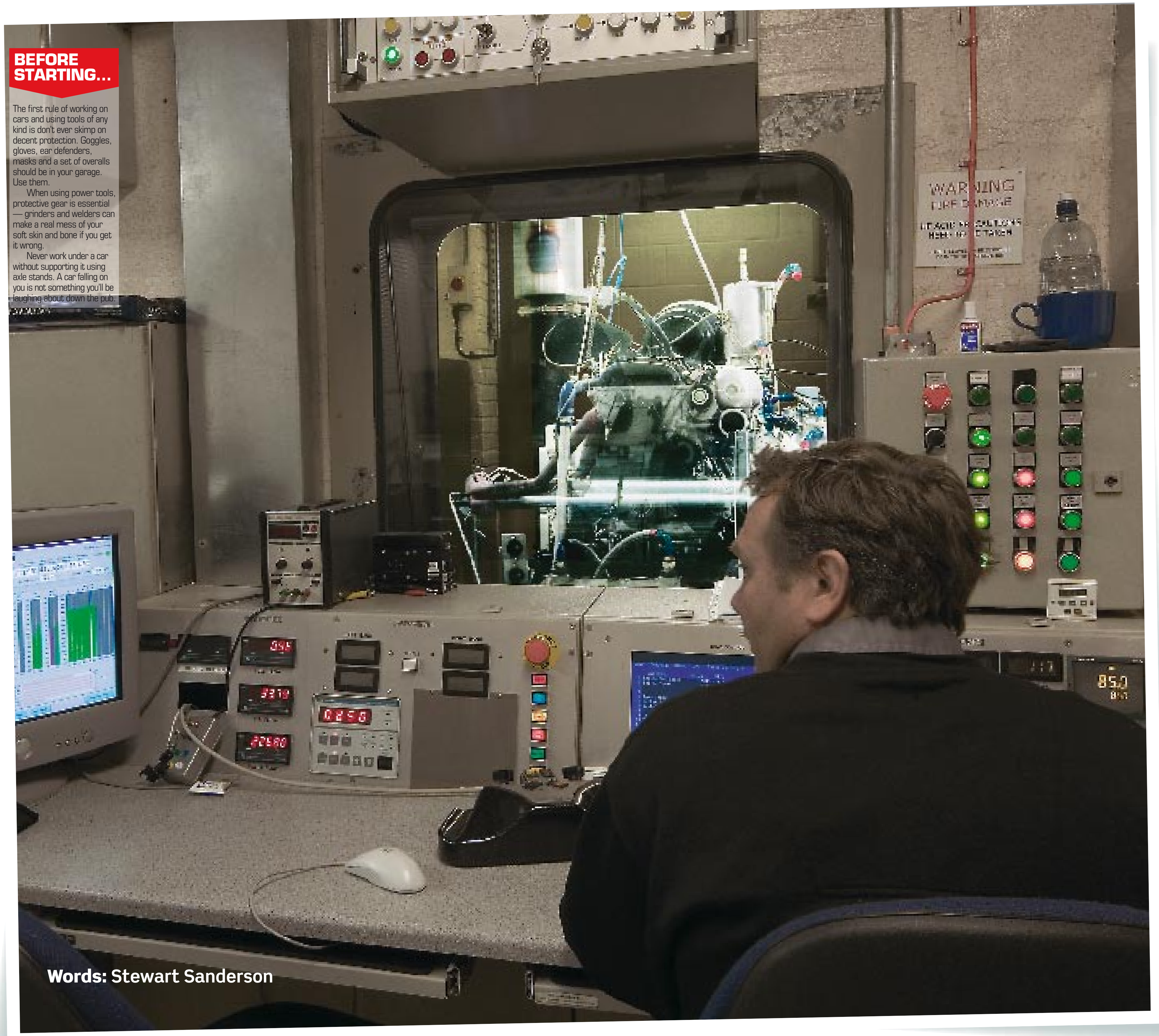
fasttech

MAKING ADVANCES



BEFORE STARTING...

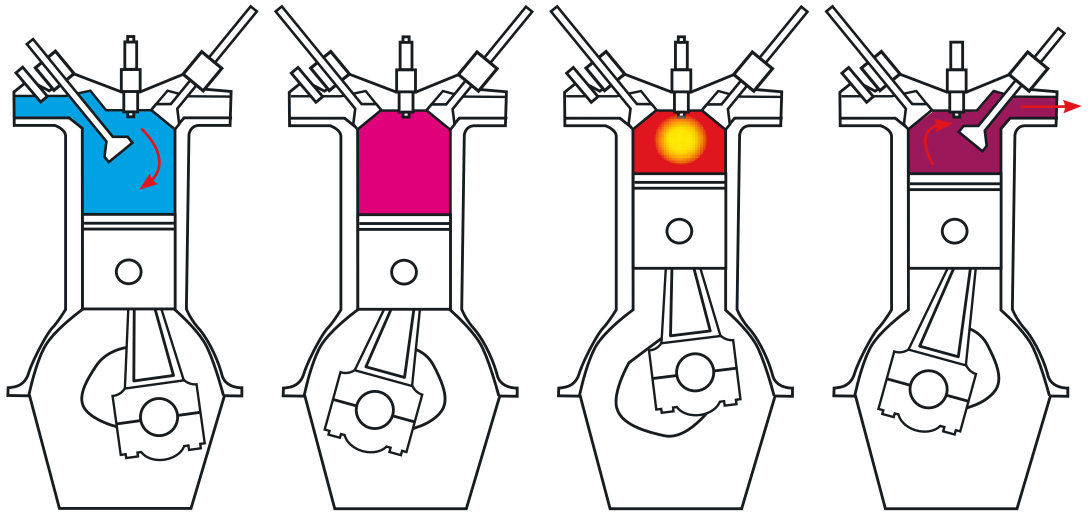
The first rule of working on cars and using tools of any kind is don't ever skimp on decent protection. Goggles, gloves, ear defenders, masks and a set of overalls should be in your garage. Use them.

When using power tools, protective gear is essential — grinders and welders can make a real mess of your soft skin and bone if you get it wrong.

Never work under a car without supporting it using axle stands. A car falling on you is not something you'll be laughing about down the pub.

Words: Stewart Sanderson

Think advancing your engine's timing is a quick and easy way to go faster? Think again. Here's what you should know before you have a go.



WE had a car in at Motorsport Developments recently that was pinking really badly. It transpired that the owner had advanced the timing as far as he could, as his mate told him that would make it as fast as it could be!

This got me thinking that maybe an article on spark timing and its purpose would be interesting, and maybe save some of you from destroying your engines. So here we go...

SPARK ADVANCE

Spark advance (or ignition timing as it's more commonly known) is the term used to describe the point in the engine cycle that the spark is generated at the spark plug in the engine's cylinder. This point is referenced against the piston's position in the cylinder at the time of ignition. As an example, if we were to fire the spark plug at the exact time the piston is at 20 degrees before it reaches the top of the cylinder, we would call this ignition timing 20 degrees before top dead centre (TDC).

This spark happens at an almost infinitely variable point in the engine's cycle depending on many different factors. Understanding some of those factors is the main reason for this feature, so as always, let's take you back to basics and I will try to explain some of the basic factors affecting the point at which we require the spark to happen. Once you have a basic understanding of this, we can then move on to the more complex variables that affect the timing of the spark.

Most petrol engines work on what is known as the four-stroke principle (see diag. above). The four strokes are: induction (the sucking in of the air); compression (the compression of the air); ignition (the ignition of the fuel and the power created); and exhaust (the release of the spent gas into the exhaust system so we can start again and refill it).

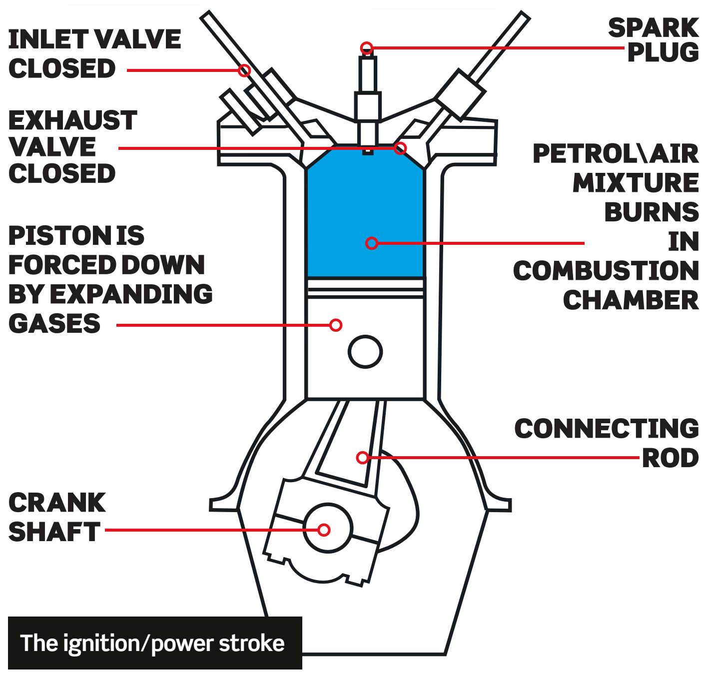
The stroke we are interested in here is the ignition/power stroke and more specifically, what actually happens both before and after we initiate the combustion with a spark from our spark plug. Incidentally, these four strokes are often easy to remember as, 'suck, squeeze, bang, blow'. You can be sure that most of the blokes reading this will smile and remember it forever now. I certainly did!

Piston heights are one way of determining compression ratio, which in turn affects compression level (see text)

COMPRESSION

So, our inlet valve opens and the piston heads downwards, creating a partial vacuum and drawing in air — just like a syringe. The intake valve then closes, sealing the cylinder completely as the piston moves back upwards and compresses the mixture into a space much smaller than it initially filled.

This compression level is determined by our compression ratio — for example, an 8:1 engine will compress the mixture into a space eight times smaller than it originally filled. And a 500cc cylinder will compress that 500cc of air/fuel mixture into a space around 62cc in size. Once



The ignition/power stroke

compressed to this immense level, our mixture of fuel and air becomes extremely volatile and a single spark from the spark plug will initiate the combustion of it and release the energy from the mixture, forcing our piston smoothly back down the bore and producing our next stroke — the power stroke.

CYLINDER PRESSURE

Simple enough to understand so far, I hope? OK, let's proceed.

One of the most common misunderstandings is that the fuel, once ignited, simply explodes and forces the piston down! Nothing could be further from the truth and if that were the case your engine would be destroyed in seconds.

To generate maximum pressure on the piston crown, we need to ensure that maximum point of expansion of the hot gases is created when the crankshaft is at an advantageous angle. That angle is normally between 10 and 20 degrees after the piston has reached TDC. This gives the maximum leverage effect possible at the crankshaft and generates the maximum torque. The pressure we are talking about here is known as the peak cylinder pressure (PCP).

Getting PCP point wrong will result in one of two things: if we achieve Peak Cylinder Pressure too late then we have missed the point of peak leverage on the crankshaft and lose a little torque as a result. Also, we will transfer less combustion heat into the water jacket around the cylinder head, thus potentially running the engine hotter.

Another by-product of late PCP is our exhaust gas is somewhat hotter due to the burn cycle continuing further down the bore than normal, carrying more latent heat that was unused for power creation on the power stroke.

PCP arriving a little too early has the potential to be far more damaging. If the peak pressure wave arrives with the piston still on its way up the bore or slightly past TDC, it will try to force it to go back down, wasting energy trying to compress the piston and con rod and naturally robbing us of important torque.

If PCP happens much too early it can be really bad and destroy things. Just imagine this scenario: we have the force of the road wheels, the transmission, the other cylinders' power strokes and the crankshaft and flywheel inertia all forcing the con rod and piston up the bore in a particular cylinder, and a huge pressure wave of combusting fuel and oxygen forcing the piston back down!

The results, as you can probably imagine can be catastrophic and terminal for the engine. Holed and molten pistons are the normal outcome of this scenario as the massive pressures lead onto artificial ignition of the fuel known as detonation or knock; this knock can act as a thermal lance and literally melt the alloy piston away...

TIMING'S RIGHT

OK, so we now know that we want to have our PCP between 10-20 degrees after TDC and we know that too early or too late is bad for our engine and/or performance. So all we need to know now, is what affects the burn and how we get it to peak at the required place with our well-timed spark.

Before you can understand spark advance requirements, you must understand a little about the fuel mixture and what happens when we initiate combustion of it. The first point to understand is that our fuel and air mixture will take a particular time to actually ignite and burn after the spark has been initiated (this time is almost infinitely variable, but that comes later). The second point to understand is that our engine is also travelling at a certain speed (revolutions per minute) and that this speed must be accounted for when planning our spark.

For now, let's imagine our engine is running at 3000 rpm. It should be fairly obvious to the majority of you that to achieve our cylinder pressure peak somewhere between 10 and 20 degrees after the piston hits TDC, we must actually start the fuel burning earlier than that.

So let's take an educated guess and fire the spark at around 20 degrees BTDC (before top dead centre). This gives us 35 degrees of crankshaft rotation for our mixture to ignite, start propagating and ultimately reach the point of peak expansion rate while at our desired crankshaft position, which we will take as 15 degrees ATDC.

It's worth bearing in mind the kind of speeds we are talking about here: 3000 rpm is 50 full engine rotations per second. And we are dealing here with only 35 degrees of one solitary turn. It is all happening incredibly fast.

After initial initiation of the spark, it normally takes between 2 and 15 degrees for our mixture to react with an exothermal process and start to raise the cylinder pressure above the compression line at which it would be with no combustion. This time delay is known as the delay period.

From here the flame front propagates rapidly outwards, ultimately reaching the PCP and then ending a few degrees after this.

Let's presume that this ignition point was perfect for our particular scenario and we reached PCP at 15 degrees. Why can't we just set the spark timing figure to 20 degrees BTDC and have done with it? Well, that's where it gets complicated and we have to start looking at the variables that affect just how fast the mixture burns, and of course how much time we have to deliver our burning fuel to achieve PCP in the correct place.

Let's look at the various factors that influence our spark timing.

ENGINE SPEED

The first and indeed main reason we need to adjust our point of spark is the fact our engine doesn't rotate at a set speed. In the example above I have used 3000 rpm and shown that we needed 20 degrees of advance to get the PCP in the correct place.

Presuming that our engine speed has doubled to 6000 rpm. What will happen if we initiate the combustion at the same place as we did earlier, 20 degrees BTDC?

Yes, that's right, our piston will have gone way past our ideal 15 deg ATDC due to the fact the piston itself is travelling at twice the speed it was earlier but our propagating mixture's flame front is travelling at the same rate as it was at 3000 rpm (this example assumes an identical volumetric efficiency at the two engine speeds).

Based on this, it's reasonable to assume that we need half as much advance at 1500 rpm as we do at 3000, as the piston is travelling at half the speed. We can also assume twice as much at 6000 rpm as the piston is travelling at twice the speed. So we now have 10 degrees at 1500 rpm, 20 degrees at 3000 rpm and 40 degrees at 6000 rpm.

If you are following me so far, then congratulations, you are starting to understand and plot your very first advance curve for a four-stroke petrol engine!

FUEL MIXTURE

The petrol mixture and composition itself will affect the spark timing quite considerably. Petrol will burn quite easily when mixed with air at ratios between 10:1 and 20:1. In most engines we typically use between 11 and 16:1. All these mixtures have a slightly different burn rate and thus a different advance requirement.

Most petrols burn fastest in the 12-13:1 range, which is of course the reason why peak power is found at this particular air/fuel ratio. It is also worth noting that the higher octane the fuel, generally speaking the slower it actually burns, so adding that ultra-high octane fuel to your engine that is not setup for it will normally cost you a few horsepower, and in reverse, running 95 RON fuel in your engine that's set-up and mapped for 98 RON will normally result in molten pistons and open wallet surgery.

CHARGE DENSITY

This is largely related to the load the engine is under, but basically, the more air we cram into the cylinder, the denser the air/fuel mixture becomes and the less advance it requires due to its increasing burn speed.

As a very simple example, the density of the air fuel mixture in the cylinder at idle will be far less than it would be at, say, 25 psi and 4000 rpm. The charge density in the cylinder normally relates very well to the torque graph, with peak torque also being peak air/fuel density ignited in the cylinder, and thus requiring the least spark advance of all due to its immense burn speed.

CHARGE TEMP

The temp of the mixture in the cylinder has a dramatic effect on burn speed and spark requirement of that particular combustion event.

A cold and dense mixture normally burns at a very different rate to a hotter and potentially less dense one. Sometimes, hotter mixtures can burn even faster than cold, requiring more retard. It's a complex subject that cannot be covered fully here.


Colder air/fuel mixture burns faster and requires less advance

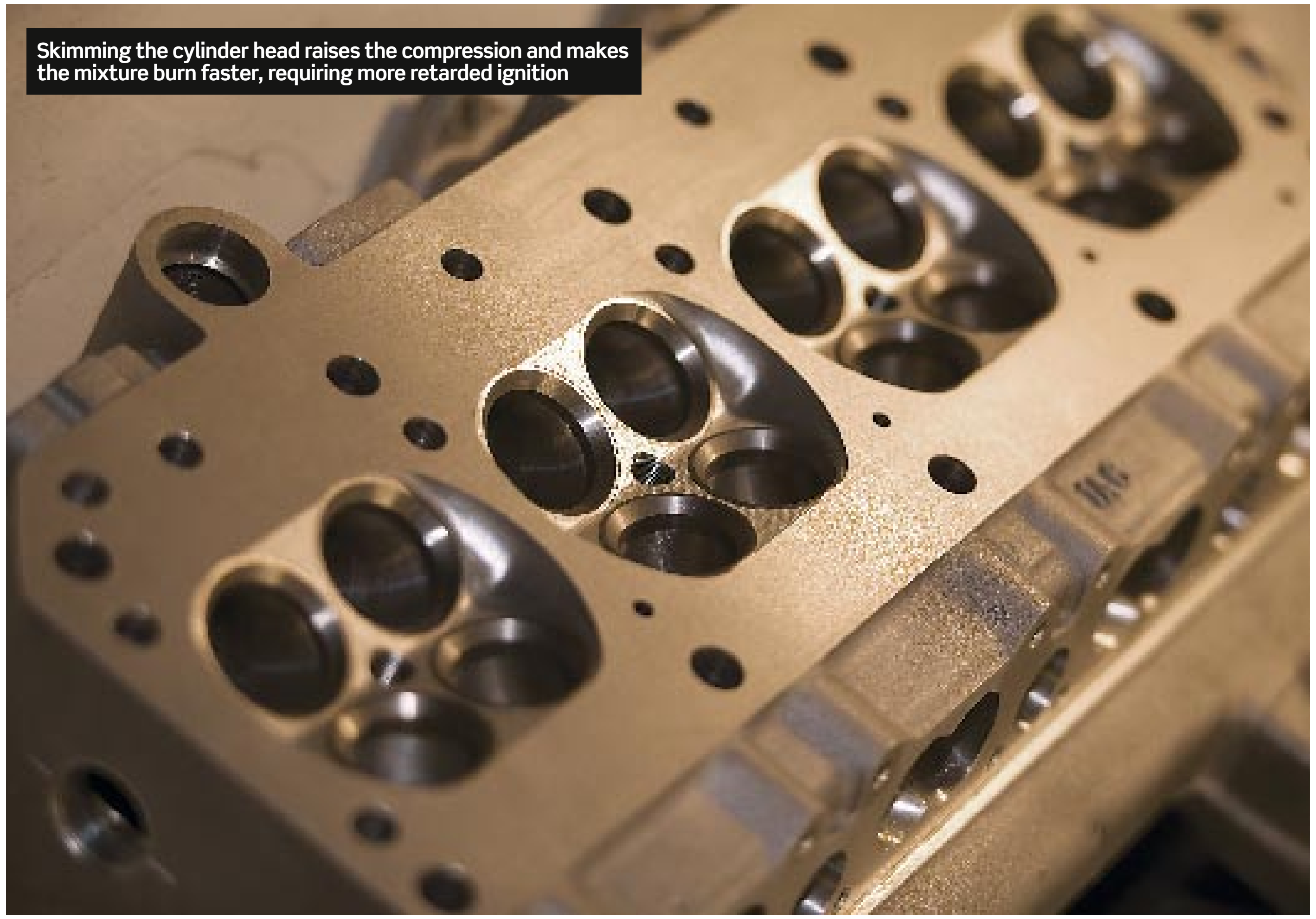
DISTRIBUTION

It is very important that the engine is designed in such a way as the air fuel molecules in the compressed charge end up in a uniform state.

The charge present between the spark plugs electrodes at the time of ignition must be of an easily combustible composition, meaning somewhere between 10 and 20:1. Ideally the charge present throughout the combustion chamber should be a similar composition and evenly distributed, so as to allow smooth propagation of the flame front at a controlled rate once the burn is initiated. Sudden rich or lean pockets of mixture can have dramatically negative effects on power output and engine health.

CHARGE DILUTION

Any exhaust gasses left over from the last exhaust stroke will dilute the fresh charge and slow down burn rates. The main culprit of this waste gas being left over is the camshaft timing. Excessive overlap can result in large amounts of exhaust gas


Skimming the cylinder head raises the compression and makes the mixture burn faster, requiring more retarded ignition


Get Peak Cylinder Pressure wrong and you could end up with a holed piston

DETONATION KNOCK

Detonation or knock is defined as a form of combustion which involves an energy release which is far too fast. This release gives rise to massive temperatures and cylinder pressures. Normally detonation is an explosion of a part of the fuel mixture not currently involved in the normal propagation process.

FLAME PROPAGATION

Propagation is the correct term for the way your air fuel mixture actually burns. It is far more like a wave than an explosion with the mixture burning smoothly from its point of ignition outwards, rather like the ripple that is produced if you throw a pebble into a nice still pond.

Fitting a larger turbo can affect the spark advance almost everywhere in the load and rev range

being present when the exhaust valve finally closes. Exhaust back pressure also has a huge effect, the higher the back pressure is, the harder it is to flow the gas out of the cylinder on the exhaust stroke. This is one of the reasons a larger turbocharger increases volumetric efficiency so much — as explained in the June 2006 issue.

So there you have it. Hopefully you'll now have some idea of not only what spark advance actually is, but also what sort of things govern the figure required, and why it is almost infinitely variable. One last subject worth covering is the common things people do that affect spark advance requirements without them knowing it.

HEAD SKIMMING

The most common thing of all is probably having the head skimmed.

Skimming the head, block or both raises the compression and instantly increases the amount that the air/fuel charge is compressed, generally making it burn faster, thus requiring more retard. Go too far and uncontrollable detonation/knock will be your only reward as the fuel is compressed to the point it auto ignites.

ADDING A LARGER TURBO

This has a large effect on the volumetric efficiency of the engine, especially if it has a larger turbine housing, and thus can affect the spark advance almost everywhere in the load and rev range. Always ensure your chip is matched to your new turbo or a meltdown could be imminent!

CAM PROFILES

Again, the volumetric efficiency of the engine is altered quite dramatically with new cams just like it is with a larger or smaller turbocharger. A camshaft profile that shifts more air and makes more power will have a different spark advance requirement both on and off its power band.

CAM TIMING

Simple cam timing adjustment is not quite as bad as new cam profiles but remember that moving the cam timing moves the engine's power band around, and thus the spark requirements. Advancing your cam will often require a spark retard at high engine revs, and vice versa.

Advancing cam timing often requires a spark retard at high revs

ENGINE CHECKS

The moral of the story is simple; when you have added a new go faster part or made an adjustment to any of the mentioned settings you must always check the engine not only for correct fuelling, but also for any engine damaging detonation/knock.

Obviously I would recommend you leave all setting and adjustment work to an experienced professional with the correct equipment to do so. Take care out there.

NEXT MONTH

CAMSHAFTS: What they do, how to time them and what different timing does.

CONTACT

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