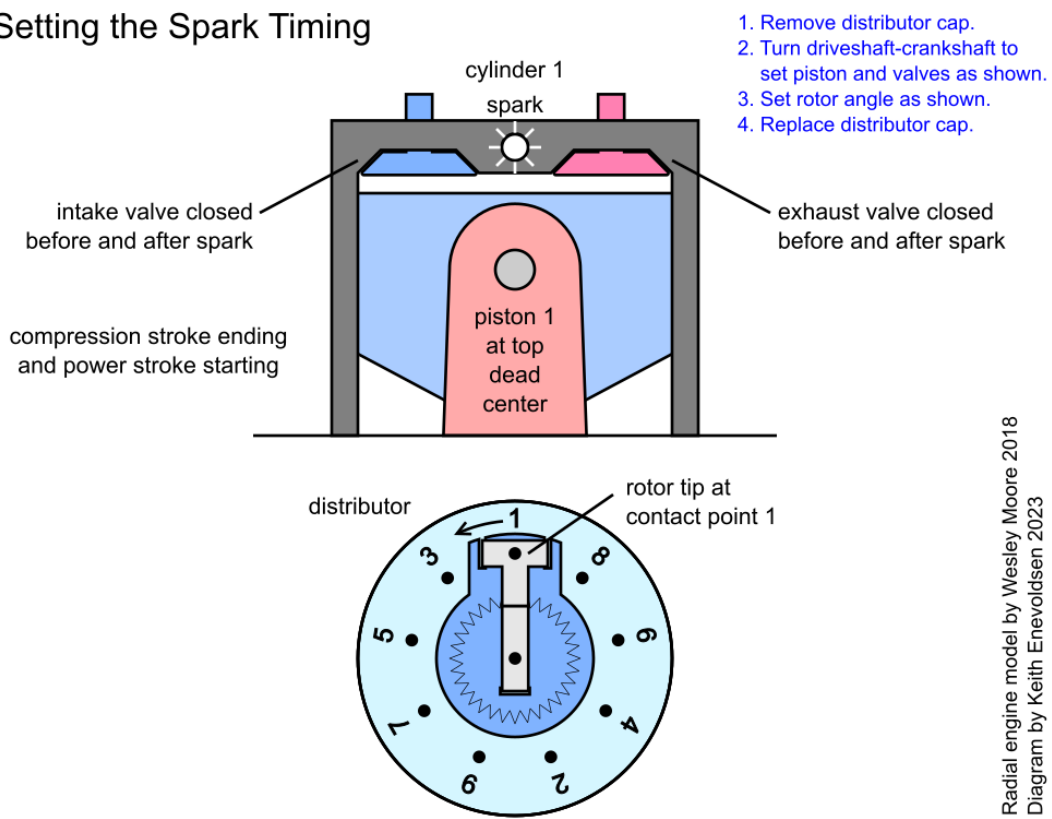


Distributor rotor installed.



Distributor cap installed.

Setting the Spark Timing



Setting the spark timing.

Radial engine model by Wesley Moore 2018
Diagram by Keith Enevoldsen 2023

| Instructions: Setting the spark timing | | |
|--|---|--|
| # | Step | Instructions |
| 1 | Remove the distributor cap. | Unlock the cap by undoing the lock screw or lock pin. |
| | | Twist the cap CLOCKWISE (opposite the rotor direction) about 15° until it stops. |
| | | Pull the cap off the twist connector ring on the front plate. |
| 2 | Turn the driveshaft to set the piston and valves to the set position. | Turn the propeller-driveshaft-crankshaft until piston 1 is at top dead center (TDC), and the valves are at the position for the spark to fire, at the end of the compression stroke and the start of the power stroke (see the diagram). |
| 3 | Set the rotor angle to be straight up or nearly straight up. | Pull the rotor straight off the spline connector on the distributor shaft. |
| | | Turn the rotor so its tip is at the contact position for cylinder 1, oriented straight up (12 o'clock position) (see the diagram). |
| | | Push the rotor onto the spline connector. You may need to turn the rotor slightly to engage the spline connector. The rotor tip should be pointed straight up or nearly straight up. |
| 4 | Replace the distributor cap. | Put the cap over the twist connector ring on the front plate, with contact point 1 about 15° clockwise of straight up, so the tabs and slots align. The tabs and slots are inside the cap, but you can look through the clear plastic to align them. |
| | | Push the cap onto the twist connector ring. |
| | | Twist the cap COUNTERCLOCKWISE (same as the rotor direction) about 15° until it stops. Contact point 1 should be straight up (12 o'clock position). |
| | | Turn the switch on. The spark plug LED in cylinder 1 should light up. |
| | | Lock the cap with the lock screw or lock pin, if necessary. |

Finer adjustments. Using the procedure above, you can set the rotor angle closely enough for this toy model. If you want finer control of the rotor angle, you will need to partially disassemble the model, as follows: Pull the front plate forward 1/2" to disengage gear33_distributor from gear24. Turn gear33_distributor about a half (or quarter) turn to shift the distributor spline connector by a half (or quarter) tooth width. Then reinstall the front plate to re-engage the gears.

Spark advance. We set the spark to fire when the piston is at top dead center (TDC). But, if you prefer, you may advance the spark to fire slightly before the piston is at top dead center, as for a real engine.

7 Troubleshooting

7.1 Troubleshooting: Gears

Goal: All gears should turn smoothly and never skip or jam. Each pair of meshing gears should be at (or near) the same level, and the gear teeth should always engage fully.

| Problem | Fix |
|---|---|
| A pair of meshing gears may be misaligned, not on the same level (within a tolerance of half the thickness of the gears), so the gears may miss or skip, causing the pistons, valves, and sparks to become unsynchronized | Reassemble the model to make each meshing pair of gears be at the same level. |
| A pair of meshing may be jammed, so you cannot turn the propeller shaft at all. Gears may jam if the gears are too close together or their shafts wobble. | Reassemble the model so the driveshaft and gear shafts are held in the correct positions. |

7.2 Troubleshooting: Pistons

Goal: All nine pistons should move in and out smoothly.

| Problem | Fix |
|--|---|
| A piston may be stuck in its piston slot because it is squeezed too tightly between the front and back parts of the cylinder. | Loosen the jammed nuts next to the cylinder on the main screws and/or the nylock nuts on the short cylinder screws that are squeezing the piston between the front and back parts of the cylinder together. |
| An outward-pushing piston may be jammed against an inward-pushing valve. The pistons should never touch the valves when the valve timing is correct. | Set the valve timing. |
| A pivot pin connecting a piston to a con rod may have loosened or fallen off. | These pivot pins are accessible when the model is assembled, so you may not need to disassemble the model. Reconnect the piston to the con rod. If your pivot pin has a screw & post that requires threadlocker, reapply primer and threadlocker (3.1). With the model assembled, the back of the piston will be about 3/8" from the back plate, so holding the back side of the screw & post is difficult. You may be able to hold it with your finger, or a piece of rubbery foam that is thinner than your finger. |
| A pivot pin connecting the master rod flange to a con rod may have loosened or fallen off. | These pivot pins are not accessible when the model is assembled, so you need to disassemble the model. Reconnect the con rod to the master rod flange. If your pivot pin has a screw & post that requires threadlocker, reapply primer and threadlocker (3.1). |
| A piston may be stuck in its piston slot because it is tilted. | You can wiggle the stuck piston to free it. You can replace that piston with a better-fitting piston. |

7.3 Troubleshooting: Valves

Goal: All 18 valves should open and close. The cam followers (grooved wheels) should stay on their cam tracks. The cam followers for the intake valves (blue) go on the front cam track and the cam followers for the exhaust valves (red or pink) go on the back cam track. When a cam follower is not on a cam lobe, the valve should be closed (or nearly closed) and the valve stem spring should lightly push the cam follower onto the cam track. When a cam follower is on a cam lobe, the valve should be open and the valve stem spring should strongly push the cam follower onto the cam lobe.

| Problem | Fix |
|---|---|
| A cam follower may have derailed from its cam track, so the valve no longer moves. | The temporary fix is to simply put the cam follower back on the cam track. First, turn the shaft to turn the cam disk to a position where the cam follower will not be on a cam lobe (a bump). Pull the con rod outward (compressing the valve spring) so you can freely move the cam follower and put the cam follower (grooved wheel) back on its proper cam track. The permanent fix is to adjust the valve so that the valve spring always pushes the cam follower onto the cam track, preventing this cam follower from derailing. |
| The pushrod may be stuck because it is squeezed too tightly between the sleeves on the long main screw that goes through the slot on the pushrod. | Loosen the nylock nuts on the long main screws that are squeezing the pushrod between the sleeves. |
| The valve or valve pusher may be stuck because it is squeezed too tightly between the front and back parts of the cylinder. | Loosen the nylock nuts on the short cylinder screws that are squeezing the valve or valve pusher between the front and back parts of the cylinder. If the valve hole is slightly too small, it may need to be sanded (see the Maker Manual). |
| A valve stem's length may not be adjusted perfectly, causing the valve to not open or close, or not fully open or close. | Adjust the valve stem length, to make it longer or shorter, by adding or removing adjustment washers on the valve stem. |
| A valve stem spring may be too short, causing the valve to not fully close. | Put in a new spring or stretch the spring to slightly increase its length. |
| A valve stem spring may be too tight around the plastic valve stem. | Put in a new spring or twist the spring to slightly increase its diameter. If the plastic valve stem is slightly too big, it may need to be sanded (see the Maker Manual). |
| A pivot pin connecting a rocker arm to a pushrod may have loosened or fallen off. | These pivot pins are accessible when the model is assembled, so you do not need to disassemble the model. Reconnect the rocker arm to the pushrod. If your pivot pin has a screw & post that requires threadlocker, reapply primer and threadlocker (3.1). |
| A pivot pin connecting a cam follower to a pushrod may have loosened or fallen off. | These pivot pins are accessible by disassembling just one part. Remove the snap ring from the rocker-pusher shaft (use snap-ring pliers), then turn the pushrod to access the cam follower. Reconnect the cam follower to the pushrod. If your pivot pin has a screw & post that requires threadlocker, reapply primer and threadlocker (3.1). |
| If the cam disk is not turning at all, the gears may not be meshing properly. | See the gear meshing fixes (7.1). |

7.4 Troubleshooting: Timing

Goal: The positions of the valves and pistons in each cylinder should match the positions shown in the four-stroke engine cycle diagram. For each cylinder, the spark plug LED should flash brightly at (or near) the moment that the compression stroke is ending, and the power stroke is starting, as shown in the four-stroke engine cycle diagram (6.1).

| Problem | Fix |
|--|---|
| The four-stroke engine cycle is running backwards! | Turn the propeller COUNTERCLOCKWISE, not clockwise! |
| The valve timing (synchronization of the valves and pistons) is not correct (it does not match the four-stroke engine cycle diagram). | Set the valve timing (6.2). |
| The spark timing (synchronization of the sparks with the pistons and valves) is not correct (it does not match the four-stroke engine cycle diagram), but the valve timing is correct. | Set the spark timing (6.3). |
| The spark timing is not correct, and the valve timing is also not correct. | Set the valve timing before setting the spark timing. |

7.5 Troubleshooting: Electrical

Goal: All nine spark plug LEDs should flash brightly.

| Problem | Fix |
|--|---|
| The on-off switch is not turned on. | Turn on the on-off switch on the front plate. (Remember to turn it off when you are done using the model.) If the battery holder has its own built-in on-off switch, make sure that switch is on. |
| The batteries are weak, dead, or missing. | Install two new 1.5V AA alkaline batteries. Use alkaline batteries that deliver the full 1.5V rather than rechargeable batteries that deliver less voltage. The LEDs will be dim if the battery voltage is low. |
| One or more wire connectors are loose. | Make sure all the (non-soldered) wire connectors are tight: (1) The front and back cable connectors are connected. (2) The front cable's ring terminals are connected to the distributor contacts. (3) The battery pack's negative (black) wire is connected to the negative (black) wires in the back wire harness. (4) The battery pack's positive (red) wire is connected to the on-off toggle switch. (5) The back wire harness's short positive (red) wire is connected to the on-off toggle switch. (6) The back wire harness's short positive (red) wire has an in-line resistor, which is plugged in or soldered. |
| The distributor rotor contacts strip may have poor contact with the spark plug wire contact points on the inside of the distributor cap. | Open the distributor cap, take out the rotor, and make slight adjustments to the contacts strip. You can slightly bend the metal strip to make better contact. You can clean or sandpaper the contact surfaces. If the rotor is missing either of its two tiny conical springs, you can glue in a new spring. Be sure to replace the rotor at the correct angle, and replace the distributor cap. See setting the spark timing (6.3). |
| The rotor may be at the wrong level, causing poor contact. | Adjust the rotor level by adding or removing a thin spacer ring under the rotor's spline connector. This will require partial disassembly of the model because the spline connector is cemented to the shaft. |
| If, after checking all the problems above, one or more LEDs still do not flash, then there may be a broken wire, a bad solder join, or a dead LED. | Use your ohmmeter to check for broken wires or bad solder joins. Replace broken wires. Re-solder bad joins. Test for dead LEDs by applying voltage directly to the LED leads. Replace dead LEDs with new LEDs of the same type. See the Maker Manual. |

7.6 Troubleshooting: Broken parts

| Problem | Fix |
|-------------------|---|
| A part is broken. | <p>Do one of the following:</p> <ul style="list-style-type: none"> • Replace the broken part with a spare part if you have one. • Fix the part. If an acrylic part is broken, or an acrylic join has failed, it may be fixable with acrylic solvent cement (using a needle applicator). See the Maker Manual. • Make a new part. See the Maker Manual. |