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Turbulence and Combustion Dynamics - Crevice Volumes - Stealth Power Thief

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01-17-2008, 06:04 PM

[#1 \(permalink\)](#)



[DavidVizard-GFN](#) [OFF](#)
Pit Crew

Join Date: Apr 2007
Posts: 840

#5 Turbulence and Combustion Dynamics - Crevice Volumes - Stealth Power Thief

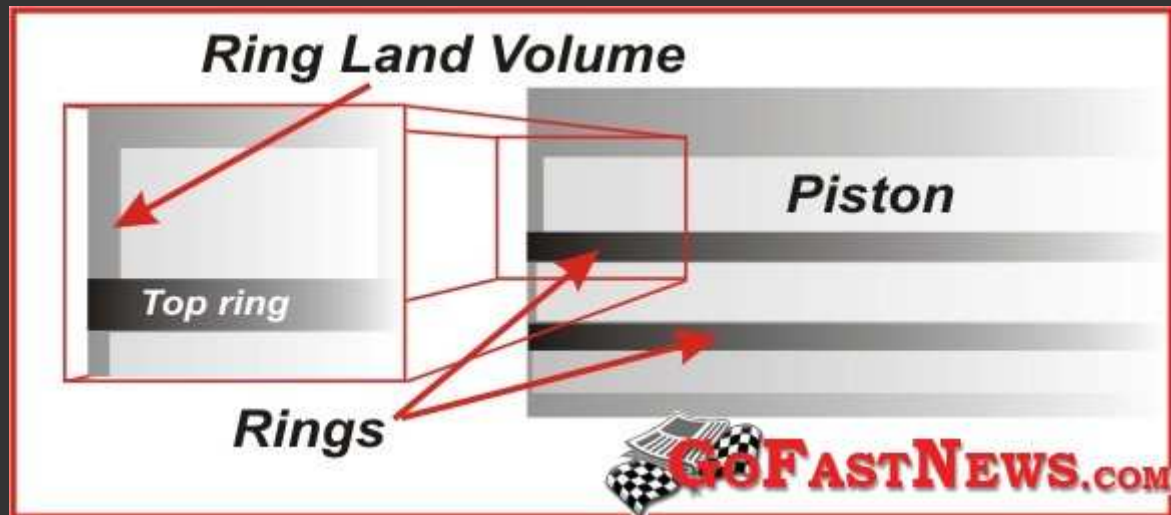


#5 Turbulence and Combustion Dynamics

In most instances crevice volumes look insignificant and that is why this power robbing element of the combustion chamber is so easily overlooked.

Just incase you were wondering what happened to part four relax, you have not missed it. I still have some work to do on the content so it is still a ways off yet.

It can be justifiable said that crevice volumes are the stealth thieves of those few HP that can so often make the difference between you winning the race and the other guy winning. However before we go down the road to investigate the disproportionately negative effect crevice volumes can have I think it would be a good idea to establish exactly what defines a 'crevice volume'. Almost certainly the worst crevice volume is that contained within the pistons top ring land as seen below.



But the top ring land is not the only crevice volume that we have to contend with although it should be the worst. A combustion chamber with a sharp corner between the floor of the chamber and the chamber wall is not so good. Some years ago I watched a combustion cycle filmed through the wall of a quartz cylinder engine. It was quite surprising to see that though there was about an 1/8 inch radius between the chamber floor and wall the charge that was immediately in that radius did not burn until much later in the cycle than the bulk mixture adjacent to it. What this told me is that the floor to wall radius in any combustion chamber needs to be as large as possible. There are also crevices between the edge of the valves and the combustion chamber or cylinder walls. These are worst on a parallel valve head such as we see used in most small block Chevy's, Fords and Chryslers (but not the new Hemi). Although we need to keep these crevices in mind the one we need to focus on the most is the top ring land volume.

Small Volume – Big Consequences.

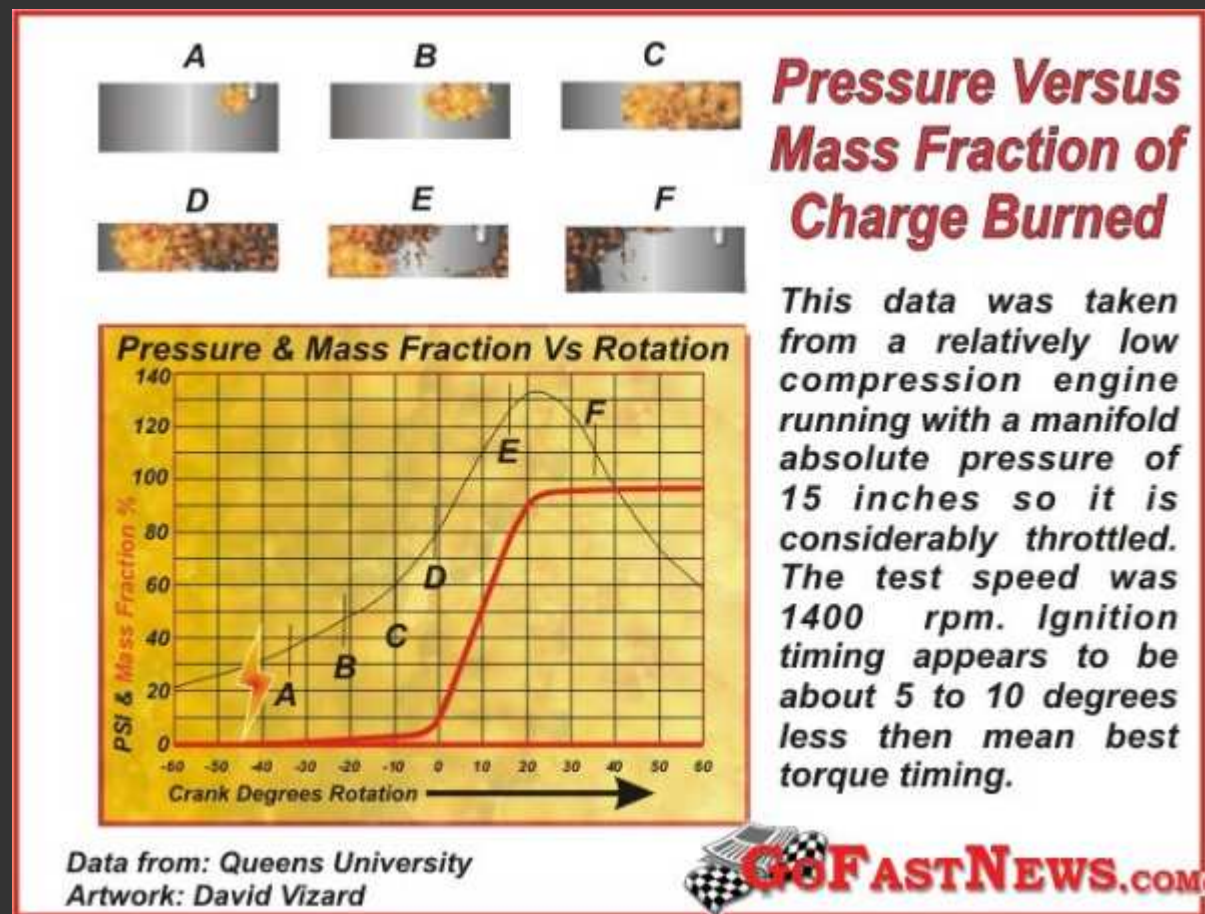
At this point you may be thinking that the ring land volume is so small compared to the volume of the rest of the cylinder that it cannot possibly have much influence on anything. At first things might look that way but the opposite is more nearly true. Let's look at the scenario involved here.

For an example let us consider the cylinder of a 350 inch small block Chevy. This, in cc's, works out to be 717 cc. To this we must add the total combustion chamber volume. Assuming a 10/1 CR this would be 89.5 cc. The ring land volume of a typical off-the-shelf hi-perf piston for this is right around 2 cc. At the bottom of the compression stroke we find that the crevice volume within the piston top ring land represents just 0.25% of the whole. That's one quarter of one percent!

Now let's take the piston to the top of the bore. Here the volume is now 89.5 cc and the 2 cc's in the top ring land represent not just one quarter of one percent but 2.4%. Lets just stop and consider what this means. In simple terms it means that almost two and a half percent of the inhaled charge now resides in the top ring land crevice volume.

At this point a doubter as to the importance of the crevice volume contained in the top ring land might just start to concede that there is some importance to minimizing the ring land volume. But it is still less than two and a half percent. If, you might say, this is as bad as it gets lets not fixate on it. Unfortunately things are about to get worse – a lot worse in fact.

As the piston comes up the bore the ring land volume tends to fill not with a combustible mixture of fuel and air but mostly a very fuel rich mixture. Any wet flow of fuel that was on the bore walls at the start of the pistons travel up the bore is scraped off by the piston rings. The motion of the piston up the bore and the motion of air and fuel into the ring land volume as compression takes place tends to push everything possible into it rather than letting anything out. By the time the piston has reached to top of the bore probably half of the ring land volume is raw fuel. As the piston approaches TDC so the combustion phase is initiated by the spark. At this point take a look at Fig 1 below.

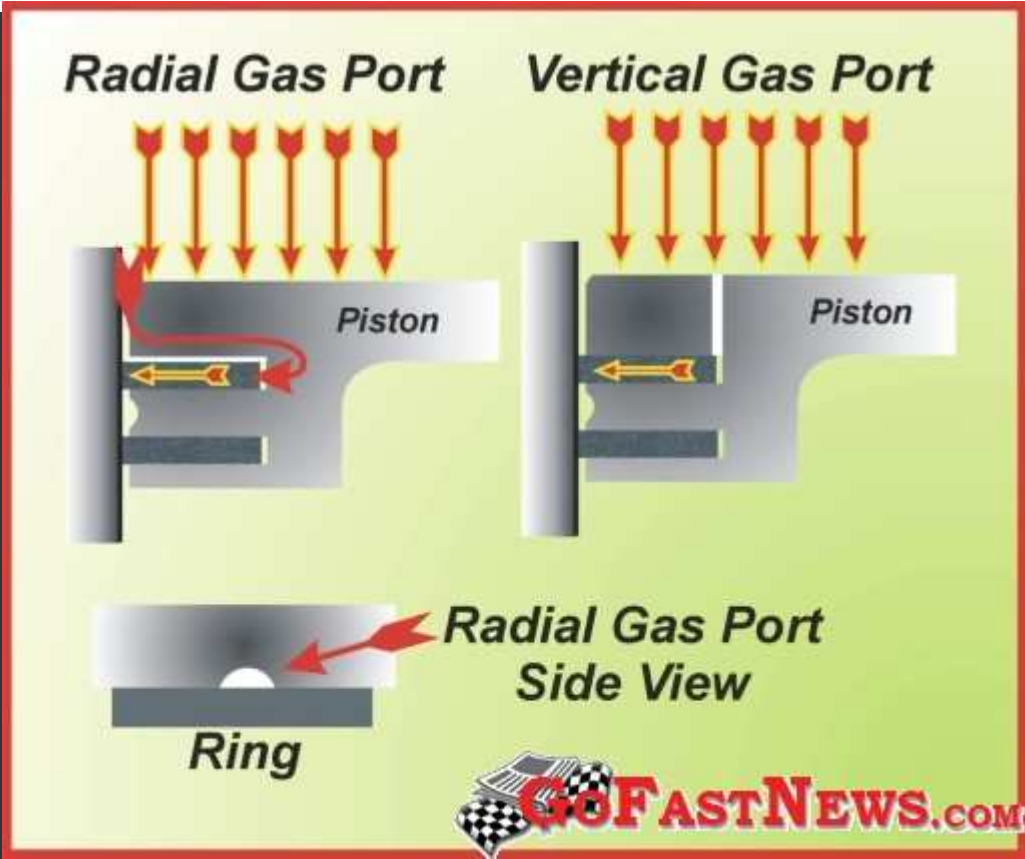


What you see in the above illustration is a computer enhanced version of the photo's taken through the transparent walls of a research engine. This was hardly a high performance engine but none-the-less what we learn from it is directly applicable. Using what we see above we will go through step by step and look at what happens to the mass of burned mixture compared to the volume. First the spark hits at 45 degrees BTDC. Note how the mass fraction burned (red curve) progresses very slowly at first. In fact after 40 degrees after the spark has fired only about 5% of the charge mass has burned. But take a look at the flame volume in the chamber at TDC. You can see that a lot more than 5% in terms of volume has burned. What is happening here is that as the mixture burns it expands and pushes the remaining un-burnt volume into a smaller space. This means we have the same type of scenario as we had when the piston was coming up the bore on the compression stroke. As the cylinder pressure rose so a greater percentage amount of charge mass ended up in the top ring land volume. At TDC only 10% of the mass has burned but the burned mixture takes up between 60-70% by volume. Assuming it was all a homogeneous mixture in the cylinder then, at TDC, we would have something in the order of 6% of the charge now in the ring land volume. That is an increase of 2400% over what was in it when the piston was at BDC!

The percentage mass burned versus the percentage volume burned charge does not catch up until about 20 degrees after TDC. At this point the mixture that was compressed into the ring land volume starts to come back out and burn. Also the fuel that was trapped there is also released as the piston accelerates down the bore. What mixture does burn is doing so too late in the cycle to contribute a proportionate share of the total energy released. If the entire 6% of the mixture that could be contained in the ring land volume were to be burned it would only contribute, at best, only about 2% of the resulting total energy.

So far we have looked only at regular style pistons as apposed to race pistons with gas porting down to the back of the top ring. Gas porting of pistons does not seem to have caught on in Europe so, for the

benefit of those so located, below is a drawing showing the two common types of gas porting.



The idea behind gas porting is to seal up the ring against the bore more effectively. Well gas porting does work but it also increases the crevice volume. So we do have to make a thoughtful trade off when designing our pistons. For what it's worth I favor radial gas ports as they just never plug up with carbon deposits.

Testing Theory.

At this point all we have done is look at what the potential for power loss from the prime crevice volume is. The dyno is now the reference point. First let's consider the eradication of the top ring land volume. During the mid 1970's the primary topic in the auto world was the problem emissions were causing in terms of power and fuel economy. Back in the 60's Sealed Power came out with a ring they called the 'Head Land' ring. This was a top compression ring that eliminated the top ring land volume. Below is a drawing of this. Sales of this ring were really lack luster until the promises of lower emissions prompted a semi-revival in interest.



About 1977 I had the opportunity of doing a back-to-back test between conventional Sealed Power top

rings and Sealed Power Head Land rings. My co-conspirators on this test managed to borrow a three gas analyzer so we could look at some of the emissions with each style of ring. I have long mislaid the test results but they were significant enough to stick in my mind.

What the head land ring delivered was a drop of over 30% of un-burned hydrocarbons and a drop of over 20% in carbon monoxide. Since it was emissions the rings primarily targeted that was good. As for power production things were less clear cut. The bottom line here was that low speed output went up. At about 1800 rpm (that was as low as the dyno would pull down the test mule) torque was up by a solid 3%. At about 3500 rpm both styles of top ring were even and at 5000 rpm the Head Land ring was down about 2-1/2%. As it happens we had a simple blow by gauge hooked up to the crank case and this showed that above about 4000 rpm the Head Land ring was losing its ability to effectively seal. I talked to Sealed Power's then Chief Engineer, Cal DeBruin, who was a friend of mine, and he confirmed what, in our case, we suspected was happening. The mass of the ring and its large face meant it was difficult to control at higher rpm and resulted in an increase in blow by.

As conclusive as it may seem that proved not to be the end of the story. Enter from the wings Del Fox. Del worked with Smokey Yunick on and off from around 1968 until a few years before he (Smokey) passed in 2000. During 1969 and 1970 Del worked full time for Smokey and did a lot of what ever engine building Smokey could not personally find the time for. As you might expect Del has more than the odd story related to finding hp and the Head Land ring design proved to be one of them.

Here is how the cookie crumbles for round two of our look at Head Land rings. For the tests I did the forged pistons used the clearances recommended by Sealed Power. That turned out to be about 0.005 – 0.006 inches. The width of a Head Land ring meant that to accommodate any rocking of the piston in the bore the face against the cylinder wall had to be a barrel form. Both Del and Smokey liked the concept of the Head Land ring and although their first round of testing showed pretty similar results to those I ran they stuck with the concept. What they did was to see if they could cut piston clearances to a minimum so as to cut the rocking of the piston in an effort to help seal everything up. Seemingly their efforts paid off as they managed to get the ring to work much further up the rpm range. Remember back then most endurance engines did not turn much over 7500 rpm.

So Far We Have Proved ---- ?

At this point we can say that eliminating the top ring groove crevice has proved that output can benefit. Other than minimizing clearances as Del Fox and Smokey Yunick did it is not quite obvious is how we can implement the Head Land ring principle in a really high rpm engine. Maybe if the ring was made of titanium it would work up to a much higher rpm as it would not weigh any more than a conventional steel ring. Yes, I realize that someone is going to say that titanium is the most seize-able material on the face of the planet and barely stops short of welding itself to ice when rubbed against it. Well the good news – if any one is interested, is that I know how to make titanium into a better bearing material than phosphor bronze. This has allowed the production of Ti wrist pins (gudgeon pins if you live in England) that have no coating, are about twice as seize resistant as tool steel pins and have a Rockwell hardness of about 76. But I digress – so far I have not been in a position to do anything with respect to a Ti ring but there are some moves employing more conventional approaches toward the reduction of the top ring land volume.

I was at lunch with Pro Stock and engine building legend Grumpy Jenkins about 20 years ago and the subject of the top rings position in relation to the crown of the piston became the topic of the conversation. Grumpy told me of the differences they had seen on a Pro Stock style small block Chevy.

After my experience with the Head Land ring and Grumpy's input I put a back to back test of a low set top ring versus a high set one on the front end of a long to-do list. The problem here is I needed to get some piston manufacturer to make two sets of pistons both for free and for no other reason than to establish what the difference might be. This opportunity came about when Moe Mills decided to leave Aries pistons and, with a partner, start Ross Pistons. Here Moe (who has given me unconditional support over the years - and you might want to keep that in mind when you order your next set of pistons) made up two sets of pistons with valve cutouts minimized for the 280 degree (off the seat duration) hydraulic cam that was to be used. The valve cutout depth is an important factor for an inclined valve engine such as a small block Chevy as the cutout can easily intersect with the ring groove. To get that top ring up as far as possible it was really necessary to make sure the intake valve pocket was no deeper than needs be. The low set top ring was 0.375 down from the piston crown while the high set one was 0.150. This gave crevice volumes of 1.36 and .55 cc respectively for a reduction of 55% in crevice volume.



What you see here is a comparison of a regular 'D' wall ring with the narrower and less wide ring used on Mahle pistons. By cutting the ring size they are in a position to take more advantage of a high set ring as it will not interfere with the valve cutout until a higher position is used. the thinner ring also allows for better conformation to the cylinder wall for a better seal.

Remember we are only looking at a reduction of 0.81 cc and you may well ask just how much a small change like that can possibly make. The CR for the test engine was a solid 10.5/1. Another feature of this test is that the pistons had a skirt profile that was intended minimize piston to wall clearance. At the open end of the pistons the clearance was only 0.001 which is relatively close for a forged piston. The clearance at the pin was 0.0035. Also I need to make it clear that when I run tests I go to a lot of trouble to calibrate the carb right on so there is a minimum of excess fuel compared to what the engine actually wants for an optimum air/fuel ratio. Additionally the carb had hi-gain boosters (Braswell carb) that delivered good atomization and the heads were of a relatively small port (165 cc) variety (ported factory 186 castings). All this should add up to a better than average quality of mixture arriving at the cylinders (ie minimum of wet flow versus airborne fuel flow).

With these pertinent parameters taken care of the tests were run. The chart below shows the results of an average of 7 runs with the best and worst tests thrown out in each case and the rest averaged.

RPM	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
Torque #1	317.8	333.1	375.0	404.8	427.8	430.2	414.6	392.1	361.3	294.1
Torque #2	324.5	339.1	377.6	410.5	432.9	432.9	419.8	398.6	367.4	302.5
Tq. Difference	6.7	6.0	2.6	5.7	5.1	2.7	5.2	6.5	6.1	8.4
HP #1	121.0	158.6	214.2	269.8	325.8	368.6	394.7	410.6	412.8	364.0
HP #2	123.6	161.4	215.7	273.6	329.7	370.9	399.7	417.4	419.7	374.4
HP Difference	2.6	2.8	1.5	3.8	3.9	2.3	5.0	6.8	6.9	10.4

**Test # 1 is low set ring
Test #2 is high set ring**

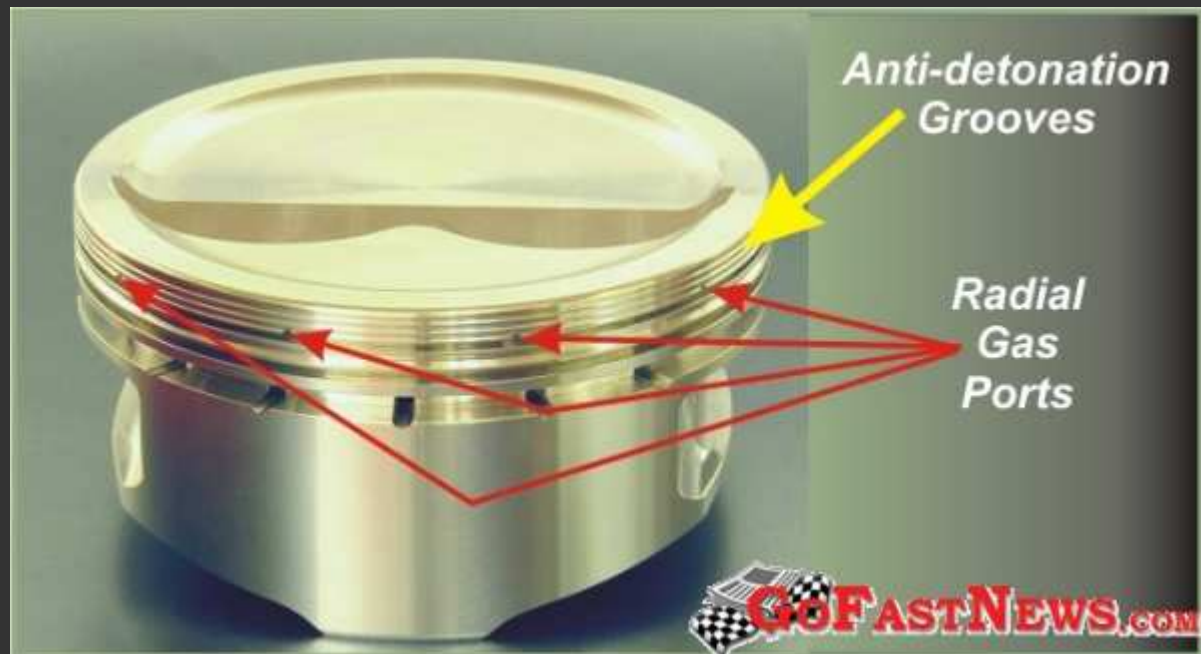
What you see here is a test done as diligently as possible with the equipment available. The situation for the 'before' test was as good as it gets with the engine showing very good brake specific fuel consumption. This indicates that the combustion process was already good. That probably meant the minimum of wet fuel entering the cylinders and consequently the minimum raw fuel into the ring land volume. Even with this best case scenario the power trend was most decidedly in the upward direction.

Talking to various piston manufactures has indicated that similar tests done on all out race engines with a much higher CR (and probably greater wet flow) have shown bigger percentage gains. This makes sense as more charge will be driven into the ring land volume the higher the cylinder pressures go. From this we can reasonably conclude that what is shown in the chart is about the minimum increase that can be expected. In round numbers we are looking at an average of 1-1/2% for some additional

cleanup on an already good combustion process. This is a pretty good result because with all the theory as to how a near unprecedented amount of charge can end up in the ring land volume has not as yet accounted for one important aspect. The reason the top of the piston is smaller is that this is where the most heat is and thus, the top expands more. What may be a 2 cc volume cold may only be a 1 cc volume hot. So, with the volume even smaller than we calculate it to be we can see that a crevice volume that is even very small has a disproportionate effect on the combustion process.

Where From Here?

Other than setting the ring up as high as possible or getting a ring company to re-investigate the Head Land ring what else can we do to rid the combustion space of the top ring land volume? About 20 years ago Cosworth made a move to do just that. What they did was to make the top land a larger size than normal then groove it. The idea was that during break in and eventual WOT operation the piston would touch the bore and wear the peaks from the grooving so that the piston almost exactly fitted the bore thus eliminating the top ring land volume at operating temperature.



Here is one of the JE pistons for the 454 small block Chevy I am currently working on. The point to note is the 'anti-detonation' grooves in the top ring land. These do allow a closer fit between piston and bore as any excess material that expands and contacts the bore is easily worn away.

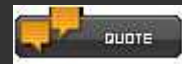
I remember talking to Cosworth's piston designer, the late Geoff Roper, about the grooving and the fact they were just starting to do this for Cup Car pistons. That move might just have been the start of Cosworth's downslide in Cup Car piston sales! I forget what Cosworth called the grooving but these days we commonly refer to them as 'anti-detonation' grooves. How they help suppress detonation has never convincingly been explained to me so I am still waiting on that one! As far as power increase is concerned I have never done a back to back test here. In spite of the fact they have now been around for over twenty years I think the jury is still out as to the advantages of anti-detonation grooves. (if I hear of anything to the contrary here I will up date this section accordingly)

One aspect that creeps in here concerns the way increasing cylinder pressure, either from compression or the combustion process, drives the charge into the top ring land volume. If you think about this lighting off the charge from the middle of the cylinder is the worst way to do things in this respect. If the charge was propagated from all around the circumference of the cylinder the highest pressures would occur long after the charge in close proximity to the ring land volume had been burned. Granted this sounds like a good way to go but firing the charge from all around the outside looks like a difficult deal to accomplish. Difficult yes – but impossible – no. About ten years ago I met a guy in California who had designed plug electrodes into a head gasket. The gasket had about 6 points around the circumference that would fire the charge. Each, might I add, fired from an independent system. FelPro apparently liked the idea – at least initially – as they acquired the rights to it. I never saw any test data but I heard it worked pretty good for emissions, mileage and power. Production it seemed, was not a

practicality, as to change plugs the heads had to be removed!



Last edited by DavidVizard-GFN; 08-18-2008 at 08:54 AM.



01-26-2008, 01:19 PM

#2 ([permalink](#))

Catherwood OFF
Garage Sweeper

Join Date: Dec 2007
Location: Palm Harbor, FL
Posts: 4

A friend who is an engineer and a smart one told me during a discussion on a now forgotten topic about fluid behavior during a pressure raising event such as the compression stroke in an engine cylinder. As the pressure goes up, the fluid gases will separate. As they separate, they tend to condense in the boundary layer of the cylinder, one liquid on one side and another liquid on another side. This could explain why the films of engine combustion look so erratic and not the uniform event expected. This could also explain why there are lean and rich areas of the cylinder. The crevices that you talked of would have a larger boundary layer and collect more condensed fuel than the smoother surfaces elsewhere in the cylinder. This also applies to oxygen and nitrogen in the air as well as the gasoline in the mixture. How to combat these?

Minimize the crevices by radiusing (?) all sharp corners and edges? Minimize the size of the boundary layer with lots of motion, swirl and tumble? A more homogeneous mixture entering the cylinder? This last question brings me to a design question.

Why are cylinder inlet ports designed more like pipes uniform in size and not more nozzle shaped? The increased motion to crowd the incoming charge in a nozzle type design would certainly cause a lot of mixing and velocity increase just before the entry into the cylinder. This increase in velocity would also help the inertial charging at high speed to offset the loss of flow due to friction. This increase in velocity would make the mixture more homogeneous and the boundary layer would be minimized. At low speed the loss due to friction would not be a factor as there would be far less demand through the ports, but velocity would be higher and mixing better while at part throttle or low speed.

Just a few thoughts and questions



02-15-2008, 11:01 PM

#3 ([permalink](#))

MadBill OFF
Garage Sweeper

Join Date: Sep 2007
Posts: 76

A most thought-provoking article, David, and timely too, as I am consulting at present on piston revisions for a builder of 600 c.i. 8,000 RPM engines whose current rings are perhaps 0.500" down, driven largely by pessimistically deep valve reliefs.

A couple of thoughts:

1. If anti-friction skirt coatings (say Swain's PC-7) were applied thickly to the piston above the top groove, the crevice volume could be reduced to essentially zero without risk of scuffing.
2. Of course if any crevice reduction strategy were to be *too* effective, the lateral gas ports might be starved for pressure. Perhaps vertical ports would be a better choice, at least initially...
3. Speaking of coatings, I know you were an early proponent of thermal barrier and anti-friction coatings, but I have heard little about them of late. Are they just old news now, or has their lustre faded for some reason? Maybe an update article is called for...



02-22-2008, 07:49 AM

#4 ([permalink](#))



DavidVizard-GFN OFF
Pit Crew

Join Date: Apr 2007
Posts: 840

OK guys some short answers here to some good points raised.

First port shapes - these are approaching a nozzle form on highly developed cylinder heads. Prime examples of this are the exhaust ports of cup car engines and the like. We will be covering theoretically optimal ports down the road when I can get to it.

As for coatings these are still a major area of experimentation with some very positive results to be had. Again I just need time to get to writing about my experiences to date testing coatings.

DV



02-22-2008, 02:00 PM

#5 ([permalink](#))**Cammer** OFF
Oil ChangerJoin Date: Aug 2007
Posts: 290**Engine Design**

The vast majority of new engine designs are based on previous OEM configurations and attending parts/packaging constraints.

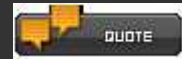
An engine designed without limitations could present vastly different intake manifold, head, and exhaust designs. These could be accompanied by related changes in the valvetrain and reciprocating assembly.

Engine coatings are not always a win-win proposition. In some instances engine coatings can be detrimental. I will expound on this at a later time.

Combustion chamber dynamics are a source of conflict even among us of the engineering persuasion. These dynamics differ cycle-to-cycle and cylinder-to-cylinder. Utilizing in-cylinder pressure data and related computer simulations offers promise in this area. Engineers are just beginning to unravel some of the complexities found in the ICE.

I will leave you with this question:

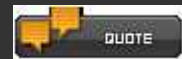
Is gas-porting a viable engineering exercise or merely a fix for an engineering deficiency? Root cause analysis of this subject could prove interesting! 😊



02-23-2008, 12:05 AM

#6 ([permalink](#))**1989GTA** OFF
Tire ChangerJoin Date: Oct 2007
Posts: 114

Would love to see the article about coatings. Not really much out there except by the manufacturers.



02-25-2008, 03:02 PM

#7 ([permalink](#))**howieschoon** OFF
Tire ChangerJoin Date: Dec 2007
Posts: 136

David,
Great Article. I have learned a lot since I joined this site just a month or two ago. I can't wait for the theoretical optimal port article and especially the coatings article. Did you recalibrate the carb between the high and low set ring tests? Do you have data on the BSFC for both tests? If you do, I think it would be interesting to see it.
Thanks for all the info,
Howard



03-02-2008, 10:25 AM

#8 (permalink)



DavidVizard-GFN OFF
Pit Crew

Join Date: Apr 2007
Posts: 840

Quote:

Originally Posted by **howieschoon** >
*David,
Great Article. I have learned a lot since I joined this site just a month or two ago. I can't wait for the theoretical optimal port article and especially the coatings article. Did you recalibrate the carb between the high and low set ring tests? Do you have data on the BSFC for both tests? If you do, I think it would be interesting to see it.
Thanks for all the info,
Howard*

Howard,
Thanks for your kind words.

When doing back to back tests to establish a trend I always recalibrate ignition and carburation.

I actually had an article on exhaust sent back to me by a so called tech editor of one popular magazine telling me the tests were invalid because I made more than one change - the exhaust and the carb jetting. Not only did this guy support his argument on the no more than one change idea but also he claimed that very few hot rodders would recalibrate after making such a change. Therefor my meticulously done tests were invalid.

Cammer,

I have lots of tests on various forms of coatings, some delived, some did very little and some actually were of negative benifit. I would like to get your take on the 'failures' here as they are often more interesting than the successes.
How about it???????

DV



03-03-2008, 04:21 PM

#9 (permalink)

1989GTA OFF
Tire Changer

Join Date: Oct 2007
Posts: 114

To David and Cammer

Maybe just post or write an article about the coatings that had a positive effect. Then we could infer that the coatings not mentioned either had no effect or were detrimental to some degree. That way you could avoid the wrath of certain folks. 🇺🇸



03-16-2008, 01:42 PM

#10 (permalink)

Cammer OFF
Oil Changer

Join Date: Aug 2007
Posts: 290

Coatings

The subject of engine coatings must be divided into types of coatings and preparation/application techniques.

I have researched various coatings with some unexpected results.

Using an example of ceramic coated piston tops found problems with: areas of thick and thin coating, porosity, crackling and cracking, peeling and delamination, and changes to parent piston material. All of these pistons were coated by well known companies. The preceding characteristics may have some roots in the preparation/application process.

Coating supplier curing temperatures and durations affected cylinder head materials, valve seats, valve guides, and various dimensional and geometrical aspects of specific cylinder heads. A possible cause for these problems may be related to exceeding design limitations of parent materials and attendant assemblies.

Some materials touted as thermal barriers actually tested as thermal conductors! Scary!

Let us look at tubular exhaust headers. A slight loss in horsepower was found on uncoated headers allowed to form rust in the tubes and collectors. On the flipside, fully coated headers showed little horsepower gain though a slight reduction in underhood temperature was noted in some tests. Some internally coated headers were not coated on the entirety of internal surfaces.

Overall, thermal barrier coatings applied by well known companies appear to be expensive given the relatively small gains noted.

I want to leave you with something positive! Friction reducing/wear reducing coatings used on piston skirts and bearings tested very well when proper preparations and processes were used in application. When using these particular coated parts follow manufacturers' guidelines for clearancing as coatings may be damaged by improper handling.

As racers we often perceive gains in performance not actually backed up by independent testing and research. Research is important to making informed decisions! It is hard to admit things do not work when you have spent alot of money to buy them!

I am looking forward to David's article on coatings!



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