Colorado Model Engineering Society

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How To Make Your Own Quality Piston Rings

The following is an introduction to a suggested method for making small piston rings, based on articles by Prof. Chaddock and Tom Walshaw (Tubal Cain), but I must admit that I've NOT yet attempted the final machining operation.

In these explanatory notes the following abbreviations will be used:- D = cylinder bore. t = radial thickness of ring.
w = axial width of ring. p = wall pressure. Fdd = force required to close ring, applied at 90 deg's to the gap, and
" " = actual quotations from the articles.

In an article in the Model Engineer (21/4/67 p.396) Professor Chaddock describes an efficient 5cc Four Stroke I/C engine, built for an attempt on the model aeroplane duration record and he details his method of making piston rings by "heat forming".

"The rings are turned to a diameter D + 0.002" and a thickness not more than 1/25 or less than 1/30 of the bore diameter. The modern tendency is to make width equal to or even less than their thickness so the same rule can be applied to width. The ring must now be cut with the thinnest possible saw or (preferred method) broken by holding in the fingers and snapping it. A tiny gag piece, of width t x 4, is now inserted into the gap to expand the ring before clamping it, with several others if required, between two metal plates by a centre bolt and heating the whole assembly to annealing temperature in a gas flame or muffle."

Professor Chaddock does not give the temperature required but says that the practical test is that if, after cooling, the ring springs inwards from the t x 4 gap then it is not fully relieved of stress and the process must be repeated. (but see later)
He says:- "Finishing the rings once they have been "heat formed" can follow conventional practice; that is, they can be closed in a tube and clamped between mandrel plates ------ for finishing the periphery and the sides lapped freehand on stone or emery paper. Very little, one or two thou' only need to be taken off in these final operations to bring them dead to size."
" -- they hold compression as well or better than a ground and lapped piston and cylinder."

He doesn't mention any 'working' gap being required and the rings he actually made were of 0.025" x 0.025" cross section to fit an 18 mm (0.709") bore.

The essay by Tom Walshaw (Tubal Cain) in the SMEE Journal (Dec 1992) is largely concerned with designing rings with the correct wall pressure for their particular application and he refers to an article by Michael Smart (M.E. 16/8/1974 p.824) in which is explained how a properly fitted ring is expanded by the pressure behind it to augment the initial wall pressure.

Tom's conclusions being that the majority of model engines were running with excessive wall pressures and he included a table of the wall pressures he had measured on a selection of commercially made 'model' rings.

He then describes a simple method of measuring it by closing the ring to its bore diameter with a force, Fdd, applied at diametrically opposite points, 90 deg's from the gap. Then :-
p = (Fdd x 0.881)/(w x D)

An expression for calculating p is given as:-
p = g x E/7.06 x D x (D/t - 1)cubed
Where g = difference between the free and closed gaps, ins. and E = Young's Modulus, lbf/sq.in.

"Values of E can vary between 12 million to 24 million lbf/sq,in. and reference to the supplier is advisable. A figure of
18 million is typical for 20-22 ton UTS, and between 15 and 17 million for the 17 ton UTS centrifugally cast iron normally available for home-made rings."

"To complete this exploration of the arithmetic, the stress in the ring can be calculated in the usual way from the bending moment - - - - - and simplified to:-
f = 3 x p x (D/t)squared lbf/sq.in."

After a long dissertation on model piston ring practice in which Tom draws on every article he could find in the model engineering press he discusses the criteria for design and comes to the following conclusions:-

"Wall pressure for models (a) Steam Plant. It is clear that the wall pressures used in our models are higher than need be, even with the plain Ramsbottom type; still more so with modern heat formed rings. For stationary, marine and road locomotive engines, all of which can be motored for initial bedding down, 6-8 lbf/sq.in. should be adequate. However, there is a small problem; the radial thickness is so small with "classical" gaps that parting off may be difficult.* For this reason I set a minimum value of "t" at 0.035", and use a smaller gap when necessary. Fixing on g = D/10 instead of 4 x t simplifies the pressure formula to:-

D/t = cube root of E/(70.6 x p) + 1

but this ratio should not be used for wall pressures above about 12 lbf/sq.in. without checking the "fitting" stress. (see later)

For rail locos it may be prudent to use slightly higher pressures. The low end of the "Chaddock standard" provides about 13 lbf/sq.in. with "E" at 17 million. (i.e. D/t = 30 and g = 4 x t), but this will vary pro rata with the value of E."

*It isn't - see method.

"(b) I.C. Engines. For the classical horizontal gas/petrol engine model I have substituted rings at 6 1/2 lbf/sq.in. with no problems, but where the designer has called for two rings I have used three. This pressure lies outside the "Chaddock standard" (t = D/33-35) so that, again ring gaps of D/10 are used. Many published designs use rings which are too wide, and I suggest w = 0.03 x B as a guide, with a minimum of 0.04".

For all other I.C. engines it is no surprise to find that adherence to Prof. Chaddock's rules will give satisfaction, though at the high end (D/25) it is important to check stresses, as the stresses are higher than the usually available 17 ton iron can carry.

For the benefit of those not familiar with these rules the figures are:-

Radial thickness, t = D/25 to D/30; ring gap, g = 4 x t.

If "E" is 17 million lbf/sq.in. these rules offer wall pressures from 28 down to 13 lbf/sq.in. The wall pressure will, of course, vary with the value of E in direct proportion. The lower the wall pressure the less friction, of course!

For very high performance engines it goes without saying that experiment is always necessary, and although it may add to the time and cost a single-cylinder prototype, arranged for measuring both oil consumption and blow-by (as well as output and fuel consumption) is well worth while. Even here I would not expect to find more than about 25 lbf/sq.in. to be necessary and that only when a single pressure ring is supported by a stepped scraper between the top ring and the main oil controller."

"Ring Fitting
(a) Running gap" After an illustrated explanation of the comparative insignificance of this gap, Tom recommends:-

"The minimum gap - for steam or I.C. - should be 0.002" and a guide might well be an installed gap equal to
0.001" + 0.001"/inch of cylinder bore."

"(b) Fitting gap. This is the dimension G when the ring is sprung over the OD of the piston when fitting. If this is excessive the ring may be overstressed, but it is the dimension G - g which is significant, so that, as already remarked, the risk of overstressing increases as the free gap is reduced. Unfortunately "the books" all seem to assume that the ring clasps the piston closely when fitting but this is not the case, and stresses based on this assumption will be too low. Geometric analysis is almost impossible, as the ring does not assume the shape of a pair of half-circles, and in any case the actual direction of the loads holding the ring apart are indeterminate. Experiments with a number of rings of various D/t ratios and values of D show that G varies from 6.6t to 7.5t. If g = 4 as under the Chaddock rules, then the ring will not be overstressed when installed - provided the working stress is safe, of course. As a very rough approximation, the installing stress can be estimated by writing:-

fi = fw x (7 x t - g)/g Where fi = installing stress, fw = max. working stress, t and g as before.

This estimate is by no means exact, but a check on the "risk" can be made by comparing the value of "g" before and after a trial fitting. If there is a marked and permanent increase in "g" then the ring is very near the limit."

The original "Ramsbottom" rings were plain circles from which a gap was cut so that the closed ring fitted the cylinder with no more than a working gap. It was realised that such a ring would not fit properly, and so could not exert an even pressure, even after hours of running. The necessary shape to achieve this was known, of course, and requires the free ring to have a radius at any point which varies as the sine of the angle of the section from a point directly opposite from the gap. Lanchester devised a machine which would turn rings to this shape, but it is doubtful whether any model engineer would undertake to make one. However, with modern NC machines the process is much easier, and many large engine rings are so manufactured."

Tom then describes how the inside of a plain ring can be peened to produce the required effect - and considers that it is too difficult with a small ring.

He next considers a tapered ring, produced by boring the ID eccentric to the OD, but rules this out as, to get the correct characteristics, it requires "t" to be reduced to zero at the gap.

Then "A near perfect ring can be achieved by "heat forming", a process which is adaptable to high volume production, and which can be used for very small rings indeed. Here, a circular ring of uniform thickness is cut with a very small gap. It is then forced into or onto a shaped former, and stress relieved so that, when cooled, the ring is of the correct form to provide both true circularity and a uniform wall pressure when fitted into the cylinder, though in almost all cases a final machining operation is carried out to "skim" the O.D. to allow for the inevitable tolerances. The shape of the former is, of course, the obverse of the shape used by Lanchester years ago.

It is an adaptation of this method which was described by Prof. Chaddock ----------- "

"Unfortunately there seems to have been a misunderstanding of the nature of the process by some, including Mr Trimble and Mr Tulloch. First, the process is NOT a copy of that used in industry and cannot form the "perfect" ring. Whilst it relies on the relationship in expression (2), in that the wedge exerts the "tangential force" there referred to, the process does not and cannot produce exactly the correct shape, This force may induce the correct bending moment in the ring, but it does not reproduce the correct deflection, for the tangential force introduces an additional compressive stress. This is small but has a devastating effect on the shape of the rings adjacent to the gap. " etc (see diagrams)

"There is no way of correcting the stresses by altering the nature of the wedge (e.g. by applying the force at an angle instead of tangentially) and the fact that the wedge may fall out after clamping up the parcel of rings makes no difference. nor is there much point in "fitting" the wedge to the angle of the gap. However, As Prof. Chaddock realised, the effect can be mitigated by carrying out a final skimming operation on the O.D. after heat treatment. This ensures true circularity and reduces the deviation from the uniform pressure condition to negligible proportions. This final machining operation is essential. However it need be no more than a skim, and the removal of 0.001" of metal should suffice for a 1" ring and pro rata for larger sizes. For models true circularity is more important than a uniform pressure."

It appears there has also been some misunderstanding about the stress relieving process, possibly because the original article also referred to "annealing". Most subsequent writers have quoted a "good red heat", though Mr Trimble quotes an actual figure of 800degs/c. as does Mr Tulloch. This is a mistake, 800degs/c. or "good red " lies above the critical temperature and a metallurgical change will occur. The Brinell hardness will be reduced as will the U.T.S. and the value ore and some grain growth will occur - just the wrong requirements for a piston ring. If the material is an alloyed iron the results may be even more serious. There is the further fact that scaling may be caused. It is not unlikely that the use of this high temperature has resulted in users going to stiffer rings than were needed, simply because the heat treatment caused a reduction in the value of "E" with consequent loss of wall pressure.

The "correct" temperature is 480 - 520degs/c. with slow heating, the temperature being held for 1 hour per inch of thickness but with at least 10 minutes for very thin rings. The stack may be air cooled from this temperature, though no harm seems to arise from oil quenching. The metal has no colour at this temperature, but Messrs Levermore, 24 Endeavour Way, London, SW19 8UH are importers of "Markall Thermomelt" crayons. A mark with one of these will turn glossy at the indicated temperature and they are available from 100degs/c. up to 1200degs/c. Alternatively, very little degradation of properties will result from heating to 550 - 600degs/c. when the metal will be just visible in a dim light, but on no account must the temperature be allowed to rise any higher. (The critical temperature is 720degs/c.) It is preferable to use the lower temperature for the full time rather than to try to speed things up by going higher. Incidentally, scaling at these temperatures is minimal - it will come off with metal polish."

Tom also devotes a couple of pages to oil control and scraper rings before concluding that a stepped scraper with a wall pressure of between 20 and 30lbs/sq.in. and with adequate oil escape holes should be adequate - and that provided the plugs don't oil up, it is wiser to tolerate a high oil consumption in a model. (Dennis Chaddock doesn't use any on his engine.)

Rings of bronze are mentioned fairly often, generally for use in gunmetal cylinders. I have had little experience of these for models, but have no doubt that they can be satisfactory. However, certain points should be born in mind. First, the working stress must be kept below the yield (or 0.1% proof) figure - typically about 20tonf/sq.in. - especially during installation. Young's Modulus is of the same order as for iron - 15 million lbf/sq.in. Second, the stress relieving temperature lies very close to the annealing temperature, and great care is needed when heat forming. On no account must 350degs/c. be exceeded and a temperature of 300degs/c. should be aimed at. This is the temperature at which bright steel turns blue - a useful guide!"

Tom's final conclusions are that for steam engines and for the classical model I.C. gas/petrol engines, which can be run in on the bench 6 - 8 lbf/sq.in. should be adequate. Locomotive rings may need higher pressures to speed bedding down, but no more than 12 lbf/sq.in. Lower pressures should be possible with properly formed rings, with consequent freer running. The workhorse type of I.C. engine may need 16 - 18 lbf/sq.in., unless the duty is severe, but even then the "Chaddock rules" should not be exceeded; 20 - 22lbf/sq.in. is recommended as a maximum, but experiment may be needed at speeds over 12,000 rpm.

Finally, and to forstall any questions, I must add that Tom did not quote any 'worked examples' for rings designed to fit these conclusions.

Phew!!

Suggested Method for making Small Piston Rings:-

First, finish the cylinder bore - to diameter D.

Decide the cross section of ring required and, if you are using a conventional, non-demountable, piston then finish it, making the ring grooves deep enough to give 0.004" clearance behind the rings.

Make the steel sleeve for the machining fixture, bored to D+0.002" and approx D long.

Chuck a length of centrifugally cast iron and drill it to within 1/16" of the inside diameter of the rings for sufficient depth. (see next)

Turn outside diameter to D+0.002" (use sleeve as a gauge) for a length equal to:- (w + parting tool width) x number of rings required plus a few spares.

Use a narrow parting tool to make a series of grooves. Depth of grooves to be exactly equal to t + 0.001". Spacing to be exactly w + parting tool width + 0.001" (lapping allowance).

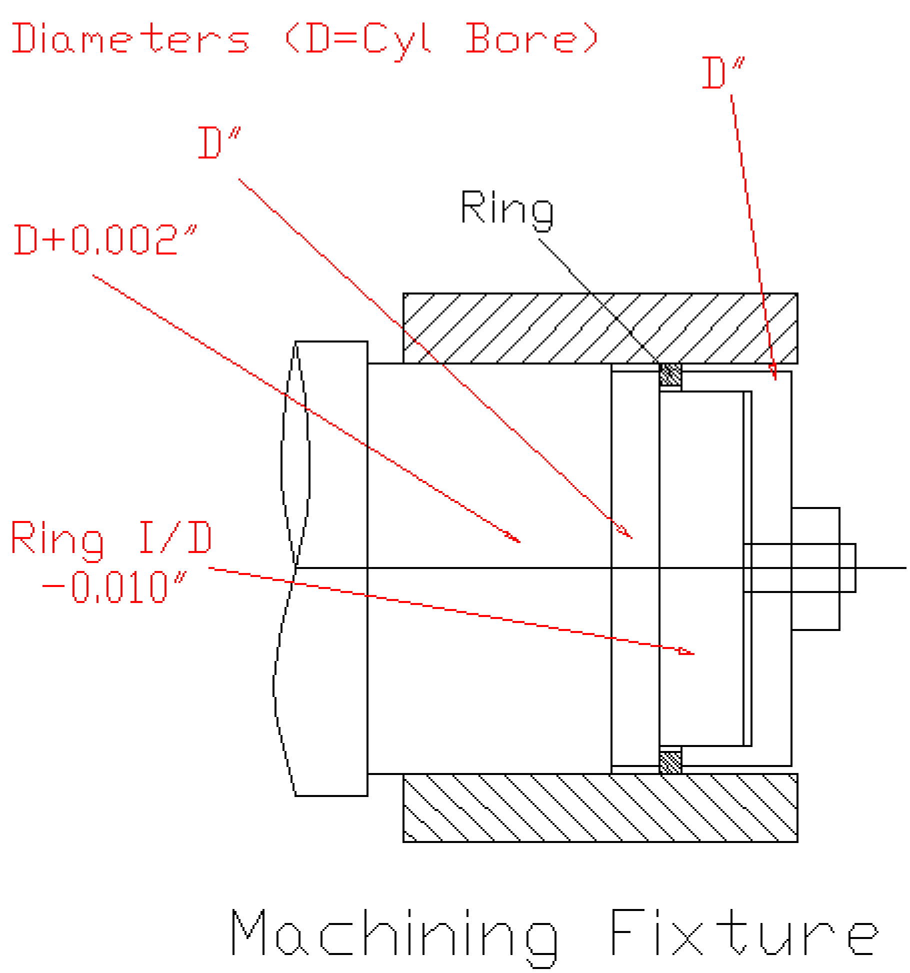
Now use a sharp fine boring tool to open up the hole to inside ring diameter. As you approach this, reduce the cut to 0.001" and 'lean' on the tool to prevent it cutting 'on the way out'. When you reach the final cut you will be rewarded by a little bunch of rings on the neck of the tool.

Use a Swiss file to break the sharp corners inside the rings so that they will move freely to the bottom of their grooves.
Make a tiny nick on the inside of each ring with a very fine triangular needle file and break it between finger and thumb, or by using the thumb to press it down onto a piece of wire on a flat surface. Very carefully dress the broken surfaces with a Swiss file (No 6 cut)

Make the wedge to hold the gaps open.

Stack the wedged rings around a bolt, clamp them between two steel plates and heat evenly to 550 - 600 degs/c, i.e. just visible in the dark, NO HOTTER! Hold at this temperature for 10 mins and then allow to cool - rings should not have scaled. (I've done this successfully on an electric cooker hot-plate, which can be set to the correct temperature first and then the rings laid on it and left for 30 minutes.)

Next make the machining fixture/clamp:-



Pack the rings into the sleeve and slide the sleeve on to the rod. Fit the disc and clamp rings securely with the nut. Slide off the sleeve and use the engine cylinder as a gauge to take a one thou' cut off the rings and reduce their diameter to D.

Finally, lap the sides of the rings to fit their grooves. They should be perfectly free but with a clearance of only 0.001" or less.

Notes.
This drawing is copied from the one accompanying Tom's article. Prof. Chaddock's drawing showed the D - 0.002" dimension as D, i.e. the required ring diameter, and also only a single ring clamped in it.

I've successfully made, and used, C.I. rings down to 1/4" x 0.010" x 0.010" (accepting 25% breakages) using this method but must repeat that I've not attempted the final skimming operation. Examination of the ring on my Stuart 10, after very heavy use, shows a perfectly even polish, but near microscopic examination of the two 0.016" square rings on my miniature marine engine, after only a few hours running, shows minute high spots at the gaps with a few degrees of darker metal extending round from them. Nevertheless, compression/performance is excellent with very low friction - several thousand rpm at 15 psi..

Since writing the foregoing, I must admit that I've had serious misgivings about my ability to machine the last thou' from one of my miniature rings. No problem with a tool post grinder or rings where 't' is over 30 thou's but for really small rings, and with tools of dubious accuracy, I would prefer a 'safer' method.

I have therefore taken the liberty of amending the Chaddock/Walshaw fixture to make the Ring I/D minus 0.010" diameter into a spigot, fitting closely into a register machined in the clamping disc: an arrangement that I would find easier to make with the required accuracy, and I would also keep to Prof. Chaddock's illustration and mount the rings singly.

The requirement for extreme accuracy when chucking the fixture could be overcome by making it the last object to be machined before machining the rings - and leaving it in the chuck.

However my own preferred method would be to make the fixture from silver steel, harden it before use and (purists need read no further!) take off the last thou' with a fine diamond file; using the fixture as a pair of 'filing buttons' and with the lathe running at about 200 rpm.

It would still require caution, these files would cut the narrow ring very rapidly but with the much larger area of the fixture to act as both a witness and a check, it shouldn't be too difficult to stop at exactly the right size.

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