Manchester XPAG Tests

Part 8 - Solutions, Tuning Distributor

Introduction

In the previous article I suggested steps that could be taken to mitigate the *Slow Combustion* problem by choice of fuel and by tuning the carburettor to improve atomisation and dispersion of the petrol. In this article I discuss how the ignition timing can be adjusted to help reduce the excess heating of the cylinder head and exhaust system caused by the *Slow Combustion* problem. Ultimately, this helps to mitigate the problems caused by modern petrol as it starts to boil or evaporate at much lower temperatures than classic petrol.

The *Slow Combustion* problem is the result of a high degree of Cyclic Variability during the combustion cycle which causes a large spread of peak pressures some of which occur late in the cycle. Firstly, this article discusses Cyclic Variability in greater detail. Secondly, it discusses the distributor advance and the importance of having the correct centrifugal and vacuum advance curves to keep exhaust temperatures as low as possible.

I repeat my warnings. Remember that our cars are all different and the severity of the problems experienced by owners will vary immensely, even between the same models of car. Most importantly, the suggestions in these articles should be taken just as that, suggestions for people to try; they are not intended as solutions to be blindly adopted. Finally, running an engine with the incorrect ignition timing **CAN CAUSE DAMAGE**. If in doubt, get your car checked by a professional tuning expert.

Ignition Advance

During the Bang (or combustion) stroke of a spark ignition engine, such as the XPAG, the interactions between the petrol, petrol vapour, air and growing flame front are very complex.

After the spark plug fires, there are three broad phases. Firstly, a fireball of burning mixture about the size of a pin head is created. This fireball grows as the flame front moves outward at approximately 35cm/sec. This speed is critically dependent on two factors: firstly having the correct, or stoichiometric, mixture of air and petrol vapour around the spark plug and secondly the pressure of the gas in the cylinder.

The mixture around the spark plug is determined by how well the petrol was dispersed in the inducted air, the quantity of liquid petrol that evaporated during the compression stroke and how well the turbulence of the gases in the cylinder produced an even mix around the spark plug. Throttle setting rather than compression ratio is the main factor determining the pressure of the gases in the cylinder when the spark plug fires. This is discussed later in this article.

Once the fireball has grown to approximately the size of a pea, the second phase begins, when turbulence takes over and spreads these ignition points throughout the volume of the cylinder rapidly igniting the remaining mixture. The temperature and pressure of the gases quickly rise, reaching a peak when the majority of petrol has burnt. During the third phase, the high temperatures, around 1,000^{o}C, complete the combustion by vaporising and burning any hydrocarbons that remain.

As the piston is pushed down, the pressure and temperature of the gasses fall, reaching around 700^{o}C when the exhaust valve opens and they are vented from the cylinder.

Maximum power is produced when the peak pressure occurs about 17° after Top Dead Centre (TDC). On the timescales experienced in a running engine, the combustion process takes a very long time. For this reason, the spark plug must be fired before the piston reaches TDC to allow sufficient time for the second phase of the combustion process to complete by 17° after TDC. This is called Ignition Advance.

After the spark plug fires, the time taken for the pressure to reach its peak is virtually constant and independent of engine revs. For this reason, as the engine runs faster, the spark plug needs to be fired further before TDC to give sufficient time for the petrol to burn. To achieve this, the Ignition timing must be advanced as engine revs increase.

In a mechanical distributor the ignition advance is achieved by the bob weights situated underneath the baseplate. As the revs increase these weights fly outwards. The weaker spring at the top on the photograph should always be in tension. It allows the weights to fly out quickly at low revs. When the thicker springs with the looped ends (at the bottom) engages, the rate of advance is slowed. Finally when the weights hit their stops around 3000 rpm, there is no further advance. This creates a 3 step curve called, the Centrifugal Advance Curve. It is very important this mechanism is working properly otherwise the engine will be running with the incorrect amount of advance through the rev range.

Below 3,000 rpm, the time taken for the combustion process is virtually constant, the Centrifugal Advance Curve is almost a straight line increasing the advance as revs increase. Beyond 3,000 rpm, turbulence begins to take effect which reduces the need for additional advance. The advance curve flattens off.

Measuring your Centrifugal Advance Curve at home is relatively easy. All you need is an assistant and a timing light with an advance facility such as those found at https://www.google.co.uk/search?q=Advance+Timing+light. Early MGs have a notch in the crankshaft pulley and a pointer on the engine cover to show TDC. Clean both of these and add a dab of white paint. Disconnect the vacuum advance (if there is one fitted) and block the pipe. Start the engine, leave it out of gear and ask the assistant to set the revs to 1,000 rpm. When the engine is running steadily, adjust the advance setting on the timing light so the mark on the pulley and the pointer on the engine coincide. You can then read off the ignition advance for that revs from the timing light.

BE VERY CAREFUL to avoid any moving parts such as the fan, fan belt or dynamo pulley.

Repeat at 500 rpm intervals up to 3,500 or 4,000 rpm if you are brave enough. At these revs the engine will sounds very noisy. Ear defenders are recommended. With this data, you can plot advance against engine revs either using a software package or a piece of lined paper.

This is a very useful exercise as it both checks your centrifugal advance is working and lets you compare your advance curve with the results from Manchester or other published curves for your car.

Adjusting the Ignition Advance Curve

There are two ways the ignition advance curve can be adjusted.

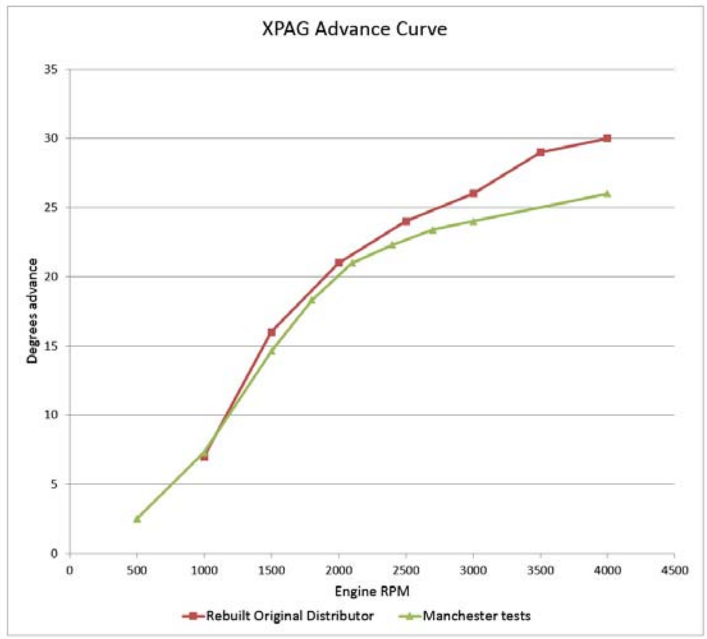
The first and simplest way is by bodily rotating the distributor. This either advances or retards the centrifugal advance curve by the same amount over the whole rev range. On some cars there is a Vernier underneath the distributor to do this, on others it is necessary to undo the distributor clamp bolt and CAREFULLY rotate it by a very a small amount. Rotating in the direction of rotation (anti-clockwise on the XPAG) retards the ignition; conversely rotating against the direction of rotation (clockwise) advances the ignition.

If you adjust your timing in this way, it is important to recheck it afterwards using the timing light.

In order to alter the *shape* of the advance curve it is necessary to change the weights or the springs, alter the stops or even prise apart the coils on the springs. However, should you think your advance curve needs to be changed, it is advisable to get this work done by a specialist such as the Distributor Doctor.

The advantage of the programmable electronic units described later in this article is that the advance curves can be set or changed on a computer.

Manchester Advance Curve



One aim of the Manchester tests was to measure both the optimum centrifugal and vacuum advance curves (the vacuum advance is discussed later in this article). The graph shows the centrifugal advance curve from the Manchester data (green curve) and that measured using the rebuilt DKY4A distributor fitted to the XPAG (red curve). (The distributor model number is stamped on its side.) The DKY4A distributor was set with an additional 5° advance compared with the factory recommended settings by bodily rotating it.

It can be seen that the curve from the rebuilt distributor advanced by 5° is correct for modern fuel up to 3,000 rpm. However beyond that it becomes too advanced. This is not ideal at the rev range where the engine is probably being run at full throttle and when pinking may occur.

It is also worth noting the need for the 5° advance up to 3,000 rpm as provides additional supporting evidence of the *Slow Combustion* problem. The ignition must be fired earlier to offset the effect of those cycles that are burning late.

Damage to the Engine

The time when the peak pressure is reached is very important. Should it occur too early it can cause a phenomenon called pinking or knocking which can damage the piston or big end bearings, too late and it can burn the exhaust valves or even crack the cylinder head.

Pinking is a mechanical tinkling sound that occurs typically at full throttle and low revs and is due to multiple ignition points in the cylinder, rather than just the one created by the spark plug. The noise is from these separate flame fronts "colliding". There are two possible causes.

First, and the most probable, is because the ignition timing is set too advanced. Should phase 2 of the combustion process, (i.e. when the ignition points have started to spread throughout the volume of the cylinder) occur before TDC, the increase in pressure caused by the burning fuel coupled with the compression from by the piston rising up the bore can spontaneously create secondary combustion points. The second cause is glowing carbon deposits on the crown of the piston or around the valves, heated by the previous cycle, that are still sufficiently hot to ignite the mixture during the compression cycle. Ironically, this can be made worse by *retarded* ignition or the *Slow Combustion* problem.

Beware, pinking is not necessarily due to an over advanced ignition, it is also possible the ignition could be too retarded or the engine needs de-coking.

The higher the octane of the petrol, the less susceptible it is to spontaneous ignition and the creation of secondary combustion points. However, once ignited, it burns at the same rate as lower octane petrol.

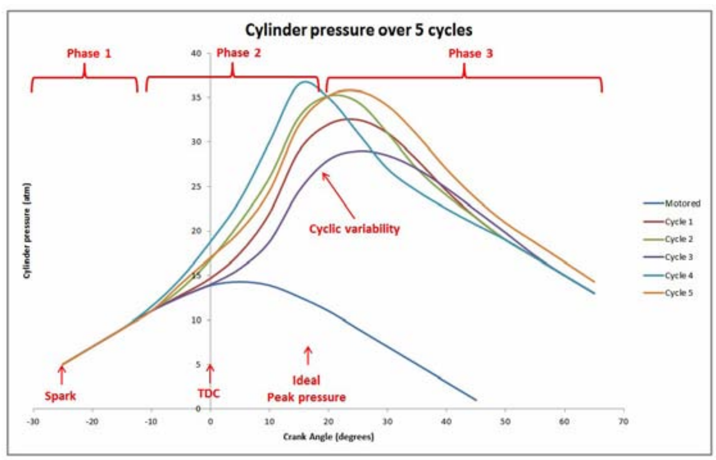
After peak cylinder pressure has been reached, the heat energy from the gases push the piston down the cylinder, cooling in the process. Combustion cycles that occur late have less time to cool before the exhaust valve opens and these hotter exhaust gases are released from the cylinder. They can also result in hot gasses blowing back into the inlet manifold when the inlet valve opens. Setting the ignition too retarded increases the number of late cycles and exhaust gas temperature.

Both an over advanced or over retarded ignition may cause damage to the engine.

Cyclic Variability

The slowest part of the combustion process is the initial growth of the fireball. This is critically dependent on having the correct mixture. A mixture that is too weak or too rich can slow this growth significantly. Unfortunately, a slow initial growth has a double negative effect. The piston will be going down the cylinder as the flame front starts to spread. This increases the volume occupied by the mixture and the flame front has further to travel. Furthermore, as the piston drops the pressure in the cylinder also drops, as a result the flame front will grow more slowly. Both these factors add further delays to the timing at which the peak pressure occurs.

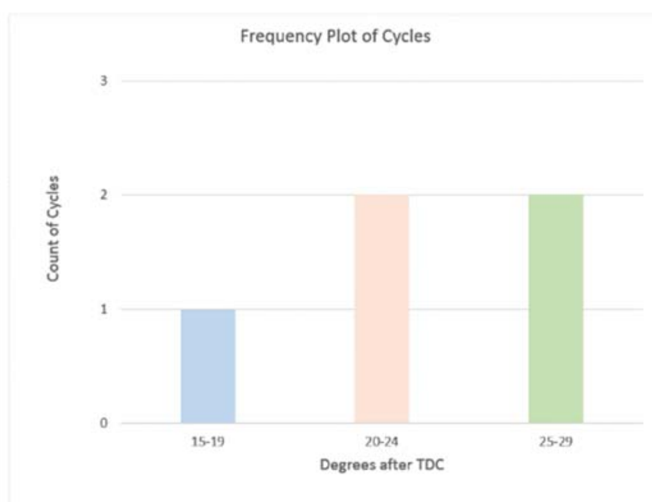
The mixture around the plug depends on a number of random factors such as the atomisation of the petrol in the carburettor and turbulent mixing. It can vary significantly between the individual cycles in each cylinder. As a result, even with a correct ignition advance, not all cycles will deliver a peak pressure at 17° After Top Dead Centre (ATDC).



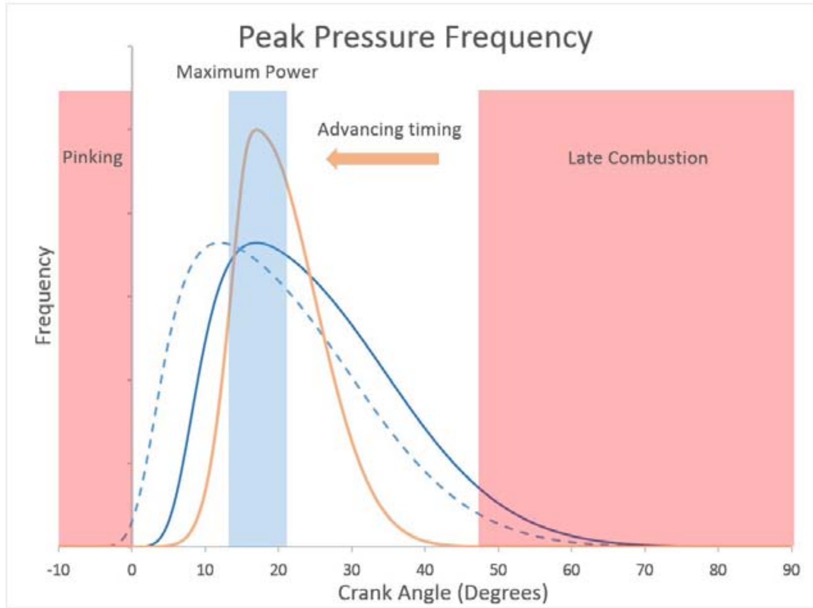
The diagram on the right shows five cylinder pressure measurements taken from a running engine. It can be seen that they all produce peak pressures at different times, or degrees after TDC.

If we were to produce what is called a *peak pressure frequency plot* for these 5 cycles by counting how many cycles occurred between 15° and 19° after TDC (marked in blue below), 20° to 24° (marked in orange) and 25° to 29° (marked in green), we would get plot like this.

Cycle 1	22° ATDC
Cycle 2	20° ATDC
Cycle 3	28° ATDC
Cycle 4	17° ATDC
Cycle 5	25° ATDC



A similar plot for a running engine covering many thousand cycles would look like the graph to the right. The red areas, marked *pinking* and *late combustion* show where the cycles may cause potential engine damage. The blue area shows the timing where peak pressure should occur to produce maximum power. The orange curve represents an ideal situation where the engine is running with low cyclic variability. The solid blue curve, probably more typical of the XPAG, where there is a high degree of cyclic variability.

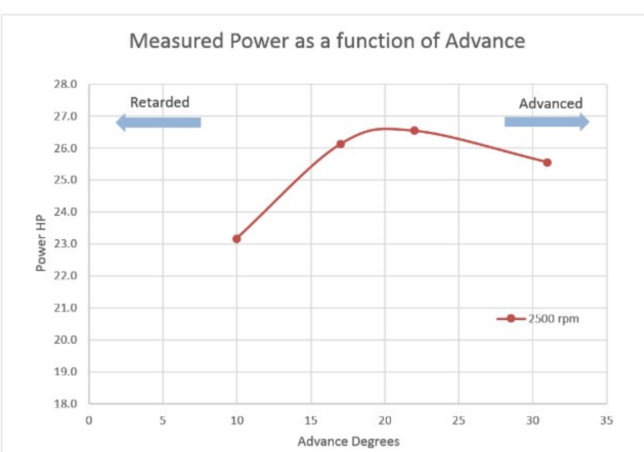


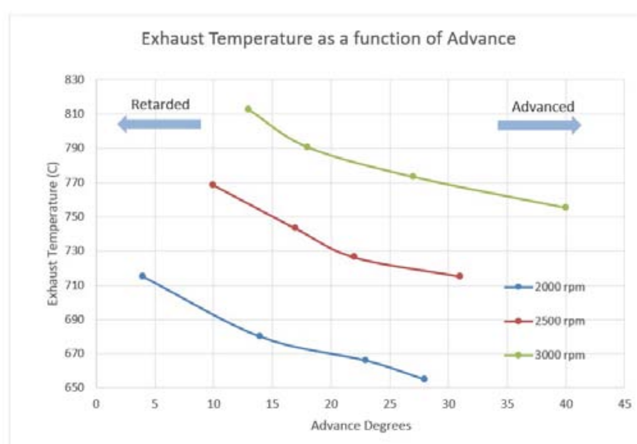
The first thing to note, is that when cyclic variability is high, there are a large number of cycles occurring in the *late combustion* region. Remember it is not that the petrol is burning more slowly, it is due to some cycles "getting off to a bad start" when the plug fires. The second thing is that there are less cycles occurring during the maximum power timing than with the low cyclic variability case (the height of the blue line is lower than that of the orange line in the blue area), a high degree of cyclic variability reduces power output.

Finally, with high cyclic variability when the engine is advanced (i.e. the curve is moved to the left) as shown by the dashed blue line, two things happen. Firstly, there is a very small change in the number of cycles in the maximum power band, i.e. the power output of the engine changes very little as the engine is advanced. Secondly, the number of late cycles are dramatically reduced at the expense of only a small number occurring too early.

This is exactly what we saw at Manchester when we measured the power output as we advanced the ignition.

Once peak power had been reached (left hand graph which follows the shape of the pressure frequency curve), power output fell very slowly as the engine was further advanced. However, advancing the ignition timing dramatically reduced the exhaust temperature (right hand graph).





When setting the ignition timing, providing you are not experiencing pinking, it is better to err on the side of being too advanced than being too retarded. This will help reduce exhaust gas and under bonnet temperatures with only a minor loss of power.

Cylinder pressure

Earlier in this article, I mentioned how the growth of the initial flame front depended on cylinder pressure, this in turn depends on throttle setting. The less the throttle is opened, the lower the cylinder pressure, the longer it takes for the flame front to grow. More ignition advance is needed to ensure maximum cylinder pressure occurs at the optimum timing. This can be achieved by adding a vacuum advance to the centrifugal advance.

The centrifugal ignition timing is set to be correct at full throttle this is when the flame front grows the fastest. However, further advancing the engine at low throttle settings can significantly reduce exhaust temperatures without the risk of pinking. This is especially important for road use where the engine is working at part throttle in the rev range where the *Slow Combustion* problem is at its worse.

The Z Magnette, MGA and the majority of later MGs were fitted with a vacuum advance as standard. This consists of a vacuum pod on the distributor connected by a fine tube to the inlet manifold or carburettor(s). At low throttle settings, the pressure in the inlet manifold is below atmospheric causing the vacuum pod to advance the timing by rotating the plate on which the points are mounted. Usually, the pods are marked with three digits, e.g. 5-13-10. This indicates that vacuum advance starts at 5 inches of mercury (inHg), ends at 13 inHg, and produces 10^{o} of distributor advance. The distributor rotates at half the speed of the engine, so this corresponds to a maximum of 20^{o} engine advance at 0.43 Bar. The different degrees of advance for given pressures is called the Vacuum Advance Curve. This is typically a straight line going from 0^{o} at atmospheric (full throttle) to the maximum around 15 inHg (closed throttle).

The cylinder pressure, when the plug fires, depends on compression ratio as well as throttle setting. For this reason engines with different compression ratios are fitted with different advance pods. The optimum maximum vacuum advance for the XPAG with a 7.25:1 compression ratio, as measured at Manchester, was found to be 15^{o} at 15 inHg.

With a mechanical distributor it is possible to vary the vacuum advance by changing the pod. On programmable electronic distributors this is done on the computer.

If your car is fitted with a vacuum advance, it is important to check that it is working properly. A simple check is to re-measuring the advance curve, as described above, this time with the vacuum advance connected. You should get a curve that runs 5^{o} – 15^{o} in advance of the centrifugal one.

Superchargers

A warning for those cars fitted with superchargers.

Superchargers **INCREASE** the pressure of the gases in the inlet manifold above atmospheric. This causes the flame front to grow more quickly requiring **LESS** advance. Setting the vacuum advance on these engines is more difficult as the pod on a mechanical distributor may not cope with positive manifold pressures.

Conclusion

This article has described how Cyclic Variability during the combustion cycle affects the timing of the peak combustion pressure and how it can result in a significant number of cycles occurring late. It is these late cycles that cause the *Slow Combustion* problem and ultimately the high under bonnet temperatures that make the volatility problems of modern petrol worse.

The importance of ignition timing has been discussed and how, by advancing the timing, it is possible to reduce exhaust temperatures suggesting the importance of the correct centrifugal and vacuum advance curves. The Manchester data showed the standard XPAG centrifugal advance curve for a rebuilt distributor were around 5^{o} too retarded below 3,000 rpm due to the *Slow Combustion* problem.

It is important the ignition timing is set correctly or the engine will be damaged, too advanced will result in pinking, to retarded burned exhaust valves and damage to the cylinder head. It is advisable to check your advance curve using a timing light and check the centrifugal advance, and if fitted, the vacuum advance are both working correctly.

It is suggested that other registers in the club arrange for a typical car to be taken to a rolling road to measure the ideal centrifugal and, if possible, vacuum advance curves. These would provide a good baseline for other owners.

The next article will discuss fitting a vacuum advance to an XPAG. The indications from my own car and others is that it makes a significant improvement to running, keeping the engine cooler in slow moving traffic and improving overall performance.