Chapter 5.

Combustion Maladies and Fuel Qualities.

Knock, Detonation, Pre-ignition, Pinking, etc.

Traditionally 'knock' means 'detonation' a condition in which the rising pressure and temperature from the burning part of the charge causes an unburnt (or partially burnt) portion to explode spontaneously (like the firing of a gun). The effect on power output is usually hardly measurable and although it does create localised thermal stress the effect on the overall heat balance is negligible.

Detonation.

In normal operation there is always a very thin layer of air (or fuel / air mixture) attached to the internal surfaces rather like the stationary boundary layer of air on the surface of an aircraft wing. Because air has poor thermal conductivity this layer has a quite profound effect as a barrier protecting the surfaces from the full heat of combustion. The shock wave created by detonation disturbs this layer and so more heat is introduced locally into the surface. It does not necessarily become a problem unless this extra heat input exceeds the ability of the structure to dissipate it to coolant. Obviously high speed detonation is therefore a much greater threat than anything that happens at low engine speeds. Unfortunately high speed 'knock' is rather less easy to detect from amongst the general mechanical noise emanating from the rest of the engine, which makes accurate audible assessment difficult.

The time spent by the piston around the top of its stroke (TDC) is a factor and with rising speed the faster movement of the piston away from TDC makes detonation less likely, but if it does occur at high speeds the situation is more threatening. The more prolonged piston dwell at low speeds coinciding with the 'knee' of the normal ignition advance curve can easily promote audible knock to cause what is often referred to as 'pinking', which is generally more annoying than harmful.

Obviously because pressure is an important factor, detonation has long been associated mainly with full throttle operation but the widespread use of feedback controlled, stoichiometric, part throttle fueling, combined with advanced ignition timing for economy, have brought it to prominence as a problem in high speed cruise situations at around 75 - 90% engine load. Whilst there are circumstances when detonation can occur at lighter loads the reduced thermal stresses and pressures generally prevent it from becoming a serious threat.

Fig. 5.1 Piston damaged by detonation.

Of course, it does not follow that the moment an engine starts to suffer detonation it is imminently close to piston failure. Many engines can tolerate moderate detonation for some considerable time and sometimes indefinitely. However there are no guarantees and sooner or later an engine that is regularly exposed to the condition is likely to suffer damage which may range from characteristic delicate nibbling of the head or piston crown, usually at a point distant from the spark plug, to total and catastrophic failure in the form of a melted or holed piston (Fig. 5.1). The turning point is likely to be when another combustion disorder, which we will meet next, starts to occur as a result of the raised local temperatures created by detonation, but it is hard to predict exactly when or if this might happen.

The octane rating of the fuel is an important factor which influences the onset of the process of detonation. It is a topic that will be returned to a little further on.

Pre-ignition – a Serious Threat.

‘Pre-ignition’ is when some phenomenon, typically a localised hot spot, ignites the charge before the spark has fired, so it is rather akin to having over-advanced ignition timing. In mild form it can give rise to engine roughness sometimes known as ‘rumble’. As it gets more serious the consequent early ignition causes negative work on the rising piston so power falls and more heat is released into the engine structure causing the condition to worsen. The spark plug electrodes can provoke pre-ignition if the heat range of the plug is wrong or if ignition timing is over advanced, sometimes resulting in a holed piston. A single cylinder engine might display such loss of power that it could even be brought to a halt by backfires into the induction port. On the other hand a multi-cylinder engine might only have one cylinder in trouble, being driven on by the others, so the driver may continue in blissful ignorance – until a thick smoke trail behind provides graphic evidence of the damage that has been done.

An important variant is ‘deposit induced pre-ignition’, sometimes known as ‘wild ping’, which became apparent in high compression ‘muscle V8s’ in the USA in the 1960s, but which was also sometimes displayed by the Jaguar HE V12, which for the European market had an exceptionally high compression ratio of 12.5:1. The condition is associated with high compression ratios and is caused by soft carbonaceous deposits laid down in prolonged light load operation, which become incandescent when suddenly exposed to high loads. This is a condition that is more likely to afflict large engines because small engines tend to be driven harder and generally avoid having the same type of soft deposits. Fortunately the deposits usually burn off before damage is done but the condition does place a limit on compression ratio other than that imposed by detonation. In the HE V12 the condition manifested itself (without harm, it might be added) when opened up after a spell of urban driving, creating ‘rattle’ and visible pale blue exhaust smoke for a couple of seconds at around 4000 revs. Fuel octane rating is not a factor in pre-ignition although other qualities of the fuel can be, but not in a pattern that is easy to follow as we shall see later. However, combustion chamber deposits can also provoke detonation which may then act as a precursor to pre-ignition. Primarily the effect then is not from increased compression ratio, although this does have some influence, but from the thermal barrier raising combustion temperatures (this, of course, is one reason why ceramic heat barrier coatings are not always as desirable as some might think).There can also be a minor catalysing effect by deposited compounds stimulating the reactions that precede detonation.

The increased local temperatures created by detonation can promote pre-ignition which in turn can promote detonation as the two almost feed off each other. Either phenomenon can add further heat to the initiating source so the condition can escalate and become extremely unstable, developing into ‘runaway surface ignition’, which can wreck a piston very rapidly and without prior warning.

There have been instances of such a problem arising in production which had not been encountered even during the most arduous factory testing – Jaguar’s unlamented 2.8 XJ6 of the late 1960s being a classic example. Pre-ignition was the culprit on that occasion, probably initiated by an unfortunate conjunction of these factors: a humped piston crown to achieve the required compression ratio; the stroke and connecting rod geometry; light load deposit build-up in a critical area. A hard driven car would not have the essential deposit build up, whereas a lightly driven car would have, but would not be running in the condition that could cause trouble. The car that was lightly driven for some time then suddenly driven hard would be the one to find itself at risk.

Events of that nature force manufacturers to indulge in extensive proving trials to ensure that, whilst their products are close to the limit, in the continual pursuit of better performance and economy, they do not step beyond the bounds of safety.

OCTANES, RON, MON, etc.

The octane number of a fuel is an indication of its resistance to 'knock'. In the UK the octane number quoted is the RON (Research Octane Number) but in other parts of the world the MON (Motor Octane Number) is quoted. Devised in 1926 by Graham Edgar the octane scale uses the paraffin n-heptane as the standard for 0 and iso-octane as the 100 standard. The octane rating of a fuel is determined from the blend of n-heptane and iso-octane which provides equal knock properties on test.

The test procedures are long established and in essence RON relates to low speed knock, which is generally audible, whereas MON relates to high speed knock, generally inaudible and potentially the much more dangerous condition. Whilst by no means definitive, RON and MON provide a reasonable guide to the anti-knock quality of a fuel. Note that the octane rating of a fuel has no direct association with either its flame speed or its calorific value, nor does it relate to any tendency to pre-ignite.

UK fuels are rated as follows:-

Premium unleaded = 95 RON / 85 MON
LRP & 4 star leaded = 97 RON / 86 MON
Super unleaded = 98 RON / 87 MON
BP Ultimate = 97 RON / 86 (estimated) MON
Shell V Power = 99 RON / 87-88 (estimated) MON
BP Ultimate 102 = 102 RON / 90 MON

The difference between RON and MON is termed the sensitivity. A higher sensitivity number indicates a fuel with resistance to low speed knock but more disposed to harmful high speed knock. However, in conforming to the MON figure it is not unknown for the RON number of a fuel to be well above specification so it is not safe to conclude that a fuel is suitable for an engine just because it gives no audible knock.

In the USA the term Anti Knock Index (AKI), also sometimes called 'pump octane' or 'road octane', is widely used but is nothing more than the average of RON and MON, i.e. R + M / 2, but of course the sensitivity is no longer discernible.

By the late 1930s aviation fuels had reached 100 octane so some means had to be found to rate fuels with even greater resistance to knock. The method devised was somewhat surprising but there was some logic to it. These higher rated fuels were given a Performance Number (PN) according to the knock free power increase the fuel would allow by increasing boost applied to the engine. Hence a fuel rated 120 PN would be suitable for a 20% power increase compared to 100 RON iso-octane fuel. Two numbers were quoted, the first being the rating at lean economy setting, the second being at rich combat setting, so a typical WW2 high performance aviation fuel would have been classed as 115/145 PN.

Ignition Timing.

It is impossible to consider the subject of detonation without taking account of the effects of ignition timing because of its significance in combination with the use of high compression ratios in pursuit of better part throttle economy.

Of course modern engines now have programmed ignition advance which can allow an engine to be designed to run closer to the detonation limit than used to be possible with mechanical methods. Consequently the simplicity of relying on a centrifugal mechanism to govern speed advance and another mechanism operated by a vacuum servo to deal with changing load has given way to much more sophistication in order to keep the engine safe in all operating conditions.

The diagram (Fig. 5.2) shows (slightly exaggerated) how the amount of ignition advance that an engine can safely tolerate without detonation (1) varies from that which a conventional centrifugal ignition advance system (2) is capable of providing.

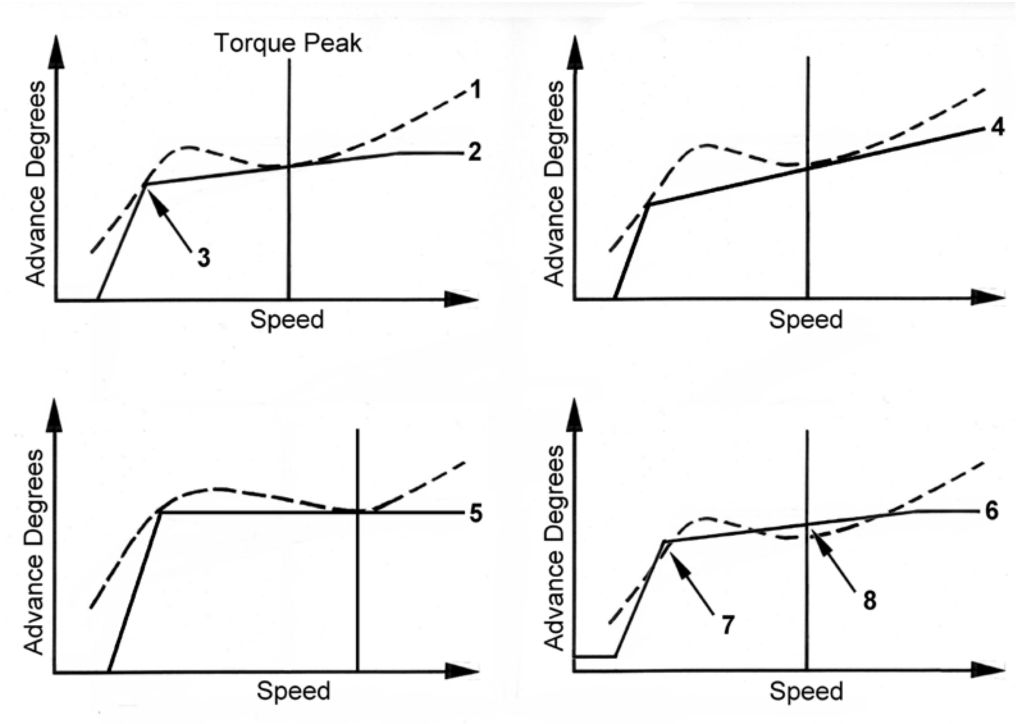

Fig. 5.2 Centrifugal advance curves.

The compromises will be obvious and clearly a centrifugal setup that gives more advance above peak torque speed (better for power) must mean less below. In effect the main advance slope can be considered as able to pivot around the maximum safe advance at the peak torque speed to bias the timing to favour either low speed or high speed operation, but not both.

The most critical areas are where the solid and dotted black lines meet - usually around 1800 - 2000 r.p.m. and again around the peak torque speed where cylinder pressures are highest. To be exact the point of maximum pressure will be slightly higher up the speed range than that for peak torque at the flywheel because of the effect of rising friction losses but peak torque is easier to identify and is near enough for practical purposes.

The lower speed coincides with the "knee point" (3) of the centrifugal advance curve and knock there is more of an annoyance than a threat because the engine can easily absorb the extra thermal stress. The situation around peak torque and beyond is where the engine can be in danger because the structure may not be able to dissipate the local heating that can be caused by detonation.

21 pages follow.