30 YEARS OF 968

TIMING IS EVERYTHING

Above The 968's arrival brought forward Porsche's own flavour of variable valve timing technology, which informs the manufacturer's car production today

VarioCam was Porsche's first variable valve timing technology and debuted in the 968. The system has come a long way since the early 1990s, but is now more important than ever...

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Variable valve timing (and control) was the must-have car technology of the late 1980s and early 1990s. Japanese manufacturers appeared to be leading the way, which must have displeased brass at Porsche no end, especially when high-tech sports cars from the Land of the Rising Sun were beginning to muscle in on Porsche's production sports car stomping ground. The German marque was quick to act, launching its catchily titled take on the idea, VarioCam, in time for the start of 968 production in 1991. The system is still in use today, albeit a in much evolved form.

Before we delve into VarioCam design and its development through the years, it's worth refreshing our knowledge of fixed engine valve timing, and therefore the need to alter it for different conditions. We'll stick to four-stroke engines using camshafts and valves because those are the only ones relevant to Porsche engines, and it doesn't really matter how many valves or camshafts there are, nor how the camshaft connects with the valves — the principles are the same.

The profile of the lobes on each camshaft are shaped to open and close the valves at a precise time, to a precise valve lift for a precise duration. There are three distinct variables to consider for each valve: when it opens, when it closes and how far it opens. There's also a fourth, referred to as valve overlap, but we'll cover this later in this article. Let's first consider the requirements for the valve positions in a quite simple four-stroke engine cycle in a single cylinder.

Starting with the piston at top dead centre (TDC) at the beginning of the induction stroke, the inlet valves open to allow air and fuel (unless we're dealing with a direct-injection engine, of course, but that's a story for another day) into the cylinder. The downward motion of the piston causes pressure reduction sucking the air-fuel mixture in. When the piston reaches bottom dead centre (BDC), the compression stroke starts. All valves are closed, and the air-fuel mixture is compressed as the piston moves back up towards TDC again.

Next up is the power stroke, where the air-fuel mixture is ignited by the spark plug (diesel is a little different, but we're focusing on the petrol cycle here). Ignition usually occurs before the piston reaches TDC, but this isn't important for the purposes of this article. The energy released by the burning of the fuel pushes the piston back down the cylinder, turning the crankshaft. Incidentally, the valves are still closed at this stage. Then, on reaching BDC, the exhaust stroke begins, the exhaust valves open and the piston pushes the spent gases out of the cylinder before the whole cycle starts again.

Now is a good time to explain valve overlap. There is often a period of time where both the exhaust valves and inlet valves are open at the same time, toward the end of the exhaust stroke and the beginning of the induction stroke. This is valve overlap. During this period, the rapid flow of gases through the exhaust ports, in conjunction with the design of the whole inlet and exhaust system, creates pressure waves that can cause suction through the intake valves, effectively allowing more air in for a given cycle, providing the exhaust valves are closed before fresh intake air exits them, of course. This is called the scavenging effect. Valve overlap is particularly useful at high engine speeds, where gas flow rates are higher, and the scavenging effect is even stronger.

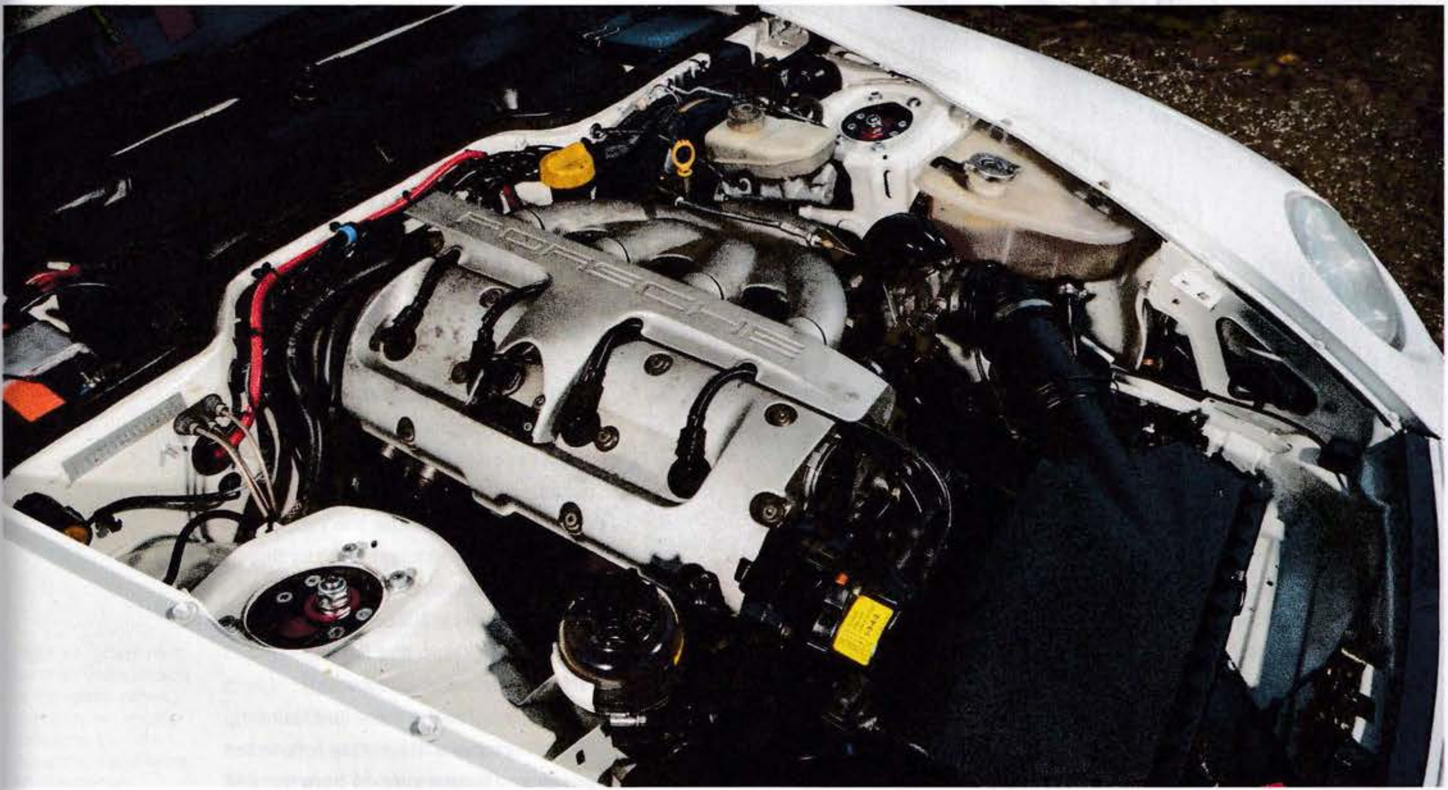
OVERLAP OF HONOUR

Unfortunately, valve overlap is less useful at idle and low engine speeds. It's not difficult to envisage some of the incoming air-fuel mixture exiting the exhaust, is it? Along with this, if overlap is too long, it can make for rough idling. This can be explained by the duration of valve overlap. With fixed valve timing, the overlap is a set number of degrees of crankshaft rotation, but the slower the engine speed, the longer it takes for the crankshaft to turn that number of degrees, which is why, at low engine speeds, the valve overlap is longer in duration. This can allow exhaust gases to flow back into the cylinder before the exhaust valves close and, if the proportion of these gases is too high, it can cause incomplete combustion of the fresh air-fuel mixture, which manifests itself as rough idling. This scenario is unacceptable in a regular road car, let alone a Porsche.

PORSCHE'S INITIAL ATTEMPT TO MINIMISE COMPROMISES WAS RELATIVELY STRAIGHTFORWARD, BUT REMARKABLY EFFECTIVE

Before variable valve timing came along, engineers of road car engines had to compromise on valve overlap – it was fixed by the design of the inlet and exhaust camshaft lobes – ensuring smooth idle was maintained. Sometimes, this meant increasing idle speed (much to the detriment of fuel economy) in a bid to maintain a useful valve overlap. It's important to note, however, valve overlap isn't the only aspect of valve timing considered a trade-off. The timing of exhaust valve opening, for example, is a compromise. To extract the maximum energy from the expanding gas in the cylinder, it makes sense not to open the exhaust valves until the piston is at BDC, but this means the piston has to push against higher cylinder pressure on the exhaust stroke, effectively wasting some of the energy gained. If the exhaust valves are opened before the piston

Below M44 three-litre inline-four is a very robust engine and will respond well to massive mileage if cared for correctly



Above 986 Boxster was the next Porsche sports car to receive a VarioCam system

reaches BDC, the cylinder pressure quickly reduces. To complicate matters, the ideal timing varies with engine speed and load.

Meanwhile, the desired timing of exhaust valve closing is precisely linked with that of inlet valve opening to create the valve overlap discussed above. Inlet valve closing, however, comes with its own set of compromises. It's all about trapping as much air as possible within the cylinder before closing the inlet valves, chiefly because this is what defines the volumetric efficiency of an engine, and therefore the performance and economy. And, as you have probably guessed by now, the ideal timing of inlet valve closing changes differs with engine speed and load range. Of course, there's a lot more to all this than we have room for across these pages, but the core message here is that, before variable valve timing, there were always compromises to be made. The first-generation VarioCam system, Porsche's initial attempt to minimise the aforementioned compromises, was relatively straightforward, but remarkably effective.

Among other technologies, development of the 944's replacement, the 968, focused on improving the performance of the outgoing model's naturally aspirated three-litre, front-mounted four-cylinder engine, which featured double overhead camshafts and four valves per cylinder (two inlet and two exhaust). The 968's updated version of the trusty inline-four retained the same layout and swept capacity as it enjoyed in the 944, but now featured variable timing for the inlet valves. The exhaust camshaft was driven by a toothed rubber belt from the crankshaft with fixed timing. A short timing chain then drove the inlet camshaft from a sprocket on the exhaust camshaft. So far, so conventional.

THE NEW WATER-COOLED FLAT-SIX MADE USE OF TWO CYLINDER HEADS AND FOUR CAMSHAFTS, MEANING IT REQUIRED TWO SETS OF VARIOCAM CONTROLS

GRAND ROTATION

The clever bit came in the small space between the camshafts, where a solenoid-operated valve moved a tensioner which, in effect, altered the timing of the intake camshaft relative to the exhaust. The engine control system, a Bosch Motronic unit, was tasked with giving the signal to the solenoid. By default, there was no valve overlap, because the exhaust valves closed at one crankshaft degree of rotation before the piston reached top-dead-centre and the inlet valves didn't open until 7.5 degrees after the piston hit TDC. This allowed for stable idle, even if the VarioCam system failed. This setting was retained up to 1,500rpm.

It was also used for engine speeds above 5,500rpm, which may sound curious given our earlier explanation of valve overlap, but the valve opening duration was fixed by the shape of the camshaft lobes, meaning Porsche's engineers found more of a benefit to closing the inlet valves later at high engine speeds than they did with valve overlap. Meanwhile, to increase torque output in the mid-range, the VarioCam system advanced inlet timing by fifteen crankshaft degrees to 7.5 degrees before TDC. This gave a 6.5-degree overlap between 1,500rpm and 5,500rpm.

Although this wasn't the only improvement to the three-litre four-pot, it was certainly a major step forward — power and torque jumped from the 944

Above VarioCam technology: the valve timing of the intake camshaft can be changed in a fully variable manner using the vane cell adjuster

S2's 208bhp at 5,800rpm and 206lb-ft at 4,000rpm to 236bhp at 6,200rpm and 225lb-ft at 4,100rpm respectively. Despite a little weight gain in the 968, the benchmark 0-62mph time dropped 0.3 seconds to 6.5 seconds and the top speed rose from 150mph to 156mph. Small gains, ostensibly, but contemporary road tests confirmed that the 968 felt notably friskier.

NEXT GENERATION

Though 968 sales never really took off in the way many hoped, VarioCam had proved itself a success. The next Porsche to get the system was the 986 Boxster. The roadster's new water-cooled flat-six made use of two cylinder heads and four camshafts, meaning it required two sets of VarioCam controls, but otherwise, the operating principle remained unchanged. The Boxster's engine was the precursor to what would power the 996, of course, and VarioCam was carried over to the first water-cooled 911 virtually unchanged. It got a major overhaul in 1999, however, with the launch of the first 911 GT3. The idea of a movable tensioner between each pair of camshafts was ditched and, instead, the sprockets turning the intake camshafts were replaced with cam phasers. Using oil pressure, these can alter the rotation of the camshaft relative to the sprocket turned by the timing chain, resulting in altered timing of intake valve operation. In crankshaft angle, the range of adjustment of this first iteration was twenty-five degrees and was operated to three distinct settings, one covering engine speeds up to 2,000rpm, the next up to 6,400rpm and then the third to take the engine to its 7,400rpm rev limit. The timings were all about performance, obviously, and the limited-production Porsche making use of them is now the stuff of legend.

The second iteration of the 996 GT3 came with further improvement in 2003, leading to even more eye-opening performance. The VarioCam system retained the same sprocket-based cam phaser idea, but the range of variation was increased to forty-five degrees and, rather than having three set steps as was the case with the first GT3, timing was continually altered by the engine control unit, allowing for much finer adjustment of inlet valve timing to suit the full range of engine speeds and loads. Though the focus was on increased performance, this also enhanced drivability, low-down torque and, remarkably, emissions and fuel economy. Porsche updated the 986 Boxster the same year, fitting it with the very same VarioCam hardware.

Right VarioCam Plus (with different strokes of the intake valves) contains two engine concepts: camshaft adjustment and valve lift changeover

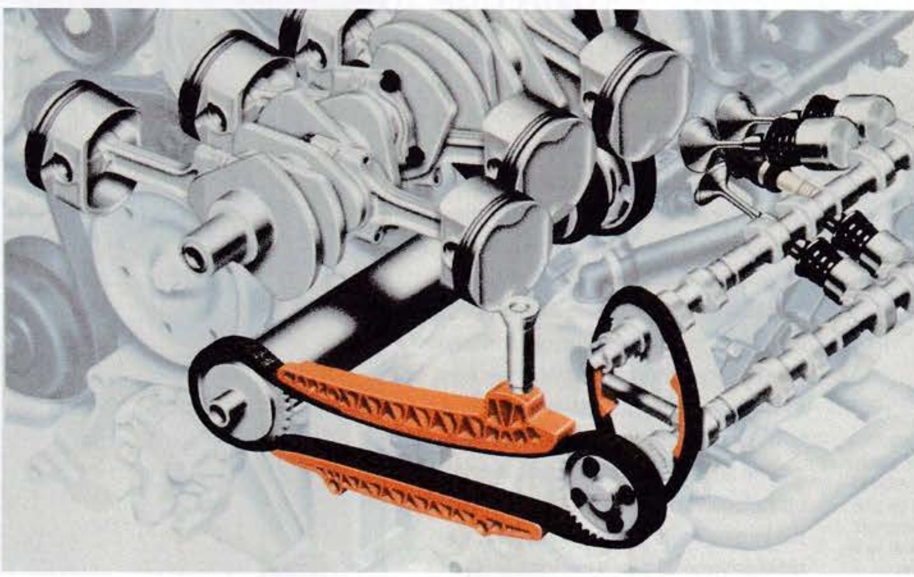
Earlier, in 2002, a significant development of VarioCam was introduced for select models. Named VarioCam Plus, it altered valve timing in the same way as before (with the cam phaser), but added to that was an ingenious way to vary the valve lift, as defined in a 1998 European patent (*Valve operating device of an internal combustion engine*) filed by Dieter Kraxner, Joachim Grünberger and Dietmar Schwarzenthal. A key component was a new switchable bucket tappet. At its centre was a smaller tappet sliding smoothly along the axis of them both, in contact with the top of the valve stem. The larger tappet was in a fixed axial position so that it could be connected with an oil pressure 'signal' that then moved a small spring-loaded pin within, ensuring the inner and outer tappets were locked together at the same height. Just as important as this neatly packaged idea was a redesigned set of cam lobes. Instead of a single profile per valve, there were three thinner lobes per inlet valve. The outer two bore a high-lift profile (10mm in the 996 Turbo), while the central cam lobe featured a profile resulting in valve lift of just 3mm. What this mean was that when the tappets were *not* locked together, the outer lobes met no resistance to push the outer tappet down (it was spring loaded against these lobes internally), allowing the central, low-lift cam lobe to control the operation of the inlet valve. When high lift was required, the tappets were locked together by the pin and the outer pair of lobes defined the movement of the valves.

A MATTER OF TIMING

Brilliant, right?! "But why?" we hear you ask. Well, it's all about stable engine running and complete combustion at low engine speeds and loads. The option to vary both valve timing and lift simultaneously allowed Porsche to optimise the 996 Turbo's engine across its operating range, from efficient idling and slow-speed driving to outrageous performance at the other end of the scale. The control and operation of these systems has, of course, been refined in the intervening years, but their principles are unchanged. Variable timing was soon added to exhaust camshafts, too (again, using cam phasers), giving even more flexibility to optimise the whole engine.

The latest change to VarioCam Plus was introduced for the 992-generation 911's turbocharged flat-six. Here, the shape of the airflow entering the cylinder at low speeds and loads is altered by using two different lift profiles for the central lobes (described earlier) on each pair of inlet valves. One of them lifts the inlet valve by just 2mm, while the other inlet valve in the same cylinder is lifted by 4.5mm. This offset causes a swirling motion of incoming air and helps reduce instability at low engine speeds, to the benefit of fuel economy and emissions. Variable valve operation may have been verging on trendy in the 1990s, when Porsche first introduced VarioCam, but it's nigh-on crucial today for a Porsche engine expected to do it all. ●

Above The 992's twin-turbocharged flat-six features a fresh round of VarioCam updates



Below VarioCam is controlled via the drive chain and provides a phase displacement for the opening times of the inlet valves