Engine Basics: Detonation and Pre-Ignition

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All high output engines are prone to destructive tendencies as a result of over boost, misfueling, mis-tuning and inadequate cooling. The engine community pushes ever nearer to the limits of power output. As they often learn cylinder chamber combustion processes can quickly gravitate to engine failure. This article defines two types of engine failures, detonation and pre-ignition, that are as insidious in nature to users as they are hard to recognize and detect. This discussion is intended only as a primer about these combustion processes since whole books have been devoted to the subject.

First, let us review normal combustion. It is the burning of a fuel and air mixture charge in the combustion chamber. It should burn in a steady, even fashion across the chamber, originating at the spark plug and progressing across the chamber in a three dimensional fashion. Similar to a pebble in a glass smooth pond with the ripples spreading out, the flame front should progress in an orderly fashion. The burn moves all the way across the chamber and , quenches (cools) against the walls and the piston crown. The burn should be complete with no remaining fuel-air mixture. Note that the mixture does not "explode" but burns in an orderly fashion.

There is another factor that engineers look for to quantify combustion. It is called "location of peak pressure (LPP)." It is measured by an in-cylinder pressure transducer. Ideally, the LPP should occur at 14 degrees after top dead center. Depending on the chamber design and the burn rate, if one would initiate the spark at its optimum timing (20 degrees BTDC, for example) the burn would progress through the chamber and reach LPP, or peak pressure at 14 degrees after top dead center. LPP is a mechanical factor just as an engine is a mechanical device. The piston can only go up and down so fast. If you peak the pressure too soon or too late in the cycle, you won't have optimum work. Therefore, LPP is always 14 degrees ATDC for any engine.

I introduce LPP now to illustrate the idea that there is a characteristic pressure buildup (compression and combustion) and decay (piston downward movement and exhaust valve opening) during the combustion process that can be considered "normal" if it is smooth, controlled and its peak occurs at 14 degrees ATDC.

Our enlarged definition of normal combustion now says that the charge/bum is initiated with the spark plug, a nice even burn moves across the chamber, combustion is completed and peak pressure occurs at at 14 ATDC.

Confusion and a lot of questions exist as to detonation and pre-ignition. Sometimes you hear mistaken terms like "pre-detonation". Detonation is one phenomenon that is abnormal combustion. Pre-ignition is another phenomenon that is abnormal combustion. The two, as we will talk about, are somewhat related but are two distinctly different phenomenon and can induce distinctly different failure modes.

KEY DEFINITIONS

Detonation: Detonation is the spontaneous combustion of the end-gas (remaining fuel/air mixture) in the chamber. It always occurs after normal combustion is initiated by the spark plug. The initial combustion at the spark plug is followed by a normal combustion burn. For some reason, likely heat and pressure, the end gas in the chamber spontaneously combusts. The key point here is that detonation occurs after you have initiated the normal combustion with the spark plug.

Pre-ignition: Pre-ignition is defined as the ignition of the mixture prior to the spark plug firing. Anytime something causes the mixture in the chamber to ignite prior to the spark plug event it is classified as pre-ignition. The two are completely different and abnormal phenomenon.

DETONATION

Unburned end gas, under increasing pressure and heat (from the normal progressive burning process and hot combustion chamber metals) spontaneously combusts, ignited solely by the intense heat and pressure. The remaining fuel in the end gas simply lacks sufficient octane rating to withstand this combination of heat and pressure.

Detonation causes a very high, very sharp pressure spike in the combustion chamber but it is of a very short duration. If you look at a pressure trace of the combustion chamber process, you would see the normal burn as a normal pressure rise, then all of a sudden you would see a very sharp spike when the detonation occurred. That spike always occurs after the spark plug fires. The sharp spike in pressure creates a force in the combustion chamber. It causes the structure of the engine to ring, or resonate, much as if it were hit by a hammer. Resonance, which is characteristic of combustion detonation, occurs at about 6400 Hertz. So the pinging you hear is actually the structure of the engine reacting to the pressure spikes. This noise of detonation is commonly called spark knock. This noise changes only slightly between iron and aluminum. This noise or vibration is what a knock sensor picks up. The knock sensors are tuned to 6400 hertz and they will pick up that spark knock. Incidentally, the knocking or pinging sound is not the result of "two flame fronts meeting" as is often stated. Although this clash does generate a spike the noise you sense comes from the vibration of the engine structure reacting to the pressure spike.

One thing to understand is that detonation is not necessarily destructive. Many engines run under light levels of detonation, even moderate levels. Some engines can sustain very long periods of heavy detonation without incurring any damage. If you've driven a car that has a lot of spark advance on the freeway, you'll hear it pinging. It can run that way for thousands and thousands of miles. Detonation is not necessarily destructive. It's not an optimum situation but it is not a guaranteed instant failure. The higher the specific output (HP/in3) of the engine, the greater the sensitivity to detonation. An engine that is making 0.5 HP/in3 or less can sustain moderate levels of detonation without any damage; but an engine that is making 1.5 HP/in3, if it detonates, it will probably be damaged fairly quickly, here I mean within minutes.

Detonation causes three types of failure:

1. **Mechanical damage (broken ring lands)**
2. **Abrasion (pitting of the piston crown)**
3. **Overheating (scuffed piston skirts due to excess heat input or high coolant temperatures)**

The high impact nature of the spike can cause fractures; it can break the spark plug electrodes, the porcelain around the plug, cause a clean fracture of the ring land and can actually cause fracture of valves-intake or exhaust. The piston ring land, either top or second depending on the piston design, is susceptible to fracture type failures. If I were to look at a piston with a second broken ring land, my immediate suspicion would be detonation.

Another thing detonation can cause is a sandblasted appearance to the top of the piston. The piston near the perimeter will typically have that kind of look if detonation occurs. It is a swiss-cheesy look on a microscopic basis. The detonation, the mechanical pounding, actually mechanically erodes or fatigues material out of the piston. You can typically expect to see that sanded look in the part of the chamber most distant from the spark plug, because if you think about it, you would ignite the flame front at the plug, it would travel across the chamber before it got to the farthest reaches of the chamber where the end gas spontaneously combusted. That's where you will see the effects of the detonation; you might see it at the hottest part of the chamber in some engines, possibly by the exhaust valves. In that case the end gas was heated to detonation by the residual heat in the valve.

In a four valve engine with a pent roof chamber with a spark plug in the center, the chamber is fairly uniform in distance around the spark plug. But one may still may see detonation by the exhaust valves because that area is usually the hottest part of the chamber. Where the end gas is going to be hottest is where the damage, if any, will occur.

Because this pressure spike is very severe and of very short duration, it can actually shock the boundary layer of gas that surrounds the piston. Combustion temperatures exceed 1800 degrees. If you subjected an aluminum piston to that temperature, it would just melt. The reason it doesn't melt is because of thermal inertia and because there is a boundary layer of a few molecules thick next to the piston top. This thin layer isolates the flame and causes it to be quenched as the flame approaches this relatively cold material. That combination of actions normally protects the piston and chamber from absorbing that much heat. However, under extreme conditions the shock wave from the detonation spike can cause that boundary layer to breakdown which then lets a lot of heat transfer into those surfaces.

Engines that are detonating will tend to overheat, because the boundary layer of gas gets interrupted against the cylinder head and heat gets transferred from the combustion chamber into the cylinder head and into the coolant. So it starts to overheat. The more it overheats, the hotter the engine, the hotter the end gas, the more it wants to detonate, the more it wants to overheat. It's a snowball effect. That's why an overheating engine wants to detonate and that's why engine detonation tends to cause overheating.

Many times you will see a piston that is scuffed at the "four corners". If you look at the bottom side of a piston you see the piston pin boss. If you look across each pin boss it's solid aluminum with no flexibility. It expands directly into the cylinder wall. However, the skirt of a piston is relatively flexible. If it gets hot, it can deflect. The crown of the piston is actually slightly smaller in diameter on purpose so it doesn't contact the cylinder walls. So if the piston soaks up a lot of heat, because of detonation for instance, the piston expands and drives the piston structure into the cylinder wall causing it to scuff in four places directly across each boss. It's another dead give-a-way sign of detonation. Many times detonation damage is just limited to this.

Some engines, such as liquid cooled 2-stroke engines found in snowmobiles, watercraft and motorcycles, have a very common detonation failure mode. What typically happens is that when detonation occurs the piston expands excessively, scurfs in the bore along those four spots and wipes material into the ring grooves. The rings seize so that they can't conform to the cylinder walls. Engine compression is lost and the engine either stops running, or you start getting blow-by past the rings. That torches out an area. Then the engine quits.

In the shop someone looks at the melted result and says, "pre-ignition damage". No, it's detonation damage. Detonation caused the piston to scuff and this snowballed into loss of compression and hot gas escaping by the rings that caused the melting. Once again, detonation is a source of confusion and it is very difficult, sometimes, to pin down what happened, but in terms of damage caused by detonation, this is another typical sign.

While some of these examples may seem rather tedious I mention them because a "scuffed piston" is often blamed on other factors and detonation as the problem is overlooked. A scuffed piston may be an indicator of a much more serious problem which may manifest itself the next time with more serious results.

In the same vein, an engine running at full throttle may be happy due to a rich WOT air/fuel ratio. Throttling back to part throttle the mixture may be leaner and detonation may now occur. Bingo, the piston overheats and scuffs, the engine fails but the postmortem doesn't consider detonation because the the failure didn't happen at WOT.

I want to reinforce the fact that the detonation pressure spike is very brief and that it occurs after the spark plug normally fires. In most cases that will be well after ATDC, when the piston is moving down. You have high pressure in the chamber anyway with the burn. The pressure is pushing the piston like it's supposed to, and superimposed on that you get a brief spike that rings the engine.

CAUSES

Detonation is influenced by chamber design (shape, size, geometry, plug location), compression ratio, engine timing, mixture temperature, cylinder pressure and fuel octane rating. Too much spark advance ignites the burn too soon so that it increases the pressure too greatly and the end gas spontaneously combusts. Backing off the spark timing will stop the detonation. The octane rating of the fuel is really nothing magic. Octane is the ability to resist detonation. It is determined empirically in a special running test engine where you run the fuel, determine the compression ratio that it detonates at and compare that to a standard fuel, That's the octane rating of the fuel. A fuel can have a variety of additives or have higher octane quality. For instance, alcohol as fuel has a much better octane rating just because it cools the mixture significantly due to the extra amount of liquid being used. If the fuel you got was of a lower octane rating than that demanded by the engine's compression ratio and spark advance detonation could result and cause the types of failures previously discussed.

Production engines are optimized for the type or grade of fuel that the marketplace desires or offers. Engine designers use the term called MBT (Minimum spark for Best Torque) for efficiency and maximum power; it is desirable to operate at MBT at all times. For example, let's pick a specific engine operating point, 4000 RPM, WOT, 98 kPa MAP. At that operating point with the engine on the dynamometer and using non-knocking fuel, we adjust the spark advance. There is going to be a point where the power is the greatest. Less spark than that, the power falls off, more spark advance than that, you don't get any additional power.

Now our engine was initially designed for premium fuel and was calibrated for 20 degrees of spark advance. Suppose we put regular fuel in the engine and it spark knocks at 20 degrees? We back off the timing down to 10 degrees to get the detonation to stop. It doesn't detonate any more, but with 10 degrees of spark retard, the engine is not optimized anymore. The engine now suffers about a 5-6 percent loss in torque output. That's an unacceptable situation. To optimize for regular fuel engine designers will lower the compression ratio to allow an increase in the spark advance to MBT. The result, typically, is only a 1-2 percent torque loss by lowering the compression. This is a better trade-off. Engine test data determines how much compression an engine can have and run at the optimum spark advance.

For emphasis, the design compression ratio is adjusted to maximize efficiency/power on the available fuel. Many times in the aftermarket the opposite occurs. A compression ratio is "picked" and the end user tries to find good enough fuel and/or retards the spark to live with the situation...or suffers engine damage due to detonation.

Another thing you can do is increase the burn rate of the combustion chamber. That is why with modem engines you hear about fast burn chambers or quick burn chambers. The goal is the faster you can make the chamber burn, the more tolerant to detonation it is. It is a very simple phenomenon, the faster it burns, the quicker the burn is completed, the less time the end gas has to detonate. If it can't sit there and soak up heat and have the pressure act upon it, it can't detonate.

If, however, you have a chamber design that burns very slowly, like a mid-60s engine, you need to advance the spark and fire at 38 degrees BTDC. Because the optimum 14 degrees after top dead center (LPP) hasn't changed the chamber has far more opportunity to detonate as it is being acted upon by heat and pressure. If we have a fast burn chamber, with 15 degrees of spark advance, we've reduced our window for detonation to occur considerably. It's a mechanical phenomenon. That's one of the goals of having a fast burn chamber because it is resistant to detonation.

There are other advantages too, because the faster the chamber burns, the less spark advance you need. The less time pistons have to act against the pressure build up, the air pump becomes more efficient. Pumping losses are minimized. In other words, as the piston moves towards top dead center compression of the fuel/air mixture increases. If you light the fire at 38 degrees before top dead center, the piston acts against that pressure for 38 degrees. If you light the spark 20 degrees before top dead center, it's only acting against it for 20. The engine becomes more mechanically efficient.

There are a lot of reasons forfast burn chambers but one nice thing about them is that they become more resistant to detonation. A real world example is the Northstar engine from 1999 to 2000. The 1999 engine was a 10.3:1 compression ratio. It was a premium fuel engine. For the 2000 model year, we revised the combustion chamber, achieved faster bum. We designed it to operate on regular fuel and we only had to lower the compression ratio .3 to only 10:1 to make it work. Normally, on a given engine (if you didn't change the combustion chamber design) to go from premium to regular fuel, it will typically drop one point in compression ratio: With our example, you would expect a Northstar engine at 10.3:1 compression ratio, dropped down to 9.3:1 in order to work on regular. Because of the faster burn chamber, we only had to drop to 10:1. The 10:1 compression ratio still has very high compression with attendant high mechanical efficiency and yet we can operate it at optimum spark advance on regular fuel. That is one example of spark advance in terms of technology. A lot of that was achieved through computational fluid dynamics analysis of the combustion chamber to improve the swirl and tumble and the mixture motion in the chamber to enhance the bum rate.

CHAMBER DESIGN

One of the characteristic chambers that people are familiar with is the Chrysler Hemi. The engine had a chamber that was like a half of a baseball. Hemispherical in nature and in nomenclature, too. The two valves were on either side of the chamber with the spark plug at the very top. The charge burned downward across the chamber. That approach worked fairly well in passenger car engines but racing versions of the Hemi had problems. Because the chamber was so big and the bores were so large, the chamber volume also was large; it was difficult to get the compression ratio high. Racers put a dome on the piston to increase the compression ratio. If you were to take that solution to the extreme and had a 13:1 or 14:1 compression ratio in the engine pistons had a very tall dome. The piston dome almost mimicked the shape of the head's combustion chamber with the piston at top dead center. One could call the remaining volume "the skin of the orange." When ignited the charge burned very slowly, like the ripples in a pond,, covering the distance to the block cylinder wall. Thus, those engines, as a result of the chamber design, required a tremendous amount of spark advance, about 40-45 degrees. With that much spark advance detonation was a serious possibility if not fed high octane fuel. Hemis tended to be very sensitive to tuning. As often happened, one would keep advancing the spark, get more power and all of a sudden the engine would detonate, Because they were high output engines, turning at high RPM, things would happen suddenly.

Hemi racing engines would typically knock the ring land off, get blow by, torch the piston and fall apart. No one then understood why. We now know that the Hemi design is at the worst end of the spectrum for a combustion chamber. A nice compact chamber is best; that's why the four valve pent roof style chambers are so popular. The flatter the chamber, the smaller the closed volume of the chamber, the less dome you need in the piston. We can get inherently high compression ratios with a flat top piston with a very nice bum pattern right in the combustion chamber, with very short distances, with very good mixture motion - a very efficient chamber.

Look at a Northstar or most of the 4 valve type engines - all with flat top pistons, very compact combustion chambers, very narrow valve angles and there is no need for a dome that impedes the burn to raise the compression ratio to 10:1.

DETONATION INDICATORS

The best indication of detonation is the pinging sound that cars, particularly old models, make at low speeds and under load. It is very difficult to hear the sound in well insulated luxury interiors of today's cars. An unmuffled engine running straight pipes or a propeller turning can easily mask the characteristic ping. The point is that you honestly don't know that detonation is going on. In some cases, the engine may smoke but not as a rule. Broken piston ring lands are the most typical result of detonation but are usually not spotted. If the engine has detonated visual signs like broken spark plug porcelains or broken ground electrodes are dead giveaways and call for further examination or engine disassembly.

It is also very difficult to sense detonation while an engine is running in an remote and insulated dyno test cell. One technique seems almost elementary but, believe it or not, it is employed in some of the highest priced dyno cells in the world. We refer to it as the "Tin Ear". You might think of it as a simple stethoscope applied to the engine block. We run a ordinary rubber hose from the dyno operator area next to the engine. To amplify the engine sounds we just stick the end of the hose through the bottom of a Styrofoam cup and listen in! It is common for ride test engineers to use this method on development cars particularly if there is a suspicion out on the road borderline detonation is occurring. Try it on your engine; you will be amazed at how well you can hear the different engine noises.

The other technique is a little more subtle but usable if attention is paid to EGT (Exhaust Gas Temperature). Detonation will actually cause EGTs to drop. This behavior has fooled a lot of people because they will watch the EGT and think that it is in a low enough range to be safe, the only reason it is low is because the engine is detonating.

The only way you know what is actually happening is to be very familiar with your specific engine EGT readings as calibrations and probe locations vary. If, for example, you normally run 1500 degrees at a given MAP setting and you suddenly see 1125 after picking up a fresh load of fuel you should be alert to possible or incipient detonation. Any drop from normal EGT should be reason for concern. Using the "Tin Ear" during the early test stage and watching the EGT very carefully, other than just plain listening with your ear without any augmentation, is the only way to identify detonation. The good thing is, most engines will live with a fairly high level of detonation for some period of time. It is not an instantaneous type failure.

PRE-IGNITION

The definition of pre-ignition is the ignition of the fuel/air charge prior to the spark plug firing. Pre-ignition caused by some other ignition source such as an overheated spark plug tip, carbon deposits in the combustion chamber and, rarely, a burned exhaust valve; all act as a glow plug to ignite the charge.

Keep in mind the following sequence when analyzing pre-ignition. The charge enters the combustion chamber as the piston reaches BDC for intake; the piston next reverses direction and starts to compress the charge. Since the spark voltage requirements to light the charge increase in proportion with the amount of charge compression; almost anything can ignite the proper fuel/air mixture at BDC!! BDC or before is the easiest time to light that mixture. It becomes progressively more difficult as the pressure starts to build.

A glowing spot somewhere in the chamber is the most likely point for pre-ignition to occur. It is very conceivable that if you have something glowing, like a spark plug tip or a carbon ember, it could ignite the charge while the piston is very early in the compression stoke. The result is understandable; for the entire compression stroke, or a great portion of it, the engine is trying to compress a hot mass of expanded gas. That obviously puts tremendous load on the engine and adds tremendous heat into its parts. Substantial damage occurs very quickly. You can't hear it because there is no rapid pressure rise. This all occurs well before the spark plug fires.

Remember, the spark plug ignites the mixture and a sharp pressure spike occurs after that, when the detonation occurs. That's what you hear. With pre-ignition, the ignition of the charge happens far ahead of the spark plug firing, in my example, very, very far ahead of it when the compression stroke just starts. There is no very rapid pressure spike like with detonation. Instead, it is a tremendous amount of pressure which is present for a very long dwell time, i.e., the entire compression stroke. That's what puts such large loads on the parts. There is no sharp pressure spike to resonate the block and the head to cause any noise. So you never hear it, the engine just blows up! That's why pre-ignition is so insidious. It is hardly detectable before it occurs. When it occurs you only know about it after the fact. It causes a catastrophic failure very quickly because the heat and pressures are so intense.

An engine can live with detonation occurring for considerable periods of time, relatively speaking. There are no engines that will live for any period of time when pre-ignition occurs. When people see broken ring lands they mistakenly blame it on pre-ignition and overlook the hammering from detonation that caused the problem. A hole in the middle of the piston, particularly a melt ed hole in the middle of a piston, is due to the extreme heat and pressure of pre-ignition.

Other signs of pre-ignition are melted spark plugs showing splattered, melted, fused looking porcelain. Many times a "pre-ignited plug" will melt away the ground electrode. What's left will look all spattered and fuzzy looking. The center electrode will be melted and gone and its porcelain will be spattered and melted. This is a typical sign of incipient pre-ignition.

The plug may be getting hot, melting and "getting ready" to act as a pre-ignition source. The plug can actually melt without pre-ignition occurring. However, the melted plug can cause pre-ignition the next time around.

Thetypical pre-ignition indicator, of course, would be the hole in the piston. This occurs because in trying to compress the already burned mixture the parts soak up a tremendous amount of heat very quickly. The only ones that survive are the ones that have a high thermal inertia, like the cylinder head or cylinder wall. The piston, being aluminum, has a low thermal inertia (aluminum soaks up the heat very rapidly). The crown of the piston is relatively thin, it gets very hot, it can't reject the heat, it has tremendous pressure loads against it and the result is a hole in the middle of the piston where it is weakest.

I want to emphasis that when most people think of pre-ignition they generally accept the fact that the charge was ignited before the spark plug fires. However, I believe they limit their thinking to 5-10 degrees before the spark plug fires. You have to really accept that the most likely point for pre-ignition to occur is 180 degrees BTDC, some 160 degrees before the spark plug would have fired because that's the point (if there is a glowing ember in the chamber) when it's most likely to be ignited. We are talking some 160-180 degrees of bum being compressed that would normally be relatively cool. A piston will only take a few revolutions of that distress before it fails. As for detonation, it can get hammered on for seconds, minutes, or hours depending on the output of the engine and the load, before any damage occurs. Pre-ignition damage is almost instantaneous.

When the piston crown temperature rises rapidly it never has time to get to the skirt and expand and cause it to scuff. It just melts the center right out of the piston. That's the biggest difference between detonation and pre-ignition when looking at piston failures. Without a high pressure spike to resonate the chamber and block, you would never hear pre-ignition. The only sign of pre-ignition is white smoke pouring out the tailpipe and the engine quits running.

The engine will not run more than a few seconds with pre-ignition. The only way to control pre-ignition is just keep any pre-ignition sources at bay. Spark plugs should be carefully matched to the recommended heat range. Racers use cold spark plugs and relatively rich mixtures. Spark plug heat range is also affected by coolant temperatures. A marginal heat range plug can induce pre-ignition because of an overheated head (high coolant temperature or inadequate flow). Also, a loose plug can't reject sufficient heat through its seat. A marginal heat range plug running lean (suddenly?) can cause pre-ignition.

Passenger car engine designers face a dilemma. Spark plugs must cold start at -40 degrees F. (which calls for hot plugs that resist fouling) yet be capable of extended WOT operation (which calls for cold plugs and maximum heat transfer to the cylinder head).

Here is how spark plug effectiveness or "pre-ignition" testing is done at WOT. Plug tip/gap temperature is measured with a blocking diode and a small battery supplying current through a milliamp meter to the spark plug terminal. The secondary voltage cannot come backwards up the wire because the large blocking diode prevents it.

As the spark plug tip heats up, it tends to ionize the gap and small levels of current will flow from the battery as indicated by the milliamp gauge. The engine is run under load and the gauges are closely watched. Through experience techni-cians learn what to expect from the gauges. Typically, very light activity, just a few milliamps of current, is observed across the spark plug gap. In instances where the spark plug tip/gap gets hot enough to act as an ignition source the mil-liamp current flow suddenly jumps off scale. When that hap-pens, instant power reduction is necessary to avoid major en-gine damage.

Back in the 80s, running engines that made half a horsepower per cubic inch, we could artificially and safely induce pre-ignition by using too hot of a plug and leaning out the mixture. We could determine how close we were by watching the gauges and had plenty of time (seconds) to power down, before any damage occurred.

With the Northstar making over 1 HP per cubic inch, at 6000 RPM, if the needles move from nominal, you just failed the engine. It's that quick! When you disassemble the engine, you'll find definite evidence of damage. It might be just melted spark plugs. But pre-ignition happens that quick in high output engines. There is very little time to react.

If cold starts and plug fouling are not a major worry run very cold spark plugs. A typical case of very cold plug application is a NASCAR type engine. Because the prime pre-ignition source is eliminated engine tuners can lean out the mixture (some) for maximum fuel economy and add a lot of spark advance for power and even risk some levels of detonation. Those plugs are terrible for cold starting and emissions and they would foul up while you were idling around town but for running at full throttle at 8000 RPM, they function fine. They eliminate a variable that could induce pre-ignition.

Engine developers run very cold spark plugs to avoid the risk of getting into pre-ignition during engine mapping of air/fuel and spark advance, Production engine calibration requires that we have much hotter spark plugs for cold startability and fouling resistance. To avoid pre-ignition we then compensate by making sure the fuel/air calibration is rich enough to keep the spark plugs cool at high loads and at high temperatures, so that they don't induce pre-ignition.

Consider the Northstar engine. If you do a full throttle 0-60 blast, the engine will likely run up to 6000 RPM at a 11.5:1 or 12:1 air fuel ratio. But under sustained load, at about 20 seconds, that air fuel ratio is richened up by the PCM to about 10:1. That is done to keep the spark plugs cool, as well as the piston crowns cool. That richness is necessary if you are running under continuous WOT load. A slight penalty in horsepower and fuel economy is the result. To get the maximum acceleration out of the engine, you can actually lean it out, but under full load, it has to go back to rich. Higher specific output engines are much more sensitive to pre-ignition damage because they are turning more RPM, they are generating a lot more heat and they are burning more fuel. Plugs have a tendency to get hot at that high specific output and reaction time to damage is minimal.

A carburetor set up for a drag racer would never work on a NASCAR or stock car engine because it would overheat and cause pre-ignition. But on the drag strip for 8 or 10 seconds, pre-ignition never has time to occur, so dragsters can get away with it. Differences in tuning for those two different types of engine applications are dramatic. That's why a drag race engine would make a poor choice for an aircraft engine.

MUDDY WATER

There is a situation called detonation induced pre-ignition. I don't want to sound like double speak here but it does happen. Imagine an engine under heavy load starting to detonate. Detonation continues for a long period of time. The plug heats up because the pressure spikes break down the protective boundary layer of gas surrounding the electrodes. The plug temperature suddenly starts to elevate unnaturally, to the point when it becomes a glow plug and induces pre-ignition. When the engine fails, I categorize that result as "detonation induced pre-ignition." There would not have been any danger of pre-ignition if the detonation had not occurred. Damage attributed to both detonation and pre-ignition would be evident.

Typically, that is what we see in passenger car engines. The engines will typically live for long periods of time under detonation. In fact, we actually run a lot of piston tests where we run the engine at the torque peak, induce moderate levels of detonation deliberately. Based on our resulting production design, the piston should pass those tests without any problem; the pistons should be robust enough to survive. If, however, under circumstances due to overheating or poor fuel, the spark plug tip overheats and induces pre-ignition, it's obviously not going to survive. If we see a failure, it probably is a detonation induced pre-ignition situation.

I would urge any experimenter to be cautious using automotive based engines in other applications. In general, engines producing .5 HP/in3 (typical air-cooled aircraft engines) can be forgiving (as leaning to peak EGT, etc.). But at 1.0 HP/in3 (very typical of many high performance automotive conversions) the window for calibration induced engine damage is much less forgiving. Start out rich, retarded and with cold plugs and watch the EGTs!

Hopefully this discussion will serve as a thought starter. I welcome any communication on this subject. Every application is unique so beware of blanket statements as many variables affect these processes.

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Main page

Return to the Back Issue page