Engine knocking

“Pinging” redirects here. For other uses, see Ping (disambiguation).

Knocking (also **knock**, **detonation**, **spark knock**, **pinging** or **pinking**) in spark-ignition internal combustion engines occurs when combustion of the air/fuel mixture in the cylinder does not start off correctly in response to ignition by the spark plug, but one or more pockets of air/fuel mixture explode outside the envelope of the normal combustion front.

The fuel-air charge is meant to be ignited by the spark plug only, and at a precise point in the piston’s stroke. Knock occurs when the peak of the combustion process no longer occurs at the optimum moment for the four-stroke cycle. The shock wave creates the characteristic metallic “pinging” sound, and cylinder pressure increases dramatically. Effects of engine knocking range from inconsequential to completely destructive.

Knocking should not be confused with **pre-ignition** – they are two separate events. However, pre-ignition is usually followed by knocking.

The phenomenon of detonation was first observed and described by Harry Ricardo during experiments carried out between 1916 and 1919 to discover the reason for failures in aircraft engines.[1]

1 Normal combustion

Under ideal conditions the common internal combustion engine burns the fuel/air mixture in the cylinder in an orderly and controlled fashion. The combustion is started by the spark plug some 10 to 40 crankshaft degrees prior to top dead center (TDC), depending on many factors including engine speed and load. This ignition advance allows time for the combustion process to develop peak pressure at the ideal time for maximum recovery of work from the expanding gases.[2]

The spark across the spark plug’s electrodes forms a small kernel of flame approximately the size of the spark plug gap. As it grows in size, its heat output increases, which allows it to grow at an accelerating rate, expanding rapidly through the combustion chamber. This growth is due to the travel of the flame front through the combustible fuel air mix itself, and due to turbulence which rapidly stretches the burning zone into a complex of fingers of burning gas that have a much greater surface area than a simple spherical ball of flame would have. In normal combustion, this flame front moves throughout the fuel/air mixture at a rate characteristic for the particular mixture. Pressure rises smoothly to a peak, as nearly all the available fuel is consumed, then pressure falls as the piston descends. Maximum cylinder pressure is achieved a few crankshaft degrees after the piston passes TDC, so that the force applied on the piston (from the increasing pressure applied to the top surface of the piston) can give its hardest push precisely when the piston’s speed and mechanical advantage on the crank shaft gives the best recovery of force from the expanding gases, thus maximizing torque transferred to the crank shaft.[2][3]

2 Abnormal combustion

Main article: cool flame

When unburned fuel/air mixture beyond the boundary of the flame front is subjected to a combination of heat and pressure for a certain duration (beyond the delay period of the fuel used), detonation may occur. Detonation is characterized by an instantaneous, explosive ignition of at least one pocket of fuel/air mixture outside of the flame front. A local shockwave is created around each pocket and the cylinder pressure may rise sharply beyond its design limits.

If detonation is allowed to persist under extreme conditions or over many engine cycles, engine parts can be damaged or destroyed. The simplest deleterious effects are typically particle wear caused by moderate knocking, which may further ensue through the engine’s oil system and cause wear on other parts before being trapped by the oil filter. Severe knocking can lead to catastrophic failure in the form of physical holes punched through the piston or cylinder head (i.e., rupture of the combustion chamber), either of which depressurizes the affected cylinder and introduces large metal fragments, fuel, and combustion products into the oil system. Hypereutectic pistons are known to break easily from such shock waves.[3]

Detonation can be prevented by any or all of the following techniques:

- the use of a fuel with high octane rating, which increases the combustion temperature of the fuel and reduces the proclivity to detonate
- enriching the air–fuel ratio which alters the chemical reactions during combustion, reduces the com-

bustion temperature and increases the margin above detonation

- reducing peak cylinder pressure
- decreasing the manifold pressure by reducing the throttle opening or boost pressure
- reducing the load on the engine
- retarding (reduce) ignition timing

Because pressure and temperature are strongly linked, knock can also be attenuated by controlling peak combustion chamber temperatures by compression ratio reduction, exhaust gas recirculation, appropriate calibration of the engine's ignition timing schedule, and careful design of the engine's combustion chambers and cooling system as well as controlling the initial air intake temperature.

The addition of certain materials such as lead and thallium will suppress detonation extremely well when certain fuels are used. The addition of tetraethyllead (TEL), a soluble organolead compound added to gasoline was common until it was discontinued for reasons of toxic pollution. Lead dust added to the intake charge will also reduce knock with various hydrocarbon fuels. Manganese compounds are also used to reduce knock with petrol fuel.

Knock is less common in cold climates. As an aftermarket solution, a water injection system can be employed to reduce combustion chamber peak temperatures and thus suppress detonation. Steam (water vapour) will suppress knock even though no added cooling is supplied.

Certain chemical changes must first occur for knock to happen, hence fuels with certain structures tend to knock easier than others. Branched chain paraffins tend to resist knock while straight chain paraffins knock easily. It has been theorized that lead, steam, and the like interfere with some of the various oxidative changes that occur during combustion and hence the reduction in knock.

Turbulence, as stated, has very important effect on knock. Engines with good turbulence tend to knock less than engines with poor turbulence. Turbulence occurs not only while the engine is inhaling but also when the mixture is compressed and burned. During compression/expansion "squish" turbulence is used to violently mix the air/fuel together as it is ignited and burned which reduces knock greatly by speeding up burning and cooling the unburnt mixture. One example of this is all modern side valve or flathead engines. A considerable portion of the head space is made to come in close proximity of the piston crown, making for much turbulence near TDC. In the early days of side valve heads this was not done and a much lower compression ratio had to be used for any given fuel. Also such engines were sensitive to ignition advance and had less power.[3]

Knocking is more or less unavoidable in diesel engines, where fuel is injected into highly compressed air towards the end of the compression stroke. There is a short lag between the fuel being injected and combustion starting. By this time there is already a quantity of fuel in the combustion chamber which will ignite first in areas of greater oxygen density prior to the combustion of the complete charge. This sudden increase in pressure and temperature causes the distinctive diesel 'knock' or 'clatter', some of which must be allowed for in the engine design.

Careful design of the injector pump, fuel injector, combustion chamber, piston crown and cylinder head can reduce knocking greatly, and modern engines using electronic common rail injection have very low levels of knock. Engines using indirect injection generally have lower levels of knock than direct injection engine, due to the greater dispersal of oxygen in the combustion chamber and lower injection pressures providing a more complete mixing of fuel and air. Diesels actually do not suffer exactly the same "knock" as gasoline engines since the cause is known to be only the very fast rate of pressure rise, not unstable combustion. Diesel fuels are actually very prone to knock in gasoline engines but in the diesel engine there is no time for knock to occur because the fuel is only oxidized during the expansion cycle. In the gasoline engine the fuel is slowly oxidizing all the time while it is being compressed before the spark. This allows for changes to occur in the structure/makeup of the molecules before the very critical period of high temp/pressure.[3]

An unconventional engine that makes use of detonation to improve efficiency and decrease pollutants is the Bourke engine.

3 Pre-ignition

Pre-ignition (or **preignition**) in a spark-ignition engine is a technically different phenomenon from engine knocking, and describes the event wherein the air/fuel mixture in the cylinder ignites before the spark plug fires. Pre-ignition is initiated by an ignition source other than the spark, such as hot spots in the combustion chamber, a spark plug that runs too hot for the application, or carbonaceous deposits in the combustion chamber heated to incandescence by previous engine combustion events.

The phenomenon is also referred to as 'after-run', or 'run-on' or sometimes dieseling, when it causes the engine to carry on running after the ignition is shut off. This effect is more readily achieved on carbureted gasoline engines, because the fuel supply to the carburetor is typically regulated by a passive mechanical float valve and fuel delivery can feasibly continue until fuel line pressure has been relieved, provided the fuel can be somehow drawn past the throttle plate. The occurrence is rare in modern engines with throttle-body or electronic fuel injection, because the injectors will not be permitted to continue delivering fuel after the engine is shut off, and any occurrence may indicate the presence of a leaking (failed) injector.[4]

In the case of highly supercharged or high compression multi-cylinder engines, particularly ones that use methanol (or other fuels prone to pre-ignition), pre-ignition can quickly melt or burn pistons since the power generated by other still functioning pistons will force the overheated ones along no matter how early the mix pre-ignites. Many engines have suffered such failure where improper fuel delivery is present. Often one injector may clog while the others carry on normally allowing mild detonation in one cylinder that leads to serious detonation, then pre-ignition.[5]

The challenges associated with pre-ignition have increased in recent years with the development of highly boosted and “downspeeded” spark ignition engines. The reduced engine speeds allow more time for autoignition chemistry to complete thus promoting the possibility of pre-ignition and so called “mega-knock”. Under these circumstances, there is still significant debate as to the sources of the pre-ignition event.[6]

Pre-ignition and engine knock both sharply increase combustion chamber temperatures. Consequently, either effect increases the likelihood of the other effect occurring, and both can produce similar effects from the operator’s perspective, such as rough engine operation or loss of performance due to operational intervention by a powertrain-management computer. For reasons like these, a person not familiarized with the distinction might describe one by the name of the other. Given proper combustion chamber design, pre-ignition can generally be eliminated by proper spark plug selection, proper fuel/air mixture adjustment, and periodic cleaning of the combustion chambers.[2]

4 Causes of pre-ignition

Causes of pre-ignition include the following:[4]

- Carbon deposits form a heat barrier and can be a contributing factor to pre-ignition. Other causes include: An overheated spark plug (too hot a heat range for the application). Glowing carbon deposits on a hot exhaust valve (which may mean the valve is running too hot because of poor seating, a weak valve spring or insufficient valve lash)
- A sharp edge in the combustion chamber or on top of a piston (rounding sharp edges with a grinder can eliminate this cause)
- Sharp edges on valves that were reground improperly (not enough margin left on the edges)
- A lean fuel mixture
- An engine that is running hotter than normal due to a cooling system problem (low coolant level, slipping fan clutch, inoperative electric cooling fan or other cooling system problem)
- Auto-ignition of engine oil droplets[6]
- Insufficient oil in the engine

5 Detonation induced pre-ignition

Because of the way detonation breaks down the boundary layer of protective gas surrounding components in the cylinder, such as the spark plug electrode, these components can start to get very hot over sustained periods of detonation and glow. Eventually this can lead to the far more catastrophic pre-Ignition as described above.

While it is not uncommon for an automobile engine to continue on for thousands of kilometers with mild detonation, pre-ignition can destroy an engine in just a few strokes of the piston.

6 Knock detection

Due to the large variation in fuel quality, a large number of engines now contain mechanisms to detect knocking and adjust timing or boost pressure accordingly in order to offer improved performance on high octane fuels while reducing the risk of engine damage caused by knock while running on low octane fuels.

An early example of this is in turbo charged Saab H engines, where a system called Automatic Performance Control was used to reduce boost pressure if it caused the engine to knock.[7]

Various monitoring devices are commonly utilized by tuners as a method of seeing and listening to the engine in order to ascertain if a tuned vehicle is safe under load or used to re-tune a vehicle safely.

7 Knock prediction

Since the avoidance of knocking combustion is so important to development engineers, a variety of simulation technologies have been developed which can identify engine design or operating conditions in which knock might be expected to occur. This then enables engineers to design ways to mitigate knocking combustion whilst maintaining a high thermal efficiency.

Since the onset of knock is sensitive to the in-cylinder pressure, temperature and autoignition chemistry associated with the local mixture compositions within the combustion chamber, simulations which account for all of these aspects [8] have thus proven most effective in determining knock operating limits and enabling engineers to determine the most appropriate operating strategy

8 References

[1] https://www.flightglobal.com/pdfarchive/view/1951/1951%20-%202155.html

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[6] "solutions for pre-ignition ("mega-knock"), misfire, extinction, flame propagation and conventional "knock" (PDF). cmcl innovations, UK. Retrieved 12 June 2010.

[7] "Turbocharger with a brain". *Popular Science* **221** (1): 85. July 1982.

[8] "Advanced simulation technologies". cmcl innovations, UK. Retrieved 12 June 2010.

9 Further reading

- *Modeling of in-cylinder pressure oscillations under knocking conditions: A general approach based on the damped wave equation*, FUEL Journal, DOI:10.1016/j.fuel.2012.07.066, ISSN 0016-2361, Feb., 2013.

- *Experimental Evaluation of Reduced Kinetic Models for the Simulation of Knock in SI Engines*, SAE Technical Paper n. 2011-24-0033, DOI: 10.4271/2011-24-0033, ISSN 0148-7191, Sep., 2011.

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- Charles Fayette Taylor, *Internal Combustion Engine In Theory And Practice, Second Edition, Revised, Volume 2*, MIT Press, 1985, Chapter 2 on "Detonation and Preignition", pp 34–85, ISBN 9780262700276.

10 External links

- Pre-ignition and Detonation by Bob Hewitt (Misterfixit) Accessed June 2007
- NACA - Combustion and knock in a spark-ignition engine
- NACA - Ionization in the knock zone of an internal combustion engine
- NACA - Interdependence of various types of autoignition and knock
- Avweb - Detonation myths
- Misterfixit - What is detonation?
- Gasoline FAQ

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