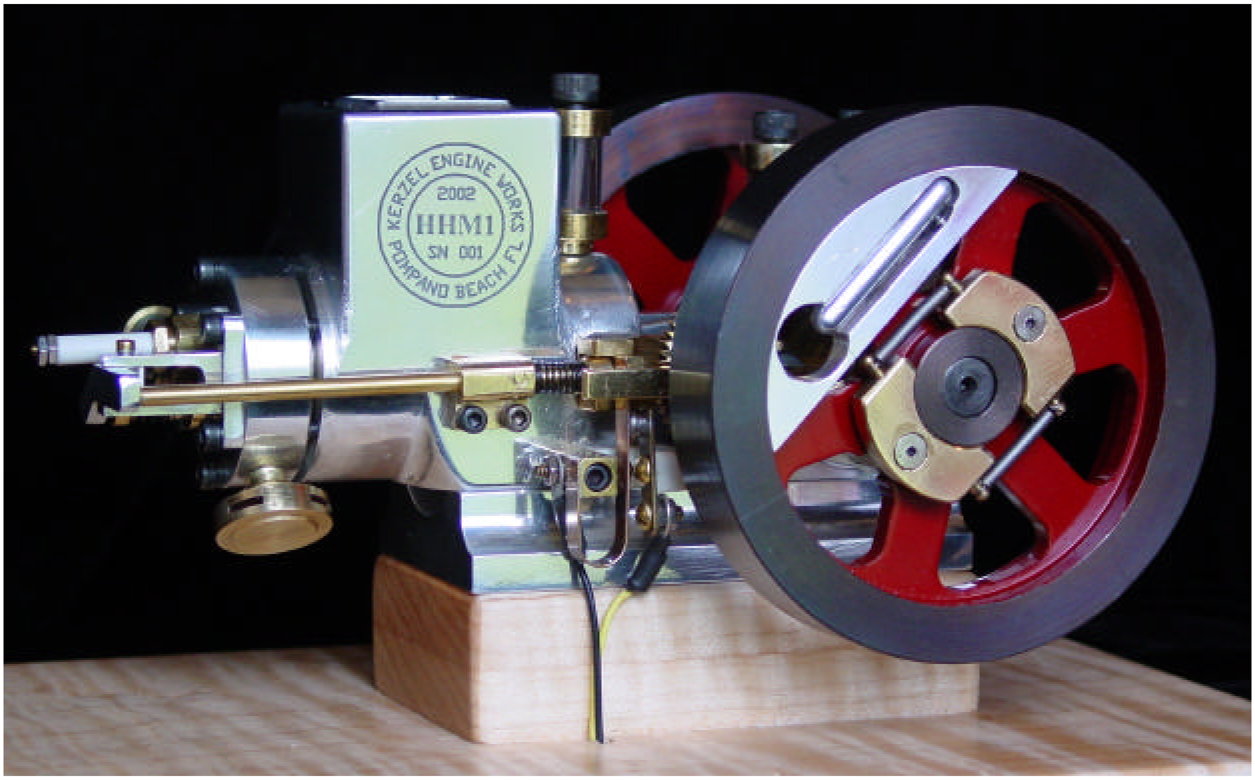
Horizontal Hit and Miss 1 - Drawing Notes



Design

In January 2001 I decided to build a horizontal hit and miss engine. I looked at the plans in Strictly I.C. Magazine and was not impressed by the boxy designs. In February, I went to an Engine and Tractor Show and saw lots of engines. I took the features from three different engines and added them to the sketches I had made. I wanted the parts to look more like the castings used in the old engines. Drawings were made of the main components and machining started in February 2001. Mid project I was distracted for many months, but in February 2002 the engine took over again. By July it was complete. It took over 3 months to get it to run good. Many little details and a lot of learning about how to operate a engine. After that I spent time testing many of the items and designs that were passed over while trying to make it run. These notes and the drawings were written as the engine is getting a final polish and paint in March 2003.

The engine runs great, starts easy, and can be taken apart, reassembled and it still works. The operating adjustments are not critical and it is a joy to watch it run.

Project

This engine is built from bar stock. It has a lot of extra machining on the parts to make then look more like old cast parts.

The plans are intended for someone willing to make their own gears and wind their own springs. These may be parts that are purchased on other engines. They are not difficult but they are extra steps.

I do not see this as being a difficult project, I also do not see it as a first internal combustion engine. Many of the engines based on a casting set would be a better first IC engine choice. As always you are planning your very first engine, I would recommend starting with compressed air or steam, progressing to a Sterling, and then building IC. There is a lot to learn.

Tools

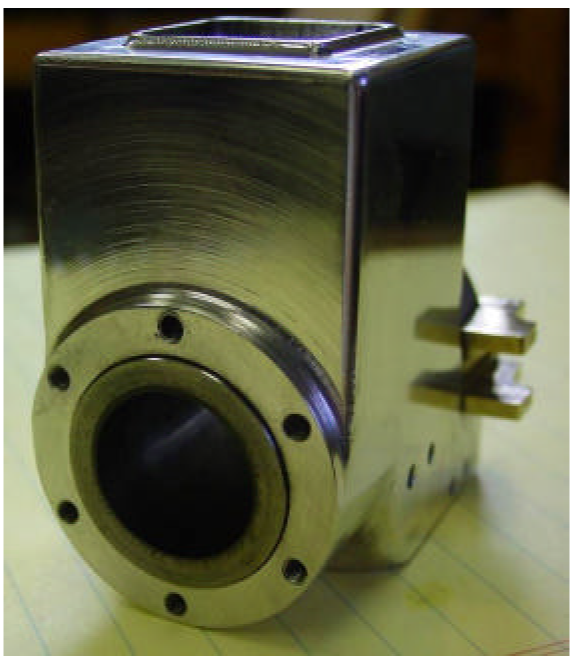
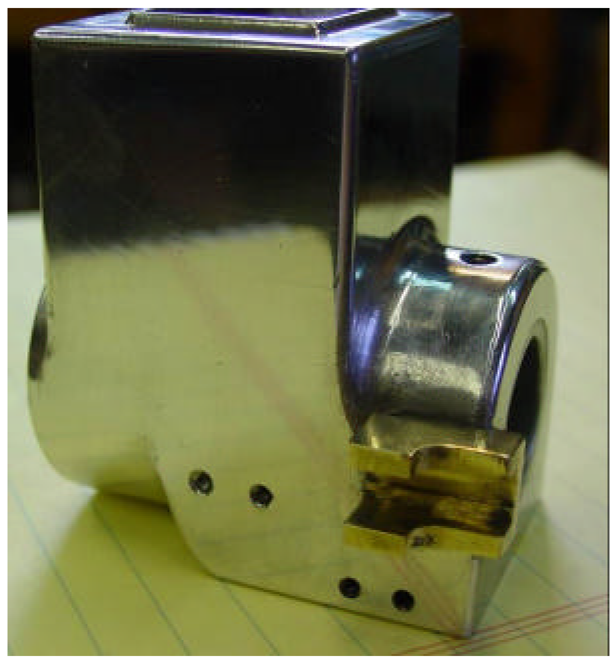
This engine requires a lathe, 4 jaw chuck or faceplate, 3 jaw chuck, vertical mill, rotary table, and various accessories and hand tools.

Instructions are given for cutting gears and winding springs. These notes and the notes on the drawing pages explain many operations in detail, especially one that may be new to the builder.

Disclaimer

Cylinder Body

The cylinder body has a lot of detail some of which could be eliminated to simplify the project. The milled curved surfaces are not essential, nor is the raised square cooling tank top.

The drawing has been broken up into machining operations.

The bore for the cylinder liner shows an under cut in the center of the cooling tank with a passage to that tank. This is a real engine cooling detail, it looks good if you look down the cooling tank, but it is not required. The engine needs no water (and never green anti freeze in a hit and miss) in the cooling tank. The size of the engine and the displacement will keep operating temperatures at about 120 F.

Piston and Rings

There has been a much discussion about piston rings and how to make them.

The mathematically derived ring is from early issues of Strictly Internal Combustion magazine (#7, 8 and 9) written by George Trimble, describes how to make a ring, expand it and heat treat it. This should produce the best sealing ring, but it is a lot of work to make the heat treating fixture. It is the method shown on the drawings.

The second type of ring is recommended by Bob Shores. It is a simplified version of the mathematic design that requires no fixture and is quicker. Without doing all the math I estimate this method is nearly 90% of the mathematical method and about ¼ of the work. I have made rings using the mathematical design and using Bob's method and cannot see or observe any difference except in the time required to make the ring.

Cutting Groves

This engine uses rings that are .020 thick based on the calculations for side wall pressure. I use a slitting saw of the correct thickness to cut the grove. A saw holder was made to hold the round saw like a regular cutting tool in the lathe. The holder needs to extend close to the teeth so the blade will not flex and cut crooked.

On my first hit and miss I managed to cut the groves so they were not perpendicular to the sides of the piston (my first saw holder design allowed the blade to flex). This allowed leakage and lower compression. Make sure the groves are square and smooth to insure good sealing between the ring edge and piston grove. This leak source is not obvious, but prevented operation.

Making Piston Rings

When the material for the cast iron piston is turned and lapped to the perfect size for the cylinder, make and extra ½ inch of material. This material will be the ideal diameter for rings and have an excellent outside finish from lapping.

Bore the material to get the required wall thickness for the rings.

Use the slitting saw as a parting tool (to reduce kerf losses) and cut several rings .001 wider than the groves cut in the pistons. Normally, I make two or more sets, and I use the best rings first.

Measure the grooves in the piston with feeler gages. Make the rings 0.0005 to 0.0010 narrower than the grooves. Use #400 grit silicon carbide wet dry sand paper to fine tune the rings thickness. Sand in a circular or figure 8 pattern. Check the rings at least 6 points around its perimeter to get a uniform thickness with a micrometer. The ring is small and cuts fast so check every few strokes.

A ring holder may help to guide the rings over the sandpaper. The ring holder is a scrap with a hole bored in it to hold the raw ring as it is being sanded.

First check to see the ring slides in the grove and moves easily while dry. Check the depth of the ring and the depth of the grove. The grove OD should be 0.005 to 0.015 smaller than the ID of the rings.

Split the ring using end nippers or diagonal cutters. The resulting break in cast iron will be rough. Sand each cut end with 4 stokes of #400 wet/dry to remove the rough broken surface. If the piston, liner and rings are all cast iron, the sanding will have produced enough gap if the ring material was exactly the same size as the piston. Larger gaps are only required if there are different metals being used.

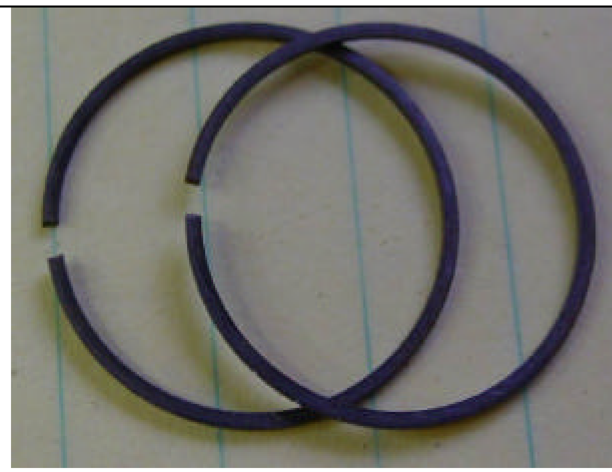
Now either make the full heat treating fixture shown or follow Bob's procedure for heat treating (see Bob Shores Engine Building Tips #6 at www.FloridaAME.org). In either case, the ring is sprung to be more open and then heated to set this new shape. This makes the ring appear larger and requires compressing the ring so it will fit into the cylinder. The rings are very fragile and easy to deform or snap, so expand them with care.

If you use the long method, heat the rings in the fixture to about 450ºF, cover with anti-scale compound, and heat to dull red for 3 minutes. Let cool slowly, dissolve anti-scale compound in hot water. Remove rings and oil immediately. About 2/3 of the gap of the heat-treating fixture will be found in the heat-treated ring. Oil them immediately so rust does not form.

Ring Holder for sanding to thickness

Rings on heat treating fixture

Fixture with rings ready to heat treat



Finished rings

Fitting Rings

Make sure the ring will go into the cylinder. I beleve the 0.002 gap used in most model engines is too large for model engines. The 4 sanding stokes should have produced enough gap, but it never hurts to check again. The gap may not be straight, but a hairline of light should pass trough.

The rings will need to be compressed before they can be inserted into the cylinder when on the piston. A compression tool can be made, but the rings can be moved with toothpicks and guided into the cylinder.

Two rings are used and the gaps are often placed at 10 and 2 o'clock positions.

Testing Piston and Rings

The rings can be tested for leakage with compressed air when the cylinder, piston, and other base parts are complete. The air can be injected using a special test plate to replace the head.

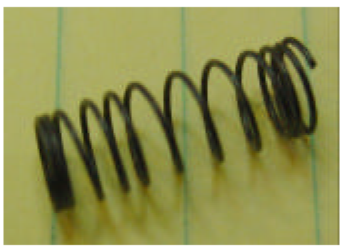
Pressurize with shop air to the maximum compression pressure and listen for leaks. The piston and rings should be oiled with #20 oil or 3-in 1 oil before testing. Rings are hard to get completely silent, but they should be nearly so.

Springs

The springs for this engine are home wound. The process is not difficult and gives the builder a lot of control over spring size and force. The music wire used is small, very springy, and has razor sharp ends. Use extreme caution when cutting, handling, and releasing tension on this wire. I highly recommend gloves and safety glasses.

An interesting web site relating to the making of springs is http://home.earthlink.net/~bazillion/intro.html . It contains helpful advice and safety tips.

Compression Springs



Three different compression springs are used in this engine. They are all the same size and number of turns but use different wire sizes for different strengths. Make the mandrel from a section of drill rod. Turn down the areas at the ends of the springs, cut a partial thread at the desired spring pitch to guide the wire.

Put the end of the wire under one jaw of the lathe when mounting the mandrel. Use the slowest speed. Guide the wire by hand, get 2 or 3 closely spaced turns, then let the wire enter the threads, finally 3 more closely spaced turns at the end. When you cut the wire it will snap back and the spring will suddenly unwind some. The spring's diameter will increase some and the length may change a little, but it will be OK. Trim the excess leaving about 1 ½ close spaced turns at each end.

Extension Springs

Extension springs are wound on a straight smooth mandrel. Wind close spaced turns for the spring's length. Trim one end and bend about 2 turns to form an end loop using 2 needle nose pliers. Measure the spring center distance from the end of the loop and form the second loop.

Heat Treating Springs

Springs need to relax for a long life with uniform tension. This is dome by wrapping the springs up in aluminum foil and heating at 450°F for 30 minutes to an hour. The springs will turn black form the air, but I find this an attractive finish. Be sure to oil them immediately so they do not rust.

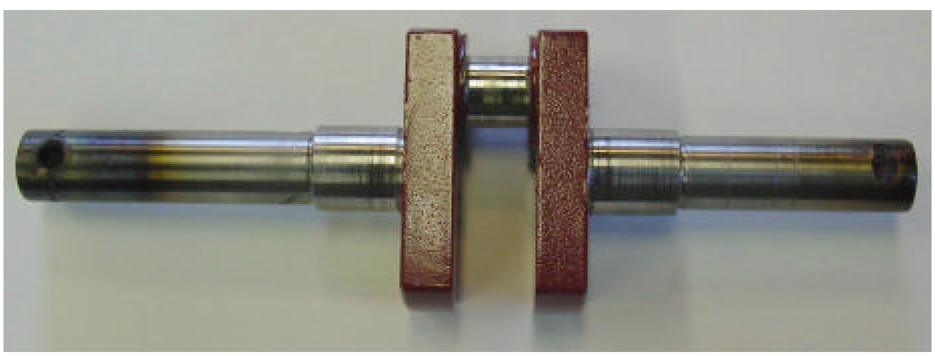
Main Bearings and Frame Assembly

The Main bearing supports and cylinder are mounted to the base. Verify the sides are parallel to each other and parallel to the side of the cylinder. Ream the main bearings .001 larger than the crankshaft diameter. Do this in the milling machine so it will be square and true. Turn the reamer by hand so it does not make an oversize hole.

The main bearings will need to be faced so crank shaft end play is 0.002 to 0.005.

Crank Shaft

The crankshaft is machined from a steel bar. During layout 2 sets of center drillings are put on each end of the blank. These must be laid out and drilled exactly or the diameters will not have parallel axis, which is essential.



Start turning the crank pin. I used a parting tool to make the deep cuts. Slow feed and re-sharpening before the last cut produced a good finish.

When the pin is done, a spacer needs to be made for the open side of the crankshaft. I made a block from scrap aluminum and epoxied it in place. This keeps the crankshaft from bending while the rest of the machining is happening.

A large amount of material must be removed to make the main shaft, I chose to saw most of it away before I started to turn the parts. As much as possible I only cut between the pin and the chuck so power did not need to travel through the pin area. The cuts that had to be made on the other end were made with great caution and low feed rates.

Connecting Rod

Prepare the material to make the connecting rod. Drill the clam end for the screws first using a #38 drill. Clamp it in place and transfer these locations to the large part and drill. Tap the large part and enlarge the holes in the clamp. Fasten them together with 5-40 screws and lay out the rest. Drill the 2 holes #19 for 8-32 screws that will mount it to a rotary table. All the machining can be done on the table. One screw must be at the table center. Use a ½ dia. End mill. Cut the various depths. The tapered center and the small end. The 1/16 round over cutting is not essential but gives a nice finish.

The drawings note that a brass or bronze bearings can be added. There is sufficient material to add these. The actual design is not critical. The Crankshaft above has no measurable wear and has been in service for 30 hours.

Flywheel

The flywheels are turned from bar stock. Cast Iron is the recommended material but steel or brass would work fine. Once the basic form has been turned holes are drilled as corners for the openings that form the spokes. This is done on a rotary table. Next use a 3/8 end mill to cut the radius of each opening. Set the table to 30 degrees off axis to cut the spoke sides. I used a 3/16 dia stone and a high speed hand held grinder tool to soften the edges of the openings.

One Flywheel, the best looking one, needs 2 extra slots for the regulator weight arms.

I put my flywheels in the oven at 450ºF for about an hour to turn them dark. They could be chrome or electroless nickel plated to reduce corrosion.

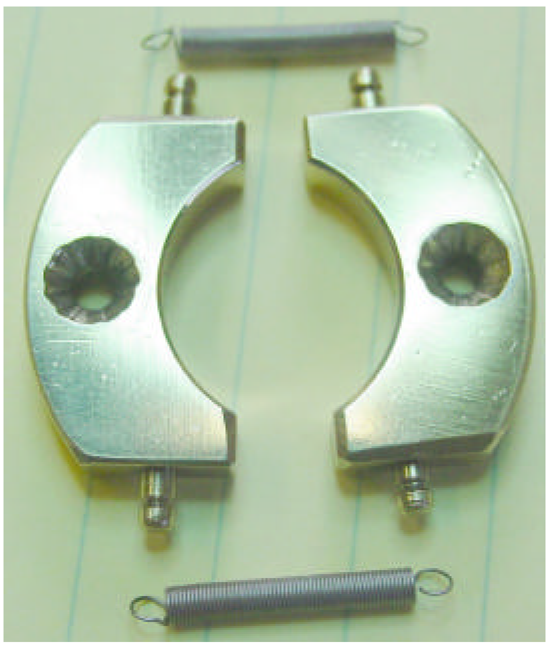
I added a spring loaded starting lever. It is not needed now that properly designed parts are used. In the beginning, hundreds of flips happened with no running. Now that all of that has been overcome it starts on the first flip and this is not needed. Add it if you want to.

Regulator

The regulator is weights on arms that move out by centrifugal force as the engines speed changes. Two springs pull the weights together and set the operating speed. As the weights move the arms they slide a bobbin on the crankshaft that moves the regulator arm. The regulator arm can move when the cam lifts the cam follower to open the exhaust valve. The regulator arm moves and prevents the exhaust valve from closing. Angles on the cam follower and the regulator arm keep them latched until the next exhaust cycle. The open exhaust valve eliminates pulling in fuel and the compression stroke and it also prevents ignition. Later when the speed drops, the bobbin will remove the force on the arm and after the next exhaust cycle there will be intake, compression and a power cycle.

Parts need to move freely. The cam follower must latch the arm.

Cutting the round ends on the arms is the only interesting part. The rotary table does a good job of this and the steps are described on the drawings.



Cam

The cam is made with offset turning. A scrap is drilled and tapped to mount the part off center. When the part is turned a radius is cut. Rotate the cam blank and cut these arcs to make the small diameter. This cam has a .050 flat at the top.

The cam is pinned to the large timing gear with 1/32 diameter SS wire. The pin allows changing the setting by drilling a second hole. The gear teeth are the coarse adjustment, and the pin refines the adjustment. If you end up with multiple holes fill the duds. Set the gears and pin so the piston is mid stroke when the cam follower is on the high flat on the cam on what should be an exhaust stroke. This should have the exhaust valve closed at top and bottom dead center.

The flat that controls the ignition needs attention. The cam follower moves towards the crankshaft when this area rotates into position. This allows the points to close and charge the coil. A few degrees later in the rotation, the points open and cause the spark. The depth and angle of the flat determine the engines timing.

This cannot be cut until the engine is nearly complete and timing set. First cut the flat to about ½ the depth shown and assemble the engine and see where the points open. At this point it should be a few degrees before TDC. As the depth is increased toward the hub, the ignition point will move toward TDC. The ideal setting is 1 or 2 degrees after TDC. The angle can be changed to get this setting if required.

My first try was way off. I soldered a scrap of brass on and just cut it again.

Gears

Cutting gears is easy, all you need are the cutters and a Machinery's Handbook. For my engine I used 48 pitch gears but they have such fine teeth they do not look right so I am recommending 32 pitch gears. Both are shown in the drawings. You can buy gears and machine them to fit, but this is interesting and a very satisfying experience.

Make the gear blank and mount it on the rotary table on an arm to give the cutter clearance. The gears are all based on dull degree movements so they are easy. Make the first cut and measure to the first cut depth shown using a drill bit in the slot. Then just rotate and cut. It is fast and easy and you get a perfect gear.

Add a 4-40 set screw to the small gear and pin the large one to the cam.

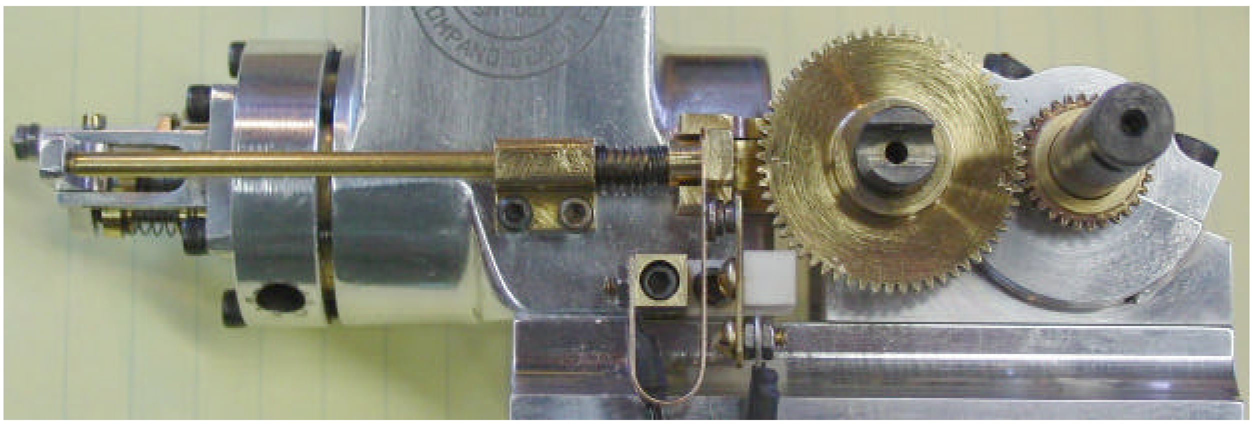
Later when the engine is complete and running, mark a tooth on each gear so they can be aligned.

Push Rod Parts

The push rod is driven by the cam follower. The cam follower slides in the brass slide on the side of the cylinder. Part of it has an angle that latches with the regulator arm. A ball bearing is the actual cam follower. The ball bearing provides low friction and a hard surface to rub on the cam. The cam follower spring forces the follower against the cam.

The push rod screws into the cam follower and there is a lock nut to secure the adjustment. This is adjusted to give .005 clearances when the valve is to be closed.

The ball end of the push rod should mate with the ball socket of the rocker arm. Adjust the bearing to get the push rod to move freely and follow the cam with out sticking. The drawing shows using a spring made from 0.020 wire, if your engine is well alligned, it should be possible to use a spring made from 0.016 wire and weaker is normally better.

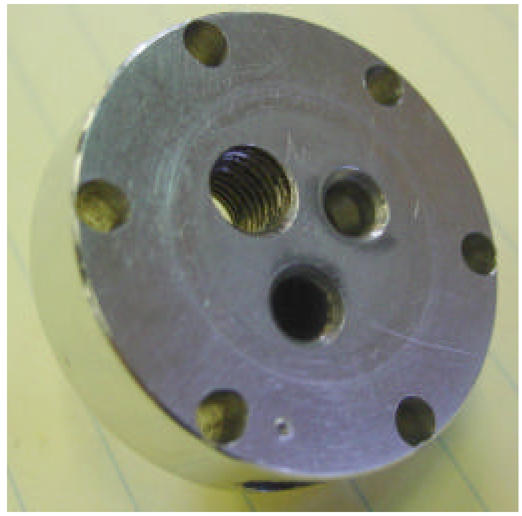


Rocker Arm Parts

These parts are straightforward. A SS ball bearing is inserted into the rocker arm and should end up centered on the exhaust valve. The hardness of the ball and its shape will make the valve operate well. The arm needs to move about 10 degrees freely in the pivot.

Head

The head needs careful layout. The valve guides are pressed into the head and drilled, reamed, and the valve seats cut in one set up to insure concentricity.



Valves

The valves are two part assemblies that are silver soldered. The drill rod stem works well and the SS head does not corrode.

Inspection

The valve needs to move freely in the bushing. The weight of the valve should be able to move it in the bushing when dry. The intake valve on a hit and miss engine uses the weakest possible spring and free motion is critical. A small leak at the inlet valve due to it not moving freely could prevent it from closing and part of the fuel mix may be lost before the valve is sealed by the increasing compression pressure.

The valve stem should be polished and the seating surface should be a smooth straight cone.

Examine how the valve and seat mate. There should be no gap on one side and nothing should change as the valve is rotated in the bushing. If there is a gap, and it moves as the valve is rotated, the valve stem is bent. If there is a gap, but it does not move, it means the valve is not perpendicular to the seat.

Testing

Pressurize the valves with shop air. Make a test plate that will mate with the head and has a under cut for the valve head and spark plug. Push the valve stems in a few times to let some air flow and clean the seating area. Listen for leaks in a quiet shop. If you hear nothing the valve is sealing and is good. Each valve needs to be checked at about 6 locations. Push the valve down and while it is open, it will rotate easily. Check the valve every 60 degrees.

If the valves leak, they need lapping. Be sure to check them at 6 points every time in the lapping process.

Initial testing does not require the valve springs be installed, the air pressure will close them. The final test however should have the springs in place just to be sure.

Lapping

Resist the temptation to use a drill motor to speed the lapping process. The lapping compound cuts fast and finger power is enough. The drill is also likely to damage the bushing or valve stem.

Us a short length of plastic tube over the end of the valve stem as a handle and to provide some flexibility. Just rotate the tube between your fingers while gently pulling the valve to the seat. 4 or 5 turns on each valve are enough for a lapping cycle.

Use a 400-600 grit lapping compound and be sure to keep it off the valve stem and out of the guide.

Clean the parts to remove all lapping compound and test them again. In the beginning, it may seem to get worse before it improves. As soon as the valve has stopped leaking at all 6 points, it done.

Spark Plug

The spark plug is a homemade unit. The center insulator is Corian. Main points are making the threads work freely and sealing all possible leaks. As the fuel is burnt, water is a by product and it will come out of any leak in the spark plug. The water then shorts it out and interrupts operation. Seal the insulator to the body and the center electrode to the insulator.

Corian slowly burns away. Make extra insulators and when sealing it all, be sure you can take it apart later.

Carburetor

Propane is my preferred fuel but carburetor details have been provided for liquid fuel (7% WD-40, 93% regular gas) is also included. Propane has no smell and always starts on the first flip.

The engine needs an air cleaner. The cylindrical one I made is made from 200 mesh SS wire cloth. Because it is a cylinder, you can't put your finger over it to choke the engine to prime the fuel system. This priming is important with liquid fuel. A round air cleaner made using the screen elements from a faucet aerator should work.

Points

The points are a simple system of 2 tungsten buttons removed from automotive points in a blister pack soldered to fingers.

One finger is a beryllium copper spring that is moved by the cam follower. Thin spring steel could be used if the beryllium copper is not available. A bending jig is made by putting a 3/8 dowel in a block of wood, and then clamping a second piece of wood to hold the short tail as the J shape is formed. This finger is soldered to the brass grounding block.

The other finger is made of ridged brass. It is mounted on a plastic insulator. This part of the points is the contact that triggers the ignition circuit.

When properly adjusted, the points are open about 0.020 when the cam follower is on the middle area of the cam. When the cam point passed by, this gap opens wider, this extreme motion is why the material is important. Brass will not flex this much. The material must be berelium copper or spring steel. When the low spot of the cam is active, the points touch and can conduct electricity.

Ignition

Using a transistor ignition is recommended. Any of the popular devices will work. Use a reliable coil to get a hot spark.

Oiling the cylinder:

One drop every 10 minutes seems ideal and leaves an oil film on the valves and top of the cylinder. Cylinder oil is critical when using fuels that do not contain oil.

An oilier has been added that uses a fluid passage packed with cotton to slow the drip rate to 1 drop every 10 minutes.

Final Checks

Before trying to start the engine there are things to check for:

1. Compression makes it difficult to turn the crankshaft on the compression stroke only.
2. Intake valve makes noise on intake cycle and power cycle
3. Check exhaust valve timing and operation.
4. Check ignition timing caused coil to turn off 1 degree after TDC.
5. A flip causes the engine to carry through 3 revolutions minimum and at least 6 if a valve is open.

Ready to run

Start with your fuel of choice. Start with the carburetor needle ¼ turn open. Try to start it. Open the needle 1/12 turns and try until it starts. Continue opening the valve until it will no longer start. Set the carburetor in the middle of thee two settings. First runs get lots of oil and are short.

The regulator should be working.

Hold the regulator arm so the engine runs at maximum speed. This should be over 1000 RPM.

Run the engine for a few minutes until it just warms up. Let it cool, the next run should be a little longer. Watch the engine and listen for strange noises. If anything strange happens, stop and find out what is happening before continuing.

After about an hour, stop and take it all apart and clean everything. Check for wear.

After a few more hours of operation it is time to stop and paint and polish the engine. A full disassembly and cleaning is also in order.

Serial Number

I would like thee engines to have serial numbers. The serial numbers will be assigned when engines run. I would hope they would be marked with the serial number. Send me a note and a photo of you complete engine and I will assign the next serial number and enter your name into a registration log.

Metric

If you would prefer metric drawings please contact me. The drawings can be converted to mm and thread sizes can be converted to metric ones. Many parts are based on USA size materials and can be changed to metric sizes. I would work with you to update the drawings to metric friendly versions.

Questions, Comments, Showing

If you have any question please write me, David Kerzel, david@FloridaAME.org. If you find errors or problems with the drawings please notify me so they can be fixed. If you have alternate ideas or a better way to make a part, I would be pleased to discuss it or add it as other possibilities.
Please also consider putting together a "Work In Progress" page and post it at www.FloridaAME.org .as you build your engine. Complete engines can also be shown in the gallery at that web site also.