THE EXPERT
**STEWART SANDERSON**

**Having worked as a tuner for 17 years, Stewart 'Stu' Sanderson is one of the most-respected names in the business. A Level 5-trained fuel-injection technician, Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.**

**Eight years ago he joined forces with Kenny Walker and opened up Motorsport Developments near Blackpool (01253 508400, www.remapping.co.uk), specialising in engine management live remapping, as well as developing a range of Evolution chips which are now sold all over the world.**

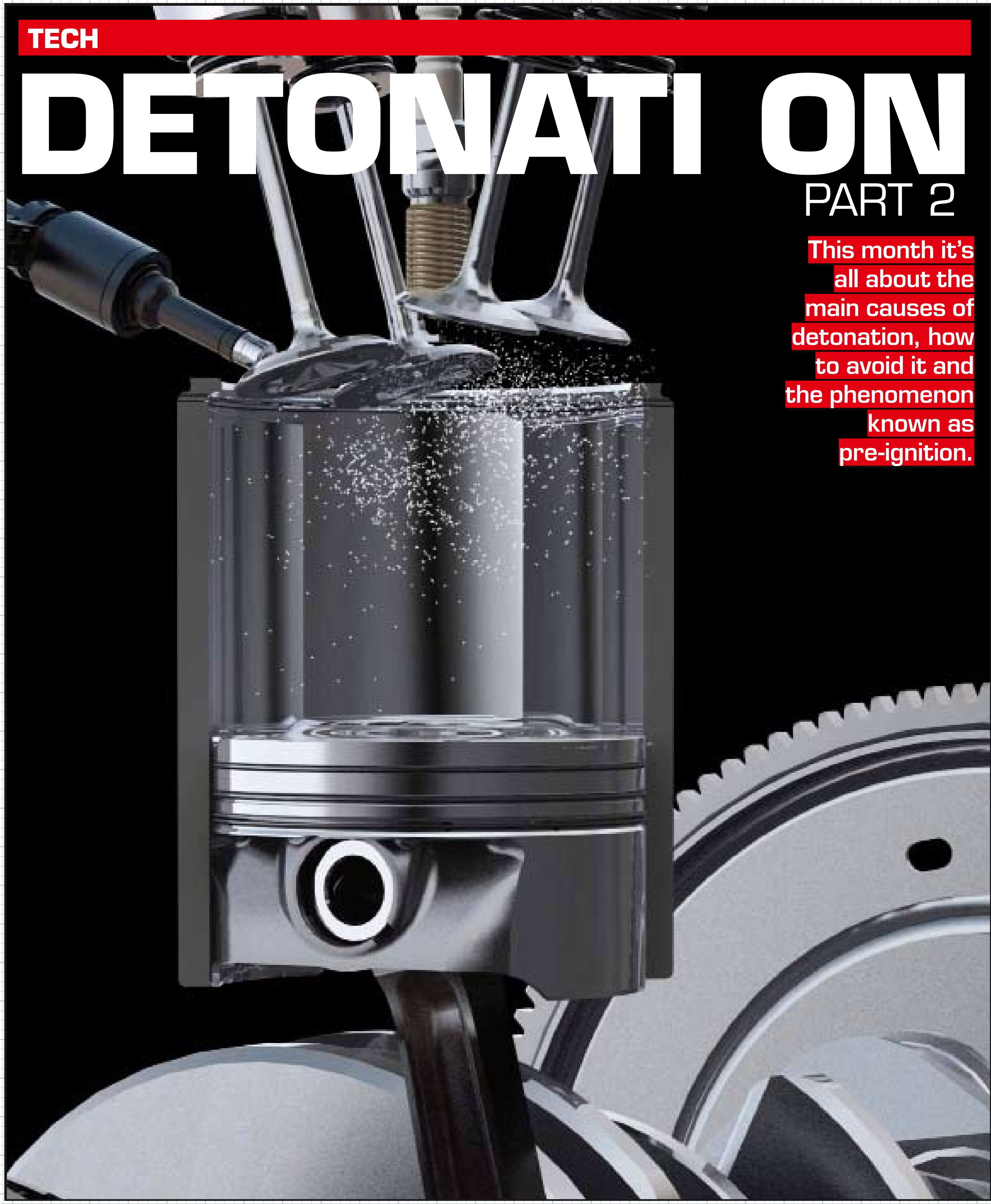
**He is the creator and administrator of www.passionford.com, which he started in 2003. It has grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web.**

**Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and importantly how they can be improved.**

TECH

# DETONATION
## PART 2

**This month it's all about the main causes of detonation, how to avoid it and the phenomenon known as pre-ignition.**



There are many mechanical things that influence your engine's sensitivity to detonation. Chamber design, compression ratio and engine timing are all pretty much fixed aspects of an existing engine so if set correctly should be OK, but be aware that they all contribute to how the non-fixed factors (spark, fuel mixture, fuel octane etc) will affect the knock limit. Discussing these fixed factors is far outside the scope of this article, so let's look at the items that can be changed.

### SPARK ADVANCE
This is one of the most common factors. Too much spark advance will start the mixture burn off too soon, which will lead to a condition where the cylinder pressure increases too soon.

Peak pressure will occur too early and the piston is not in an optimum position to be pushed back down the bore due to the crank angle. This will cause so much heat build up that the mixture not yet burning can spontaneously combust. Retarding the spark is the immediate solution to this.

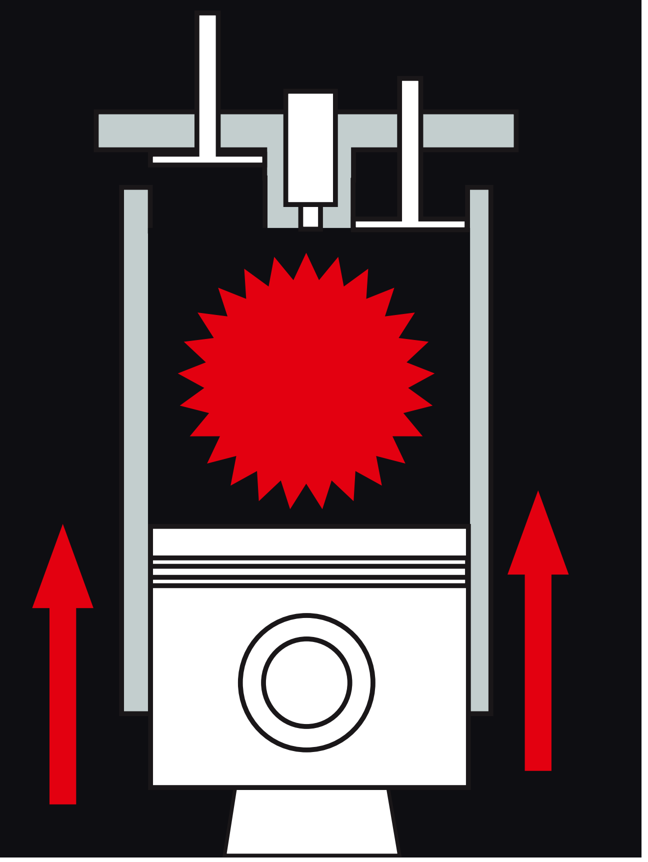
### FUEL OCTANE
The octane rating of any given fuel has a dramatic effect on your engine's susceptibility to detonation.

A fuel's octane is its ability to resist detonation. It is determined using quite old but specific tests where you run the fuel in a test engine at a known speed and measure what compression ratio it ultimately starts to detonate at, then compare that to a test fuel of known quantity. It is more complex than that but this explanation will do for our purposes.

Suffice to say running a 95 Ron fuel in an engine being controlled by a 98 octane optimised engine management program is a disaster waiting to happen, and it's one that I still see weekly when we have unusual detonation levels on an engine we are mapping. In general, performance engines work best on performance fuel...

### FUEL MIXTURE
If the fuel mixture is too lean detonation can occur. Any fuel mixture will have a specific burn temperature and speed.

### IGNITE TOO SOON
**Pre-ignition usually occurs when the the air/fuel charge is ignited by a glowing spark plug/valve edge/carbon ember before the piston reaches TDC on the compression stroke**



Typical pre-ignition damage is a hole in the centre of the piston

Remember physics at school when you were taught to get your Bunsen burners bright blue before using them because an orange flame was too cool? The orange flame was dull and burnt slowly so looked like a lighter flame, whereas the blue flame was intense and burnt fast, like a jet engine.

This is entirely the same concept. If we lean the fuel off we tend to find it burns faster, and that means our max spark advance is now too advanced and will bring the peak pressure too soon in the piston's cycle. If we lean it off, it tends to burn hotter, and you already know what happens when we get the gas too hot. It spontaneously combusts...

### AIR TEMPERATURE
Air temperature affects the density of the air fuel mixture, and the density in the cylinder affects how fast the mixture burns, thus altering our spark timing requirements again. Plus, when you compress hot air it ultimately gets hotter than it would were it cold to start with. And you already know the problems that are created when we heat our fuel mixture up!

### INTERCOOLERS
It is worth mentioning intercoolers at this point because while it does fall into the air temperature category above, the bigger and more efficient it is the less likely we are to have detonation due to air temperature.

I've lost count of the times I have seen these

Spark advance and fuel mixture can be adjusted during a mapping session

items totally obstructed by things such as spotlights, newspapers, blocked with flies or on some occasions, 65 percent full of oil! So technically, intercoolers can cause detonation if they are not actually doing any cooling, and especially if they are carrying oil which they then deposit into the airstream and onwards into the combustion chamber, thus lowering the octane of your air/fuel mixture.

Det cans aren't fancy, but allow you to hear detonation or knock

## EXHAUST BACK PRESSURE

When we have excessive exhaust back pressure we directly affect the engine's volumetric efficiency quite dramatically by increasing each cylinder's pumping losses. The harder it is to pump the waste gas out of the cylinder on the exhaust stroke, the more of it we leave in the cylinder ready to be mixed with our nice fresh air/fuel mixture for compression on the next stroke. Since it is exhaust gas not only does this weaken our mixture, it is of course extremely hot gas… Can you see where this is going?

## HOW TO DETECT IT

If it's very severe and your engine isn't running a big air filter and noisy exhaust you may be lucky enough to hear it making a metallic pinging noise, similar to having a nail on a string bouncing along under your car, or small tacks being rattled in a biscuit tin. It's hard to describe clearly as it sounds different on every engine type so you'll need to hear it for yourself.

The best way to detect detonation is with in-cylinder pressure monitors, and then we can actually see and record it on a screen. However, the last time I priced this system it was in excess of £60,000 so that's no use as a general tuning option. This brings us on to detonation cans. In their simplest form they are a set of ear defenders connected to an engine via some pipe. The pipe is connected to a hard copper pipe bolted to the engine that acts as a pick-up. The pick-up is tuned in length to give the user a good audible range of around 3–15khz, and that will amplify most detonation nicely.

There are various forms of electronic knock detecting headphones on the market and many elegant solutions that can give you a visual indication in your cabin, so some Internet research is in order if you want to get a system for your own car.

## HOW TO AVOID DETONATION

We can only avoid det altogether by running a management system that can see it happen and take positive steps to eliminate it. (Most OE systems since around 2000 do this) The best we can do as enthusiastic owners is to make sure our system is up to scratch by ensuring a professional gives it the once over occasionally and checks it under full load to ensure it's not leaning out due to a faulty fuel pump, fuel regulator, squashed line, blocked filter, bad sensor reading etc.

## CHANGE ENGINE DESIGN TO ALTER OR SUPPRESS DETONATION

There are a few things we can do, the main two are as follows:

**Maximise the engine's compression ratio:** Most production engines are optimised for the type or grade of fuel that the market place desires or offers. Engine designers use a term known as MBT (Minimum spark for Best Torque) to calibrate an engine for maximum efficiency and power. It is our aim to operate an engine at MBT at all times.

If we look at any engine rotating at 4000rpm at full power, loaded up on a dyno and using decent fuel we may find we can adjust the spark advance up to 28 degrees with no measurable knock and the power output at its greatest. However, this will rarely be the max advance we can give the engine, but we normally find that the engine will not produce any more power beyond it and drop power if we run any less, this therefore is our MBT point for that load cell.

Suppose the manufacturer decides he wants to run on really poor quality unleaded fuel and asks to have the engine recalibrated because it will knock badly on its current settings, we would probably find that we had to back the advance down to around 20 degrees of advance because this lower octane fuel knocks if we try to subject it to our intended peak cylinder pressure when running full advance. Because we have had to retard the spark advance, our peak cylinder pressure will have moved away from its perfect position of around 14 crankshaft degrees after top dead centre, and because of this we have lost maybe 10 percent or more of our engine's power.

That isn't an acceptable power drop so we need to look at redesigning the engine. Normally the first thing we'd do is drop the compression a little. This will allow us to run the correct amount of advance again to give our fuel time to burn at the correct rate and apply peak pressure to the crankshaft at around 14 degrees ATDC again. This you'll remember from earlier articles is where we need to make peak cylinder pressure to ensure we get the best energy from our combustion.

**Improve your combustion chamber design:** The design of your combustion chamber greatly affects the engine's sensitivity to detonation. The best thing you can do to a combustion chamber to decrease sensitivity and likelihood of detonation is to increase the burn speed. It's actually quite a simple concept; the faster the gas burns, the less time the end gas has to detonate. If it can't sit there soaking up latent heat from its surroundings and the effects of compression while having the compression pressure acting upon it, it can't detonate.

Faster combustion has a second advantage too. Faster burns require less spark advance and this means that the pistons will have less of their stroke wasted combating pressure build up from a slow burning and expanding mixture, so it becomes more mechanically efficient. While most people accept that more advance is good, they often forget that we only actually want as much as is required to get the job done in the most efficient manner with that particular engine design.

**"A SPARK PLUG HEATS UP TO THE POINT WHEN IT BECOMES A GLOW PLUG AND INDUCES PRE-IGNITION."**

## THERE'S MORE

As well as detonation and pre-ignition, there is a third phenomenon called detonation induced pre-ignition. It's not as common as either issue on its own, but it can and does happen.

The scenario is usually the same in all engines, imagine an engine under extreme load that is detonating lightly for a long period of time, the spark plug heats up due to the pressure spikes and unstable combustion to the point when it becomes a glow plug and induces pre-ignition. Carbon and valve edges can react the same way.

Remember, if you find signs of pre-ignition in your failed engine, it's worth looking for the signs of prolonged detonation to go with it.

# PRE-IGNITION

Pre-ignition is absolutely not the same as detonation. Detonation always occurs after the intentional ignition event (the spark plug firing) and pre-ignition occurs before the intentional ignition event, hence the name.

## WHEN DOES PRE-IGNITION NORMALLY TAKE PLACE?

You should always consider the following events and get them clear in your mind when looking at pre-ignition.

The charge first enters the combustion chamber on the intake stroke as the piston travels down the bore and reaches bottom dead centre. At which point the piston then reverses and starts to compress the incoming charge on its way back up the cylinder. It is between bottom dead centre (BDC) and top dead centre (TDC) that the charge is easiest to ignite, this is because it becomes proportionately harder to light the air fuel mixture the more we compress it.

Pre-ignition will always occur somewhere within this compression stroke. The nearer to BDC it occurs, the worse the damage is likely to be and the faster it will become terminal for affected components.

## WHAT CAUSES PRE-IGNITION?

As with detonation there can be a multitude of causes for pre–ignition but the most common are incandescent material in the combustion chamber and a glowing spot somewhere in the combustion chamber is the most likely point for pre-ignition to occur. If you have something glowing, like a spark plug, valve edge or a carbon ember, it could ignite the charge while the piston is very early in the compression stroke. This is probably the most common cause of all.

## INCORRECT SPARK PLUG HEAT RANGE

All spark plugs have a heat range which must be adhered to, otherwise you will have a plug that turns into a glow plug and starts pre-igniting fuel when it comes into the cylinder. We quite often see spark plugs fitted to an engine, especially modified ones, which have too hot a heat range for the cylinder pressure we're generating.

## WHAT HAPPENS WHEN THE CHARGE PRE-IGNITES?

The results from pre–ignition are always serious and unavoidably so. Under pre-ignition conditions your engine can spend the entire compression stroke trying to compress a gas that has already been ignited and is trying to expand. This puts an incredible strain on your internal components, at the same time as adding some incredible levels of heat. Substantial and terminal damage usually occurs very quickly.

## DAMAGE CAUSED

The typical pre-ignition indicator is a hole right in the middle of the piston. Trying to compress an already burning mixture causes the engine parts, and in particular the piston, to soak up tremendous levels of heat in an extremely short space of time. The only parts that can survive this type of abuse are those with a high level of thermal stability such as cylinder heads and bore walls, but even these are by no means safe!

Sadly for the piston, being aluminium it has a very low thermal inertia (aluminium soaks up the heat very rapidly). The crown of the piston is relatively thin and when it gets to extreme temperatures it simply cannot reject the heat. The load placed upon this part is extremely high and as a result the piston tends to literally melt, right in the middle where it is structurally weakest.