3.1 Detonation & Pre-Ignition Theory

Before reading this page, make sure that you have read the combustion dynamics page first.

Detonation

I have already explained what takes place within a combustion chamber where the gas burns at a uniform rate. Now lets see what happens when things go wrong.

There are three forms of abnormal combustion.

1. Detonation
2. Pre-Ignition
3. Detonation of fuel before Ignition or (Pre-Ignition due to Detonation).

The picture below shows examples of microscopic melting increasing to physical chunks of the piston breaking away at the wrist pin. The pits are molten melting of the aluminum piston when the shock waves scrub the protective boundary layer away from the metal parts. Notice that the most severe damage occurs at the edge of the piston where the shock waves reflect back.

As you may recall, increased fuel octane will increase the temperature required for spontaneous combustion of the gas. But any gas will spontaneously ignite at some given temperature. If the pressures and resulting heat generated by the combustion chamber reaches that spontaneous combustion temperature of the gas, havoc breaks loose within the combustion chamber, and the above picture shows the results.

With normal burn rates. The linear expansion of pressures are handled by the engine parts. This is because the energy expended by the burn is extended over a lengthy period of time (tens of crankshaft degrees). Detonation expends this energy all at once which creates a spiked compression pressure rise. This spiked pressure rise hammers against the piston top and combustion chamber walls, and makes that metallic hammer sound, sometimes referred to as a ping or rattle. Some forms of detonation make very little noise yet cause very great damage. This sudden release of energy has several down sides.

First, it places severe stress on the engine parts,

Second it rapidly expends the burn energy of the gas so none is left for the rest of the power stroke, with most of the energy being spent as heat.

Third this sudden release of gas energy heat (and little or no work) must now be absorbed by the engine cooling system.

Fourth, it causes shock waves that will rip the gas boundary layer from the metal, which allows full combustion temperature, 3000 to 5000F degrees, to come in direct contact with the metal engine parts. This metal exposure to the burn temperatures starts out as microscopic melting of metals such as pistons and spark plug electrodes, but when left unchecked can result in actual burning through of piston tops and cylinder heads. Even when the temperature rise doesn't melt engine parts it can break parts, Also this increased heat is added to the cooling system and may well exceed its capacity and blow out coolant. When the cooling system blows out coolant, the remaining low coolant is unable to remove the engine heat and the over temperature cycle continues. As the engine head temperature rises, the combustion temperature also rises because the quenching effect is reduced. This snowball effect results in more detonation and leads to major engine failure, if not detected and stopped.

Fifth, when the shock waves reach the chamber boundaries, the reflected shock waves are additive at that point and tend to break parts such as piston ring lands. (See illustration below). When two boats pass each other in opposite directions, their wakes cross and become additive into a larger wake. The same thing happens within the combustion chamber edges, when reflected shock waves cross and become additive, and the resultant pressure wave spike goes way up and starts breaking things at the edges of the combustion chamber.

3.1.1 Potential for detonation can be reduced by:

- Reducing the temperature of intake air. This can be done many ways.

1. Thermal management (Barriers & Dispersants on Intake and Exhaust manifold).
2. Thermal management (Barriers & Dispersants on Pistons & Combustion Chamber).
3. Inner coolers on Turbo applications or cold air induction).

- Increasing chamber surface to volume ratio (Reduce Compression).
- Increasing quench area to cool the gas (Piston to head .040 in.).
- Richer fuel mixture due to cooling effect
- Higher Octane gas
- Improving homogeny of gas, faster burn time
- Using fuel that burns faster (Racing Gas).
- Optimum spark plug location
- Increased coolant system efficiency
- Retarded ignition advance
- Methanol Injection
- “NOTE” Some of these changes can improve performance but some will reduce performance. **Thermal Management will only improve performance.**

3.1.2 Pre-Ignition

Pre-ignition has a simple definition, something ignited the fuel before the spark plug. Pre-ignition is caused by abnormal hot spots within the combustion chamber. Any kind of deposit on the piston crown or the cylinder head may get hot enough to glow and ignite the gas. Any sharp metal edge in the chamber will also glow and pre-ignite the gas. Make sure there are no sharp edges in the combustion chamber before assembly. Pre-Ignition will many times result in detonation This pre-ignition is undesirable for several reasons.

First and foremost, the burn cycle starts early. This is the same as advancing the MBT ignition point which will advance the PCP sooner than 16 degrees ATDC. This results in less power produced by the power stroke, and more heat forced into the cooling system.

Secondly, since the burn started sooner, the pressures before TDC will be greater, resulting in reduced pumping efficiency of the engine.

Third, the heating effects of the gas will be increased due to the steeper pressure rise before TDC, and this may result in spontaneous combustion which is detonation.

Fourth, since the peak cylinder pressure (PCP) is no longer at 16 degrees ATDC, the piston is not expending much twisting torque action to rotate the crankshaft. Instead it is just pushing nearly straight down with little twisting torque action.

Fifth, If PCP occurs BTDC. The piston will try to reverse the engine rotation. This is like putting a brake on the piston. A shock wave can be felt through out the vehicle.

3.1.3 Detonation of fuel before Ignition or (Pre-Ignition due to Detonation).

This is the most destructive force an engine can endure, Pre-ignition due to detonation. Lets get a true understanding of what takes place.

Your engine is at 5000 RPM. Detonation occurs before Ignition. The engine is rotating clockwise and the piston tries to turn the engine counter clockwise. Life expectancy of an engine with this problem is measured in milliseconds. The piston stops but the crank keeps rotating. Something just broke and it's your wallet.

Although the severity of this form of detonation may be rare, It's becoming more of a problem with the hybrid Rice Rockets and Street Machines. Racing fuels are expensive and not readily available at all gas stations. So the best fuels available are premium grades, 92, 95 octane. **They are not racing fuel**. Premium pump fuels do not have the octane rating nor the burn rate to adequately operate these engines under maximum load. Again lets get a true understanding of what takes place.

1. Lets use a generic 2 liter engine.
2. Turbo charged it with 30 Lbs. Boost.
3. Nitrous 150 HP Shot.
4. 92 octane pump gas.

We're Racing at max. rpm, full boost and nitrous. Combustion chamber temperatures rise at an exponential rate. The compression stroke increase the fuel charge temperature and the first form of detonation begins. Detonation starts backing down the degrees of the engine rotation. The fuel charge temperatures are now so hot, that any compression of the fuel takes it over it's ignition point. In a blink of your eye Detonation forms before ignition. The results are self explanatory.

Thermal Management Coatings are not a cure-all. But can significantly reduce the causes of detonation and pre-ignition.

1. Cool incoming air fuel mixtures,
2. Reducing hot spots by distribution of heat more evenly.
3. Increase coolant system efficiently etc.
4. Retaining minimal heat on the surfaces of pistons so less heat is transferred to the fuel charge.
5. Allowing more efficient combustion.

There's **NO** Coating or performance part manufactured that will fix neglector, or carelessness. It's your responsibility to keep a close eye on tuning, fuel mixture, engine temperature or noises. Keep good records of everything you do to the vehicle. It takes just one major mishap and your racing season is over.

JCM Machine has been involved in every form of racing imaginable. Cars, Motorcycles, go carts, tractors etc. We've raced our own, and sponsored many. Our Motto is simple. If the car the driver or the engine is not right. **WE'RE NOT RACING**. Put it on the trailer and race another day when everything is right. Safety should always be your first concern. "**Its Beer and Pizza Time"**

I hope this article has helped you understand the differences between normal and abnormal combustion.

Charles Borrini
Owner of JCM