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The new “cylinder on demand” technology

Summary

Another big step forward in efficiency from Audi – the “cylinder on demand” system

Audi has once again lowered the fuel consumption of its engines. The 4.0 TFSI, which will make its appearance at the beginning of 2012 in the Audi S6, S6 Avant, S7 Sportback and S8, features the new “cylinder on demand” technology. Bentley was also involved in the development process of this new engine and will install the engine in the Continental GT in the near future.

When this twin-turbo V8 is operating at part-load, four of its cylinders are deactivated. This lowers fuel consumption according to the NEDC test cycle by about five percent and reduces emissions by approximately 10 to 12 g/km *(16 to 19 g/mile)* of CO_2. Add to this the effect of the engine start-stop system – fitted in the Audi S models – that shuts down the engine when the car is standing still, and the reduction in emissions on Audi models can be as high as 24 g/km *(38.62 g/mile)* of CO_2.

The occupants of cars equipped with this new technology enjoy the same high standard of journey comfort as ever. When the 4.0 TFSI is running on four cylinders, no unpleasant noise or vibration is evident inside the car. This is achieved with two accompanying high-end Audi technologies: Active noise control (ANC) and active engine mounts.

Cylinder deactivation on the new 4.0 TFSI is activated at low loads, low to moderate engine speeds and in third gear or higher. If these operating characteristics are present, the system closes the inlet and exhaust valves of cylinders 2, 3, 5 and 8. Efficiency is then higher in the active cylinders because the operating points are displaced toward higher loads.

An enhanced version of the Audi valvelift system closes the valves by means of sliding sleeves on the camshafts. Just before this happens, the combustion chambers are filled with fresh air. Fuel injection and ignition are shut down. The reduced internal cylinder pressure in relation to the injection of exhaust gas is an important efficiency factor.

The instrument-cluster display indicates when the four-cylinder operating mode is active. If the driver depresses the accelerator pedal firmly, the deactivated cylinders cut in again. All these changeovers take place quickly and smoothly.

The “cylinder on demand” system is permanently ready for use, even with the automatic transmission in the “S” mode and the dynamic setting of Audi drive select. In the NEDC test it reduces fuel consumption by around five percent. Add to this the effect of the start-stop system that stops the engine when the car is at a standstill, and the system can reduce fuel consumption by as much as 12 percent. The engine’s efficiency potential becomes especially evident at the speeds at which the car is most frequently driven. At 80 km/h *(49.71 mph)*, for instance, the gain in efficiency is 12 percent for all S models, and can still be as high as seven percent even at a road speed of 130 km/h *(80.78 mph)*.

When the 4.0 TFSI is operating in the four-cylinder mode, two high-end technologies counteract unwanted noise and vibration inside the car: Active noise control (ANC) and active engine mounts.

ANC records the overall interior noise pattern in a precisely differentiated manner at four microphones, and analyzes it to identify potentially disturbing constituents. If necessary, the system then emits an opposing sound via its loudspeakers, which cancels out the original noise so effectively that the car’s occupants cannot hear it. The active engine mounts use a similar principle. If the sensors detect vibration from the engine, counter-vibration is stimulated until the vibration falls to an imperceptible level.

The total effect of these high-end methods – Active noise control, active engine mounts and fresh-air injection into the cylinders – is to make Audi “cylinder on demand” technology both refined and highly efficient. This solution is clearly superior to previous ones offered by competitors. It provides customers with genuine fuel economy benefits and yet no drawbacks – a crucial test that all Audi innovations have to pass.

In the spring of 2012, when the new 4.0 TFSI becomes available in the large Audi S models, its consumption in the S8 will be no more than about 10 l/100 km *(23.52 US mpg)*. The S6 and S7 Sportback will consume distinctly less than 10 l/100 km. Two versions of the V8 engine will be launched: with an output of 309 kW (420 hp) and a maximum torque of 550 Nm *(405.66 lb-ft)* for the S6, S6 Avant and S7 Sportback, the equivalent figures for the S8 being 382 kW (520 hp) and 650 Nm *(479.42 lb-ft)* torque.

The 4.0 TFSI incorporates a whole cluster of high-end technologies. In addition to the “cylinder on demand” system they include twin-scroll “biturbo” turbocharging, a comprehensive thermal management system, minimized internal friction and innovative cylinder head construction with the exhaust valves on the inside and fresh air intake on the outside. This layout keeps the engine compact, with a length of only 497 mm *(19.57 in)* and short gas flow paths with minimum frictional losses.

Full version

The new 4.0 TFSI engine with “cylinder on demand”: high-end technologies for efficiency and refinement

Audi continues to increase the efficiency of its engines. The new 4.0 TFSI, a powerful V8 with twin turbochargers, is equipped with “cylinder on demand” technology. When operating at part load, four of its cylinders are deactivated. This reduces fuel consumption by an average of five percent. To complement this system there are two further technologies: Active noise control (ANC) and active engine mounts. They ensure that the car’s occupants do not hear or sense any disturbing noise or vibration even if the engine is operating in the four-cylinder mode.

The “cylinder on demand” system

On the new 4.0 TFSI, cylinders are deactivated if the load on the engine is low. The upper limit for the deactivation to take effect, depending on engine speed, is between about 25 and 40 percent of maximum torque, in other words about 120 and 250 Nm *(88.51 and 184.39 lb-ft)*. In this operating range the mean effective pressure rises to eight bar. Coolant temperature must be at least 30°C *(86°F)* and third gear or higher must have been selected. The engine must be running at more than idle speed, namely between 960 and 3,500 rpm.

If these preconditions are satisfied, the system closes the inlet and exhaust valves of two cylinders on each bank. The V8 continues to run as a V4 with a regular firing order, but with the mixture in only two cylinders instead of four being ignited on each revolution of the crankshaft. Instead of 1 – 5 – 4 – 8 – 6 – 3 – 7 – 2, the firing order is then 1 – 4 – 6 – 7; efficiency in the active cylinders is increased because the operating points are displaced toward higher loads.

Intelligent operation: the enhanced AVS system

The necessary valves are closed on the four camshafts by an enhanced version of the Audi valvelift system (AVS). Its sleeves can be slid sideways electromagnetically, and have an additional “zero-lift” cam; since this does not move the cam followers, the valve springs keep the valves closed.

At the same time, the engine management system shuts down fuel injection and ignition. The four-cylinder status is visible on the instrument panel, on the driver information system display: the fuel consumption indicator bar turns green and a text message is also displayed.

In the deactivated cylinders, the pistons continue to move because they are being driven by the crankshaft; before the valves close the combustion chambers are again filled with fresh air and the fuel injection and ignition shut down. This intake of fresh air lowers pressure in the cylinders and reduces the energy needed to move the pistons – an important factor for increased efficiency.

As soon as the driver presses firmly down on the accelerator pedal, the deactivated cylinders cut in again. The return to eight-cylinder operation, like the cylinder deactivation process, takes place so smoothly and quickly that it is difficult to notice. It is completed on average in just 300 milliseconds. The actual changeover naturally involves a temporary drop in efficiency, so that the reduction in fuel consumption only sets in three seconds or more after cylinder deactivation.

Audi has therefore developed a control logic that monitors movement of the accelerator and brake pedals and the steering wheel by the driver. If an irregular pattern is detected, cylinder deactivation may be inhibited in certain situations, for instance at a roundabout or when the car is driven hard on interurban roads. Cylinder deactivation lasting only a few seconds would tend to increase fuel consumption rather than decreasing it.

The “cylinder on demand” system is ready to operate all the time, even in the S mode of the automatic transmission or the dynamic setting of Audi drive select. It saves the most fuel when the car is driven steadily at a moderate speed, in the manner customary on many main roads. At 80 km/h *(49.71 mph)*, for instance, the gain in efficiency on all “S” models is 12 percent, and even at 130 km/h

(80.78 mph) a seven percent saving is attainable. On the standard NEDC test cycle the increase in efficiency is more than five percent, and if the effect of the start-stop function that switches off the engine when idling is added to this, the total economy effect is around 12 percent.

Bentley was involved in the development process of this technology and will install the groundbreaking new 4.0 TFSI engine in the new Continental GT.

In the part-load range, the GT will use the “cylinder on demand” system deactivating four of the eight cylinders and thereby reducing fuel consumption in the NEDC cycle by up to 40 percent. Bentley has already installed a similar system on its “large” V8 in the Mulsanne, which has a displacement of 6.75 liters and delivers over 1,000 Nm *(738 lb-ft)* of torque.

The quiet running allied with the harmonious power development of the 4.0 TFSI will blend perfectly with this grand tourer when it is introduced in 2012.

ANC and active engine mounts

V8 engines are not only noted for their pulling power and harmonious throttle response but also for their smooth running. This is also true of the new Audi 4.0 TFSI. When the V8 engine operates as a V4, its crankshaft and reciprocating components tend to generate higher torsional vibration, depending on load and engine speed. This causes airborne noise to reach the interior of the car. The exhaust system, which is of large size, also emits drumming noise that is difficult to suppress completely despite the use of an intelligent flap-valve system. The aim is therefore to reduce all these disturbing noises to a level that the driver and passengers cannot hear.

ANC: noise and opposing noise equals no noise

Active noise control (ANC) counteracts unwanted noise by generating a similar noise. This principle is known as destructive interference: If two sound waves of the same frequency are superimposed, their amplitudes – the peaks and troughs that determine the sound pressure – can be arranged to cancel each other out. The amplitudes must be of the same strength, but the phases opposed by 180 degrees. Acoustics experts refer to this as “noise cancellation”.

The Audi models in which the new 4.0 TFSI will be available are equipped with four small microphones; these are visible in the roof lining. Each of them registers the complete noise spectrum in its immediate area. From these signals the ANC control unit computes a differentiated spatial sound image; information on actual engine speed is also obtained from the crankshaft sensor.

In all the previously calibrated zones in which the system identified disturbing noise, it emits a targeted, precisely modulated cancellation sound. A particular challenge is for the ANC to react especially quickly and accurately in the short periods during which cylinder deactivation or reactivation takes place.

Active noise control is active whenever needed – whether the sound system is switched on, deactivated, loud, soft or muted. It operates with whichever sound system is installed, even with the Bang & Olufsen Advanced Sound System.

Active engine mounts: counteracting vibration for greater refinement

Audi normally uses firm, sporty settings for its engine mounts. For many years now certain models – notably the A8 at the top end of the range – and various engines have had switchable electromagnetic mounts. These have two operating settings: at idle speed they have a “soft” characteristic to prevent noise and vibration from reaching the interior, but when the car is being driven a firmer damping rate is selected in order to suppress engine vibration.

The active engine mounting that Audi has developed for the 4.0 TFSI takes this technology a decisive step further – it cancels out engine vibrations with out-of-phase counter-oscillations. The key component is an electromagnetic oscillating-coil actuator. This has a rapid stroke that is transmitted via a flexible diaphragm to the hydraulic fluid in the mounting, which also absorbs oscillating movements from the engine. In the fluid these are overlaid by the actuator movements and cancelled out.

The control units for the active engine mounts receive their signals from two sources. Engine speed is detected by the crankshaft sensor; these signals are used to compute the precise phase and frequency of the actuator signal. Acceleration sensors on the two engine mounts supply the data that determine the amplitude necessary to cancel out the vibration.

When the new 4.0 TFSI is running in the four-cylinder mode, it generates a certain amount of engine vibration and drumming noise of what is known as the second order. They are not typical of a V8, but the counter-vibration generated by the active mounts reduces them to an undetectable level.

At idle speed with all eight cylinders in operation, engine excitation of the fourth order occurs. This too is largely eliminated by the active engine mounts so that the engine appears to be running even more smoothly.

The new 4.0 TFSI

The new Audi 4.0 TFSI is a high-tech unit. In addition to the “cylinder on demand” system, it has a number of other features designed to boost its power output and efficiency still further. Two versions of this twin-turbocharger V8 are being launched. In the S6, S6 Avant and S7 Sportback it develops 309 kW (420 hp), in the S8 382 kW (520 hp). Maximum torques are 550 and 650 Nm *(405.66 and 479.42 lb-ft)* respectively. In all the Audi models available with this engine it has an average fuel consumption of 10 l/100 km *(23.52 US mpg)* or lower.

The 4.0 TFSI has a displacement of 3,993 cc, a bore of 84.5 millimeters (3.33 in) and a stroke of 89 millimeters (3.5 in). The 4.0 TFSI is the most recent addition to the Audi family of vee engines, and has all their typical features. The included angle between the cylinder banks is a classic 90 degrees. As a space-saving measure, the chain drive to the four camshafts and the auxiliaries is located at the rear of the engine.

The cylinder block is made from an aluminum-silicon alloy by a low-pressure chill casting process that achieves a high standard of homogeneity. The high proportion of silicon makes the cylinder walls extremely resistant to wear. A rigid bedplate for the lower main bearing bridges increases the rigidity of the block still further. Extremely compact design keeps the length of the engine down to only 497 mm *(19.57 in)*. This enables it to be installed directly above the front axle, and promotes good weight distribution, which in turn makes the car even more dynamic on the road.

Like almost all Audi engines, the new 4.0 TFSI follows the downsizing principle, with forced aspiration in the form of turbocharging taking the place of sheer engine size. This principle harmonizes perfectly with FSI direct fuel injection. Each cylinder bank has a twin-scroll turbocharger to deliver fresh air to the engine.

From each pair of cylinders, the exhaust ports lead separately to a manifold and the turbocharger housing; they are not combined until immediately ahead of the turbine. This prevents the exhaust gas flows from influencing each other and guarantees rapid torque build-up and excellent throttle response.

This principle ensures powerful torque build-up at an early stage when accelerating from idle speed. Even at 1,000 rpm the 4.0 TFSI reaches a torque of 400 Nm *(295.02 lb-ft)*. The top version is ready to deliver its maximum torque of 650 Nm *(479.42 lb-ft)* all the way from 1,750 to 5,000 rpm; the 550 Nm *(405.66 lb-ft)* torque of the other engine version is available even earlier, from 1,400 to 5,250 rpm. The nominal peak engine speeds are 6,000 and 5,500 rpm respectively.

Another innovation: cylinder head construction

The turbochargers and their charge-air intercooler – an air-to-water heat exchanger – are located in the vee between the cylinder banks instead of in the more customary position on the outside of the engine block. The cylinder heads have a new, innovative layout, with the exhaust side on the inside and the intake side on the outside.

This layout is more compact, improves thermodynamic performance and keeps the gas flow paths short, with minimum frictional losses, so that the 4.0 TFSI reacts spontaneously to accelerator pedal movements. Hot components, especially the manifolds, are extensively insulated to ensure stable thermal conditions in the vee of the engine.

The fresh air intake systems are mounted on the outside of the cylinder banks. Switchable flap valves in the inlet ports cause the incoming air to rotate in a drum-like pattern. This imparts intensive swirl to the fuel-air mixture and cools the combustion chambers. The engine's compression ratio can therefore be higher despite the use of turbocharging, but without the risk of inducing combustion knock.

The 4.0 TFSI makes use of all the technologies from the Audi modular efficiency platform. They range from the engine start-stop system to a recuperation system and a variety of measures aimed at reducing friction. During assembly of the V8 at the Audi factory in Györ, Hungary, high-end technologies such as plate honing are used. The gudgeon pins are given a fine diamond-like carbon (DLC) coating, and the valve springs have a relatively low compression rating.

The innovative thermal management system uses a ball valve to disconnect the water pump during the engine warm-up phase. There is no coolant flow at all through the engine, the oil reaches its operating temperature more rapidly and the phase in which high frictional losses occur is shorter.

The seven-speed S tronic and the eight-speed tiptronic transmission available with the 4.0 TFSI engine are included in the thermal management concept. The oil pump builds up pressure in two stages. Oil jet cooling for the piston crowns and cylinder walls is controlled according to a mapped characteristic.

The difference in power output between the two versions of the 4.0 TFSI is due mainly to the use of either a single-branch or dual-branch intake system, the turbocharger operating settings and the top version’s additional oil cooler. There are further differences relating to the crankshaft and its main bearings, the compression ratio, valve timing and the injectors.