

Observations on Constructing Successful Miniature IC Engines

Miniature Exact Scale Models



I have been involved in Micro Machining since the late sixties. So naturally when I became interested in building scale models in the late eighties, they ended up being on the smaller side of what was typically encountered at the time. Fortunately there was much information available on the construction of model engines, but unfortunately little of it seemed to apply to the type and size engines I wished to build. Bits and pieces were gathered from helpful individuals at early Model Engineering shows, but most was learned through trial and error during initial construction.

This discussion will deal with issues encountered while constructing miniature exact scale (Exterior) four-stroke spark ignition Internal Combustion engines with bores of 0.625" and smaller. The goal when constructing these engines is to have them start, idle and run similar to the full size engine that they are scaled from for demonstration purposes only. They have not been designed for maximum RPM or power output.

High performance and scale operation rarely come together in the same engine and generally require quite different construction techniques & materials. As mentioned this discussion will center around miniature engines in scale with the goal of scale operation for display and demonstration purposes. It is not presented as the right way or the only way to construct a miniature engine, but as a option or suggestion based on several thousand hours constructing several successful engines. It also covers concerns and questions I had before constructing my first miniature engine and was unable to get a consensus on before construction. Having built larger engines as well as smaller engines there seems to be a break point at about 0.750" bore. Anything above

that seems to be quite forgiving and anything below that is not, to the point of nothing consistent applies.

Construction Equipment

Normally this would not be a topic discussed in a article on Engine construction. However, when constructing miniature engines, at least part of the construction will require some form of accurate Micro Machining. Since Micro Machining is quite different than typical machining encountered on full size equipment in a home shop environment, a brief discussion is probably in order. Most of us have probably heard the old saying that, "You can machine small parts on a large machine but you can't machine big parts on a small machine." It is of course true that it is difficult to machine large parts on a small machine. However while it may be possible to machine small parts on a large machine, in some cases it certainly is not practical. For those in doubt, this statement can be easily demonstrated. In addition, critical small parts for a successful miniature engine will not be practical on heavily worn or inexpensive import equipment of any size. Most work on miniature engines will be most practical on about a 4" lathe and comparable Mill supported by at least a 10" quality lathe and comparable Mill.

Small equipment should have variable speed motors since most speed & feed rate information rarely applies in micro machining. Surface finish is easily determined by varying the speed under load. All machine axes should be controlled by lead screws with calibrated hand wheels.

In addition, spindles should have a wide range of accurate holding options. One highly desirable option will be the

ability to use ww/8mm watchmakers' collets in both a small lathe and mill as well as other collet options.

Other highly desirable equipment includes Mini oxygen-acetylene torches for silver soldering small detail with orifices down to about 0.005". Another must is a small bead blasting cabinet to clean up solder, remove tool marks and form metal in some cases on small parts.

Block Construction

For miniature exact scale engines I personally prefer steel for block construction. This allows me to silver solder detail to the block that otherwise would be more difficult to install or machine as one piece. It also offers more strength and stability in very thin areas. It can also be sand or bead blasted to simulate a scale cast surface. Other material can of course be used with equal success.

Crankshaft Construction.

For miniature engines I have used everything from Hot Roll steel to carbon steel such as A-2 Drill Rod. The most important thing when selecting steel for this project will be something that is stable and will not warp during machining. I would suggest purchasing metal for this item from a local metal supplier so the type and characteristics of the metal are known. I have never found the need to harden and temper a crankshaft for this size engine.

One of the difficulties of constructing a miniature engine is to create enough flywheel weight to get the engine to idle. For most miniature engines this is not possible if the engine and flywheel are held to exact scale. One way to offset part of this problem is to build a crankshaft as heavy as possible if it is not visible. In other words, construct a crankshaft leaving as much metal on it as possible. Where possible I enlarge the inside of the crankcase and in turn leave even more metal on the crank to completely fill the crankcase. This additional weight along with a scale flywheel will many times produce a reasonable idle speed. The only down side is that it limits crankcase oil reserves if splash lubrication of rod caps is used.

All of my crankshafts are machined from one piece for strength and accuracy. Journals are machined with a thin blade cut off tool. First each side of the journal is plunge cut and then the center is removed by as many cuts as required. The journal is left slightly over size until all material is removed. Then the cut off blade is used to take about a 0.002"

cut and moved from side to side as many times as required to reach appropriate size for final polishing/lapping/grinding.

When the crank is complete it is balanced by supporting each side on sharp knife edges with the flywheel installed or what ever will be attached to the crank.

One of the things that will be repeated many times in this discussion will be the fact that miniature engines must be as free from friction as possible for proper operation. The crank is of course no exception. When a crank is mounted in the block it should rotate several turns on its own after a sharp twist of the hand. This freedom of movement should be accomplished before moving on to the next item.

Connecting Rods

When building scale miniature IC engines below 0.625" bore, minimal strength will be required in the connecting rods unless very high RPM or power output is desired. For this reason I found connecting rods made from Bronze to

be perfectly serviceable in most cases. This also eliminates the need for bearing inserts since bronze is an excellent bearing material. Without inserts the rod will have additional strength because of a more solid mass. I have also found that balanced rods produce a smoother running engine. I do this by holding

one end of the rod with a pin and then weighing the other end with a firearm reloading powder scale. (See Photo 1 directly to the left)

Some scales may require additional weight to balance the beam when the pan and pan holder are replaced by the suspension hook.

Once one end is weighed and recorded, the other end is weighed. In addition to adjusting the weight of each end, each rod is weighed for overall weight and adjusted so each is the same.

One other item that can give a problem on small rods is fasteners holding the rod caps in place. In many cases fasteners such as 00-80 and 00-90 or smaller may be required because of space limitations. The problem with fasteners such as 00-80 is that they have coarse threads in relation their body size. This causes two problems. One, it decreases fastener strength and Two, the coarse threads come loose much easier than fine threads. Unfortunately fasteners in sizes such as 00 are not generally available in threads finer than 80 TPI. If required, information on the construction of fine thread miniature Taps and Dies to make your own fasteners is available in the January-February 2008 Issue of *Home Shop Machinist*.

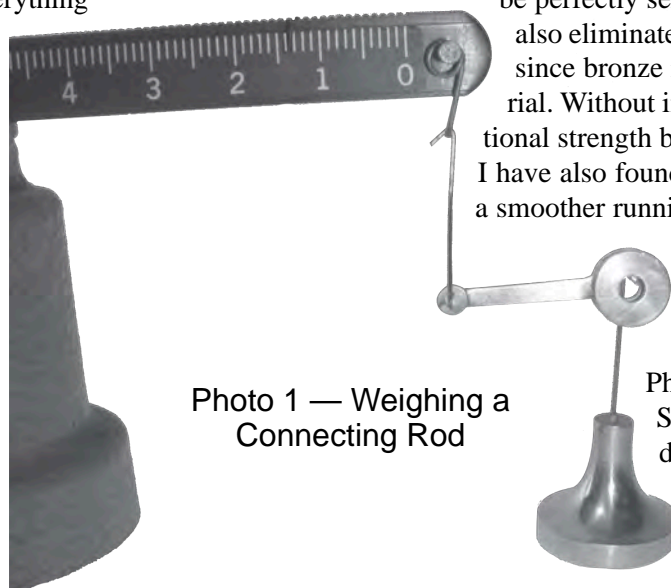


Photo 1 — Weighing a Connecting Rod

Cylinders And Pistons

One of the most important and critical parts of building an engine is proper construction of the cylinders. Without proper construction of the cylinder you cannot properly fit pistons or rings regardless of how they are made. For the typical miniature engine the cylinders should be straight and round from end to end. The easiest way I have found to do this is to bore the cylinder and then lap it round and straight. If liners are used in a miniature engine they will most likely be very thin and most likely distort when installed. This can be corrected by boring and lapping after installation. Lapping will require a certain degree of skill or practice. Information is readily available in any machinist hand book or even better a demo from a skilled person.

It is more important that each cylinder be lapped straight and round than for each to be exactly the same diameter.

the top of the cylinder and pushed about flush with the top of the block.

Next I rapidly slide my finger off the piston and it must jump out of the top of the cylinder. If it will not, the engine will not run well or maybe not at all. If it will not I then try to determine if the problem is the piston or the cylinder. I generally do this by fitting a new piston and redoing the tests. If I still have a problem I then re-lap the cylinder and start over.

When starting with the largest cylinder you now may have a piston that may only require a slight amount of fitting for the next cylinder. Because I generally use steel cylinders I personally prefer a high grade of cast iron for pistons. Cast iron is more porous than most other materials and holds more lubrication.

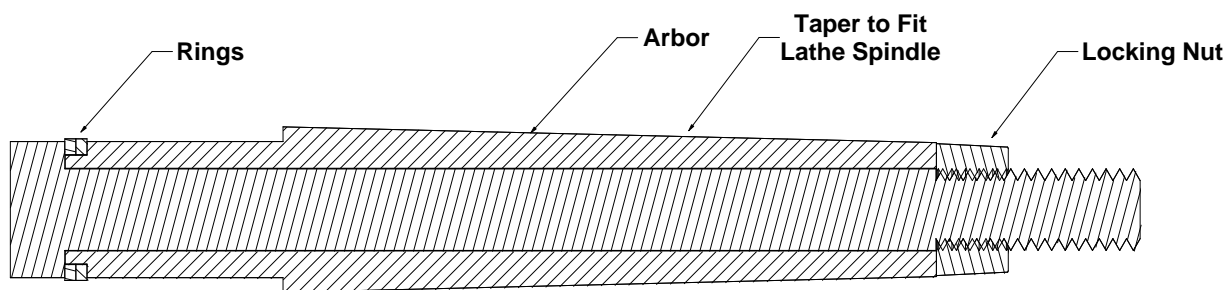
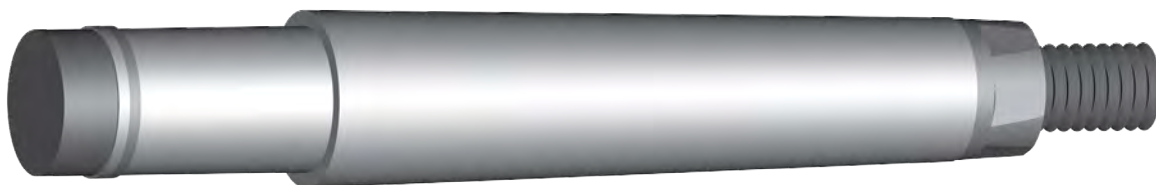


Illustration 1 — Piston Ring Arbor



(They should be close.) Personally I lap down to a 320 grit as a final finish for cylinders. Because I generally use steel for block construction as previously mentioned, my cylinders are also normally steel.

Once the cylinder or cylinders have been properly constructed, pistons can then be constructed and fitted to each cylinder. Because I fit each piston, I number them so they remain with the cylinder they were fitted to. Again as previously mentioned, the pistons need to be fitted so they have friction free operation but offer a maximum seal against combustion.

I first machine pistons to about 0.0005" oversize. I always start with the largest piston if there is such a thing. They are then lapped or sanded until, when dry, they will just fall through a dry cylinder under their own weight at room temperature. Next the bottom of the cylinder is sealed, generally with a rubber plug. Then the piston is inserted in

Piston Rings

Probably one of the most discussed (many heated) aspects of IC engine construction is the making of piston rings. My personal experience has been that there has been no one way that works for all sizes of model engine piston rings. Again there seems to be a separation at about 0.750" bore size.

For rings over 0.750" I have used most of the published methods with more success with some than others. However under 0.750" I have had little success with these same methods, especially the ones involving heating the rings. Miniature engines, with properly fitted pistons as previously discussed, will run without piston rings. For these engines piston rings will add an extra layer of protection against wear from operation, but only if properly constructed and fit.

My personal specifications for miniature engine piston rings is as follows. Again the rings must offer absolutely as little friction to engine operation as possible. In the

compressed state they must fall through the cylinder the same as described for fitting the piston. Also in the compressed state they must offer the same compression with one end of the cylinder sealed as with the piston test.

In addition they must be able to be installed in the cylinder and when viewed against light, not have any light visible between ring and cylinder wall. To keep friction to a minimum the cross section of rings for my personal miniature engines has been no greater than 0.015" x 0.015". All rings have been constructed of the highest grade and finest grain cast iron available from reputable metal supply houses.

Rings are constructed and tested as follows:

First the outside of the ring is turned on a lathe from bar stock to the closest standard size larger than the cylinder bore.

Next the inside diameter is bored smaller than the final ID of the ring. From this point the number of rings needed are parted off from the work piece. They are then placed in a vise in a small mill and are cut open with a jewelers slitting saw.

The width of the saw will determine the amount of compression the ring will have. For miniature engines I normally make the cut width about 8% of bore diameter. Once the slot is cut the ring is then placed in a watchmakers wheel chuck or a watchmakers wheel chuck in the compressed state where the final ring ID is bored. The final ring width is also cut while in the pot chuck if need be.

Once the final ID/width is cut, the rings are then mounted on an arbor where they are held in the compressed state for machining the OD to a proper fit in the cylinder. The arbor can be seen in Illustration 1. As mentioned at the beginning of this section, the OD of the rings was cut to standard dimension. This allows the rings to be mounted on the arbor and then compressed evenly over the arbor using a standard collet such as R-8 or C-5. Once evenly compressed over the arbor with a collet they are locked in the compressed position by tightening the nut on the back of the arbor. The arbor is then mounted in the Lathe to machine and lap the OD. For repeatability reasons when removing and replacing the Arbor to test ring fit, I prefer a Morse Taper arbor mounted in the lathe spindle.

As with the piston, I machine the rings to within 0.0005" oversize and then lap to fit the cylinder the same as the piston. The Arbor itself is machined about 0.001" under size so the fit of the rings can be determined. Only when the rings achieve the free movement and compression test as performed with the pistons are they removed from the arbor.

The third test is to install each ring by itself in the cylinder and do a light test. When held up to a light there should be no light next to the ring and cylinder wall. If the rings fail any one of the three tests they are remade until they pass. At this point the rings are installed on the piston that was matched to the cylinder. This way all cylinders, pistons and

rings remain together.

For miniature engines I do not heat or harden the rings. It has been my experience that rings of the cross section mentioned warp in all different directions when heated. If they are hardened from this process then they would need to be ground to fit properly or to the standard I wish them to meet for my engines. I prefer that they remain soft so that they rapidly seat at the slower speeds of a scale operating engine. I have never had a small ring wear to the point of needing replacement, but if they do, I will simply make new ones.

Valves

Proper fitting of the piston and rings will not be effective unless the valves properly seat and seal to retain compression for combustion. Because of the very small volume involved in miniature engines, this is very critical. For this reason I machine all valves in one piece. This assures that the seating surface of the valve will be centered to the stem and allow for correct seating to the valve seat regardless if the valve rotates in the guide.

After the valve and its seat have been machined and the guide has been installed, the valve is then seated to the head. The most effective system I have used for this, is the same system used in the automotive industry. A tight fitting guide is installed in the valve guide and a small stone is then mounted over the installed guide. The end of this stone is dressed to the desired angle that you wish to have for a valve seat. By rotating the stone back and forth a few times you will produce the desired seat.

From that point everything is cleaned and the valve is installed dry for testing. In addition the valve stem where it meets the valve guide is sealed with grease. I test all valves with a automotive hand vacuum pump connected to the intake or exhaust port. All valves must hold vacuum when dry before I move on to the next one. For a complete and detailed explanation of this procedure see issue # 6 of *Model Engine Builder*. All of my valves for miniature engines are machined from stainless steel.

To Be Continued In Issue # 16



Using Automotive Oil On Your Tools

by Dick Pretel

Automotive oil has strong detergents that may stain metals so don't leave it on tools you care about or in ball bearings. There are more-than-adequate Way and Spindle oils that are made with synthetics and are designed specifically for these tasks.