High Power Two Stroke Design Part 3

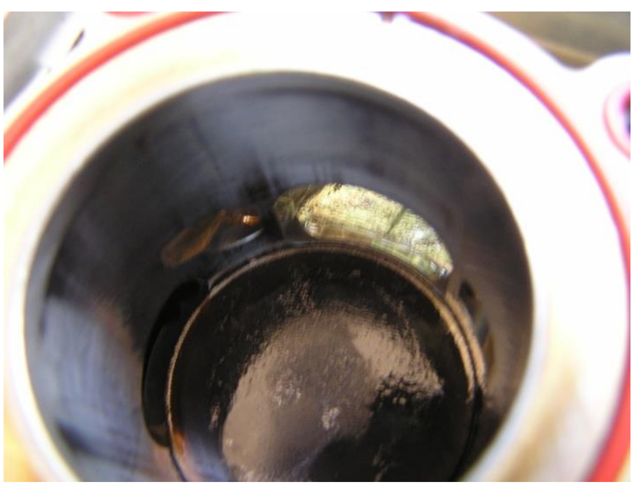
There are many important details in small two stroke engine mechanical design. One of the first is piston sealing and friction. Piston friction is one of the major losses, especially in small engines where the cylinder surface is large for the displacement. The best method for small diameter cylinders has been the ringless piston design. Here a high silicon aluminum alloy piston is matched to a chromed brass or aluminum cylinder liner. Careful fitting at the top combined with an increasing clearance below the exhaust port top edge, results in good high pressure sealing at the combustion chamber and adequate sealing of the crankcase. Lots of oil in the fuel helps make the seal. This system hasn't been used in mass produced engines with much over a 25 mm bore, though some successful racing engines have used this design with a 29 mm bore. The most notable failure of a ringless piston was the CMB 35 with a 35 mm bore cylinder. High temperatures from gasoline as a fuel compared to nitro/alcohol mixes contribute to the problems. I'm not aware of any successful gasoline fueled engines that use ringless pistons.

Failed AAC CMB 35 Piston & Sleeve

Ringed pistons have been used a very long time. They are tolerant of diameter changes due to tolerance and temperature, but still require a very round cylinder. Their seal depends on fit to the lower side of the groove in the piston, fit to the cylinder bore, and ring gap. Using two rings helps solve the gap leakage problem, but doubles the friction. All serious small racing two strokes run a single ring. Again, lots of oil helps make the seal. Ring flutter is caused by the ring's inertia breaking the seal with the bottom edge of the ring groove when the piston changes direction at top dead center. Since this happens when the pressures to be sealed are highest, ring breakage can happen. Making the ring very thin for weight and friction reduction helps. Today, a thin, hard, heat resistant ring coupled with a hard, smooth cylinder coating seems to be the best combination.

Piston cooling has also been an issue in two strokes. Two factors make it less of a problem in small engines. The above mentioned large surface area to cylinder volume ratio helps dissipate waste heat. Running the fuel through the crankcase cools the bottom of the piston. Larger, high power two strokes need oil cooled pistons when they use outside scavenging blowers. Even so, I've melted the pistons on several 11 cc nitro engines when tested on the same inertial dyno as our gasoline engines. The nitro engines develop about the same power but are considerably closer to the edge of failure than the 26 cc gasoline engines. A gasoline engine with similar relative power will need a lower inertial load on the dyno to keep cylinder pressures down in the lower rpm area.

All the engine parts need to be accurately made and aligned. As was mentioned above, the ring must be round and run in a round cylinder at all temperatures. The area above the exhaust port is the most critical. Below is a failure caused by an out of round cylinder. Note both the shiny spot on the bridge between the intake and exhaust as well as the area just above the exhaust port. There are other shiny areas that indicate a local tight fit. Peeling chrome caused the scoring on the piston. There are limits to how much of this out of roundness can be tolerated.




Failed CMB 35 Ringed Piston & Sleeve

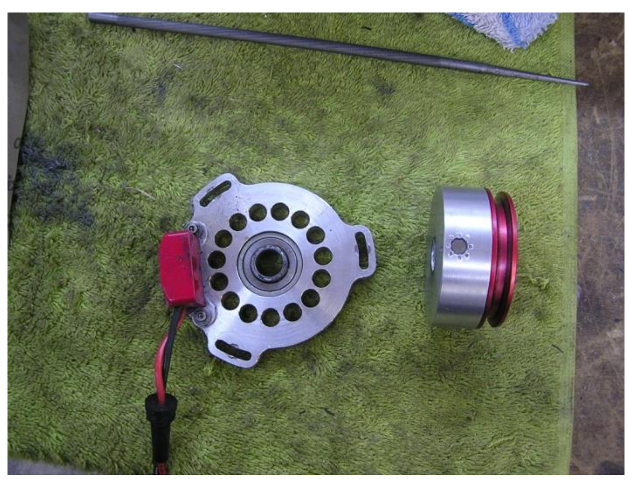
The crankshaft must run at right angles to the cylinder under load. Deviations in this area load the edges of the connecting rod big end bearing. Since this is the most critical bearing in a high output two stroke, much deviation will cause failure. Sleeve bearings are more tolerant in this area, but needle bearings are not. Can an overhung crankshaft design work rather than the conventional large engine crankshaft with bearings on both sides of the rod? Again this seems to be a size issue. Smaller engines can be made with relatively huge crankshafts which work with an overhung design. As crankshaft weight becomes significant, a stiffer basic design is needed. I think the easier to construct, overhung design could still work with a 26 cc engine. See Big End Blues in the April 2012 Propwash for other big end bearing issues.

Other issues affecting dynamic rigidity are crankshaft bearing support and cylinder block design. A one piece cylinder is more rigid than the multi piece design used on all but the smallest engines. A good example is the durability at higher rpm and power of the last 7.5 K&B design compared to their old style K&B 7.5 cc engine's design.

Old Style K&B 7.5

K&B Pro 7.5

The one piece crankcase is better at holding the crankshaft aligned. We found that the CMB 35 crankshaft flexed enough to cause flywheel strikes despite being supported on both sides by bearings. A double bearing output side helped. See below. The magneto was replaced with the Quickdraw electronic ignition system as well.



CMB 35 Front Bearing

This same problem has been found on several engines with stock Zenoah crankshafts. So far the solution has been double ball bearings on the crankshaft. I think widely spaced bearings on an overhung crankshaft could be just as rigid.

Another, more extreme solution is to make the crankcase out of a stiffer material than aluminum; steel. It would be heavy and probably unnecessary to cast all the crankcase out of steel, but steel front ends have been tested. The main advantage seems to be equal thermal expansion of all the pieces. This means the crankshaft bearings don't lose their press fit and the end play doesn't increase. A steel spacer/seal locks the inner races together for controlled end play that doesn't change with temperature.

Crankshaft with Inner Bearing Race Spacer/Seal and Front Plates

See the Wakkerman engine site for a good discussion of these issues and much more. Ceramic ball crankshaft bearings are the current state of the art and probably should be included in a new high performance design.

An often neglected issue in a high rpm engine is windage and viscous drag between the crankshaft and crankcase. A Zenoah was built with all the internal clearances reduced as much as possible to increase crankcase compression. Surprisingly, power was lower, probably due to viscous drag. The consensus is that at least 1 mm clearance is needed around the rotating parts. Streamlining the rod may also help.

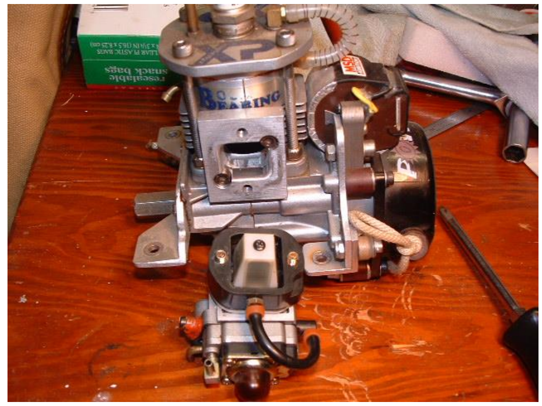
Another important issue for the crankcase volume is where it's located. If most of the crankcase volume is in or around the transfers, it is easy to get the mixture into the cylinder. Mixture trapped under the piston or in the crankcase valve mechanism will be harder to get into the cylinder. Piston skirt windows into the transfers have often been used to help.

The crankcase valve system has a lot to do with flow into the cylinder. The simple two stroke gets mixture in and out of the cylinder through ports in the cylinder wall. These ports and their passages have been discussed in parts one and two. Getting mixture into the crankcase can take a more complex valve. Whether this is even needed was discussed in part two.

However, all current crankcase compression two strokes use a valve to regulate flow into the crankcase. The simplest is the piston skirt controlled port into the cylinder. Because this valve opens and closes symmetrically around top dead center, the time it can remain open is limited by flow out of the valve as the piston descends. This also restricts the length of time the valve can stay open to allow complete crankcase filling. Usually opening and closing between 70 and 80 degrees either side of top dead center is used. That restricts the total open duration to 140 to 160 degrees. Piston ports have been used that open 100 degrees or more before top dead center. However, starting and part throttle operation become difficult. Intake tuning can overcome the blow back over a narrow rpm range, but there is little power outside this range.

Rotary valves overcome this limitation. They typically open around 150 degrees before top dead center as the piston rises and close around 60 to 70 degrees after top dead center as the piston descends. This gives a larger open duration of 210 to220 degrees. Another point is that the transfer ports open around 115 to 120 degrees before top dead center. That means the intake is open for around 30 degrees at the same time the transfer is open with a typical rotary valve. This allows the pipe to "suck" mixture into the crankcase as well as into the cylinder from the crankcase.

The simple solution to the problem of inexpensive piston ports versus expensive rotary valves has been to put a reed valve in the piston port. A lot of experimentation has resulted in reed valve designs for larger engines that are almost as good as a rotary valve. This has not been true so far for model size engines.



Model Reed Valve

Piston Port with Reed Valve

Inexpensive industrial engines still use piston ports to keep costs at a minimum. However, only the very early model engines used piston port intakes. Several different rotary valves have been tried in model engines. The most common is the crankshaft rotary valve. This valve doesn't require extra parts, cutting down on costs and friction. It is limited in size by the largest bearings that will fit in the crankcase.

Crankshaft Valve

"Russian" Drum Valve

A very similar valve is what I call the "Russian" drum valve for its popularity in the K engines. It was also used in the MAC engines. It allows a larger size valve than the crankshaft rotary valve but with additional parts and friction. Like that valve, it increases crankcase volume a long way from the transfer passages.

A different drum valve is more common. It has all the advantages of the "Russian" valve but with lower crankcase volume. However, the oil in the mixture isn't directed over the rod big end bearing.

Drum Valve

Most large rotary valve two strokes use a disk valve. Model high power engines use this valve as well. In model engines it has traditionally needed to fit into the crankcase, restricting its diameter. This isn't necessary and a larger disk can be fitted. This valve is often called the Zimmerman disk valve after the designer who popularized (but did not invent) it. It has the advantage of simple construction and moderate cost, but adds friction and has a large diameter for a given flow.

Model Disk Valve Zimmerman Disk on a Zenoah

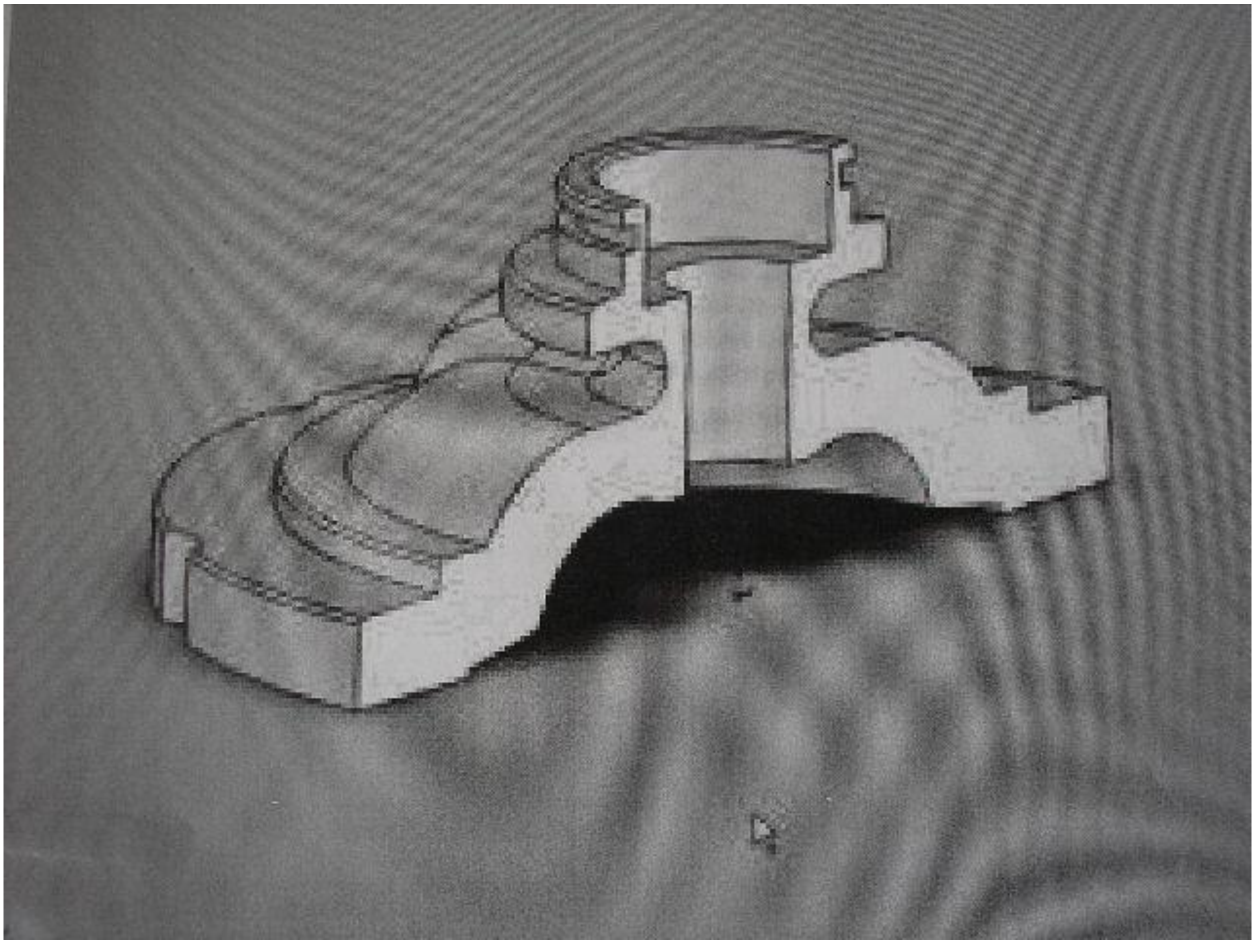
The final style valve used on model engines is the bell valve. It was designed by Paul Bugl and used in the HB engines. It's by far the hardest to build, but has the largest flow for its size. Like the drum valve, it doesn't direct mixture flow over the big end bearing. It also is probably only suited for an overhung crankshaft design.

HB Bell Valve — Jim Allen's Bell Valve

The last feature that needs to be discussed is the combustion chamber. Typically this is a hemispheric bowl surrounded by a squish area that's very close to the piston crown at top dead center. The squish both cools the mixture to prevent preignition and forces the mixture into the combustion area at high speed. There has been a lot of investigation into the exact squish shape and area as well the combustion chamber shape and volume. Neels vanNiekerk has an excellent analysis of the current state of understanding here.

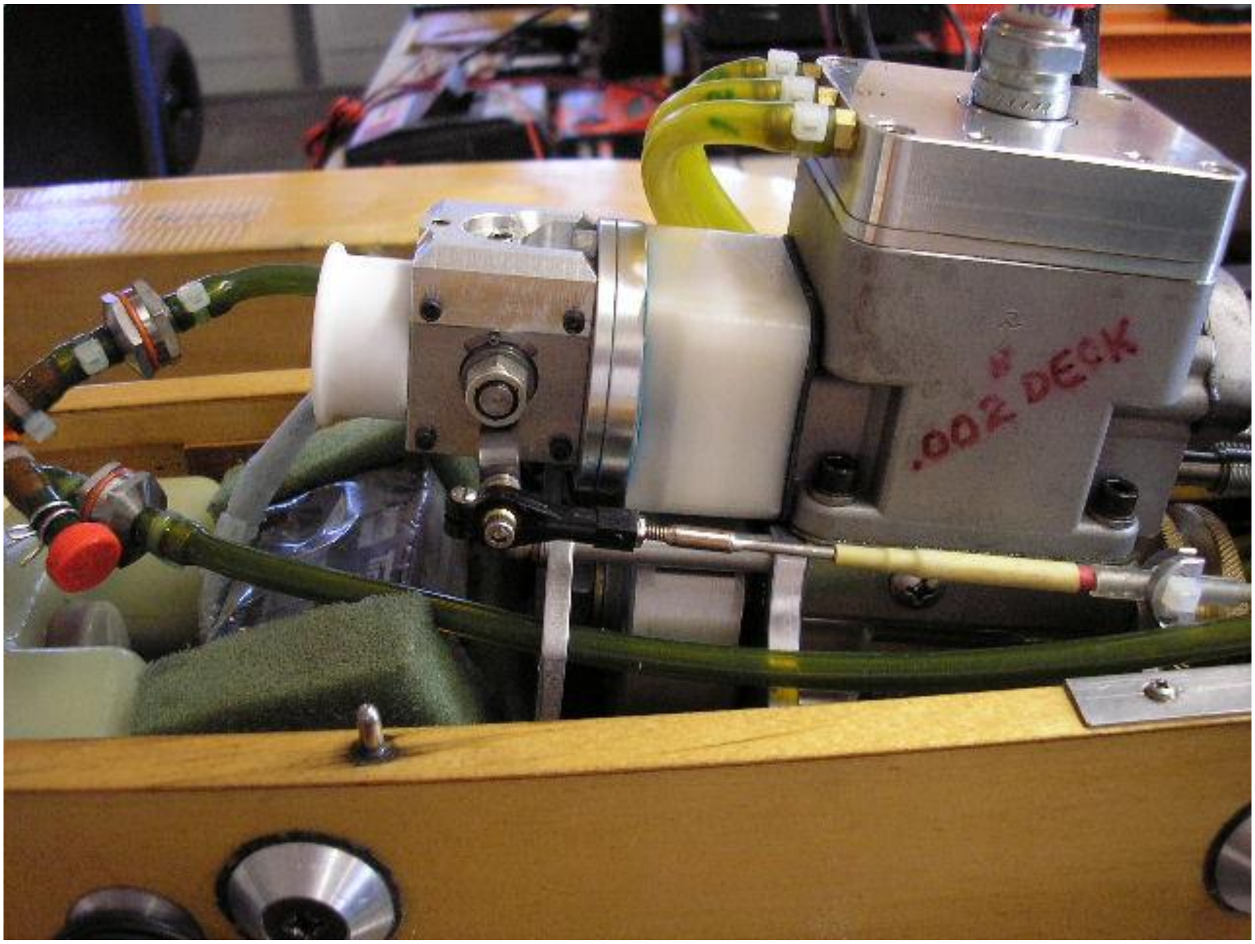
The most recent interesting combustion chamber shape is the toroidal combustion chamber. It seems to make more power in larger, racing two strokes, but I haven't heard a good explanation of why. The exact shape and plug to head space seem to be critical. In models it can be hard to get a standard spark plug in the available space. Jim Allen has been experimenting with a toroidal head button with a surface discharge plug in a Quickdraw and reports increased power. Note also how the insert is machined to cool the spark plug.



Toroidal Head Button

Ignition hasn't been an issue so far in 26 cc engines. Experiments with a simple electronic system and various amounts of spark advance show no improvement so far in modified Zenoahs. Quickdraws can run more ignition advance giving a little more power with suitable fuel. However, surface discharge plugs in high compression toroidal heads may need a better ignition system. Fortunately, there are several choices. The Power Spark system has been used in model gasoline engines.

Electronic injection doesn't seem to have any advantages so far in 26 cc engines. Its main advantage in 50 cc and larger two stroke engines is lower emissions with good power. However, pumper carbs start to have problems delivering enough fuel at high rpm. A lot of the advantages of fuel injection have been used in model nitro engines a long time. Pipe pressure to the tank combined with a very simple carburetor seem to compensate for engine fuel demands over the narrow throttle and rpm ranges boats usually operate. OS 9B and MAC 84 carbs have run on modified Zenoahs for years. More recently a really large bore nitro style carb has been run on a 26 cc Quickdraw with good results.



.750 Bore Carb

Jan Thiel predicted that a two cylinder 50 cc engine could develop 39 horsepower at 23,000 rpm. That would be over 19 horsepower from a 25cc racing engine. Will we be able to get to Jan Thiel's predicted power with some or all of the innovations covered in this series of articles? I think it's possible.