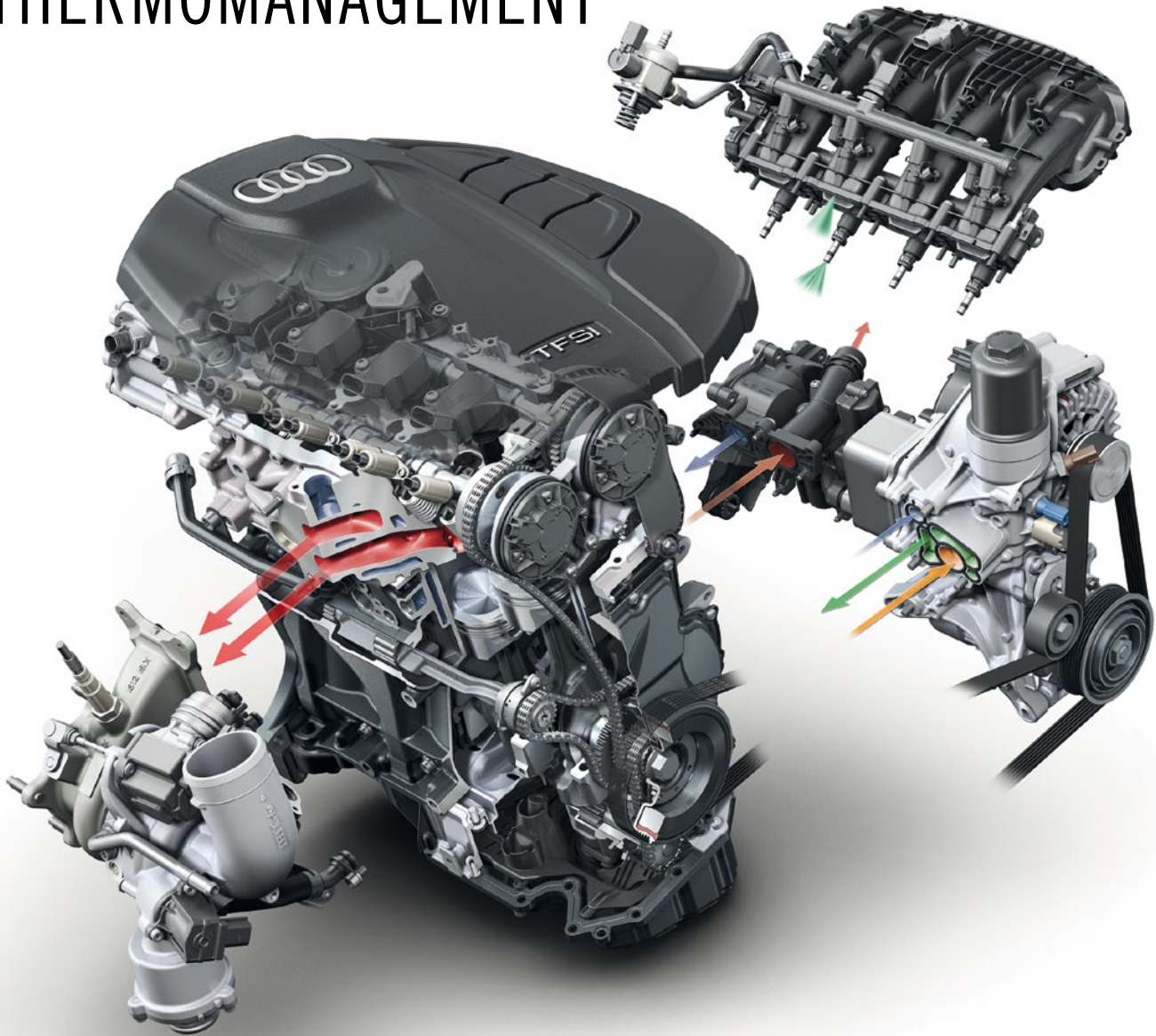


THE NEW 1.8 L TFSI ENGINE FROM AUDI

PART 1: BASE ENGINE AND THERMOMANAGEMENT



The launch of the new 1.8 l TFSI engine marks the third generation of the successful four-cylinder gasoline engine family from Audi. It has been completely revised in order to meet ambitious CO₂ targets and ensure compliance with future Euro 6 emissions standards. The new generation features numerous innovative technologies, including an exhaust gas cooling system integrated into the cylinder head, a dual fuel injection system with direct and port-fuel injection as well as the Audi valvelift system with twin camshaft adjustment. A new-style fully electronic coolant control also enables an innovative thermomanagement system to be implemented. This first part of the article details the base engine and the thermomanagement system of the new engine. The second part of the article, which will be published in MTZ 7/8, covers the mixture formation, the combustion method and the turbocharging.

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INTRODUCTION AND REVIEW

The history of Audi inline four-cylinder TFSI engines extends back to 2004, when the world's first direct-injection turbo engine, based on the tried and proven EA113 engine series, went into production as the 2.0 l TFSI [1, 2]. Development of the concept for the EA888 engine series with chain drive [3] had actually begun back in 2003, with the aim of replacing the successful timing belt driven EA113 series. The EA888 engine was designed from the very beginning as a “global engine” for the VW Group (across all brands and platforms) and for worldwide application (across all markets). Following the successful launch of this completely new engine generation in spring 2007 (gen. 1) [3] and the introduction of the Audi valvelift system [4] as well as numerous measures to optimise friction in the 2009 models (gen. 2) [5], a further groundbreaking optimisation (gen. 3) is about to be put into production in the Audi A4/A5 family, ❶.

The first and second generation EA888 engines are already more than meeting their original objective of serving as “global engines” (i.e. for a wide variety of vehicle platforms and Group users), having reached production levels of over one million units a year.

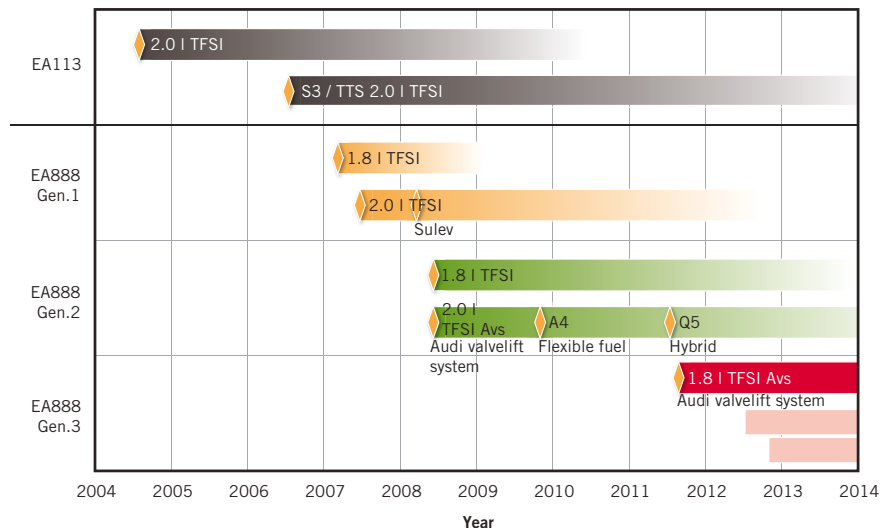
The inline-four TFSI engine series EA113 and EA888 have achieved an unmatched record of success since 2005, winning a total of ten awards in the prestigious “In-

ternational Engine of the Year” and “10 Best Engines” competitions. The third generation of the EA888 now marks the next chapter in the history of inline-four TFSI engine technology, and is poised to continue the success story. Other variants (with varying engine capacity, power output and torque specifications) are in preparation alongside the third generation unit presented here.

ENGINE FEATURES AND TECHNICAL HIGHLIGHTS

The development objectives for the third generation of the EA888 I4 TFSI engine series were:

- : development of a modular kit for 1.8 l and 2.0 l variants with a high proportion of identical components
- : installation in all VW Group transverse-mounted and longitudinal-mounted platforms
- : reduction of internal friction in the engine
- : improvement in power, torque and fuel efficiency
- : further improvement in comfort attributes
- : preparation for conformance to all future emissions standards (e.g. Euro 6)
- : preparation for deployment on all markets
- : enhanced robustness for increasing hybridisation and deployment in emerging markets
- : further weight reduction.



❶ Roadmap of Audi inline four-cylinder TFSI engine technology [1, 3, 5, 6, 7, 8]

For the third generation of the EA888 engine, the tried and proven power train layout with Lancaster balance was adopted, also incorporating further improvements in terms of internal friction. For example, the main bearing diameter has been further reduced; the balance shafts are in part roller bearing mounted; and the pressurised oil circuit, including the control oil pump, has been optimised.

To improve the torque characteristic, the tried and proven Audi valvelift system

has been adopted from the 2.0 l second generation predecessor engine, and an additional exhaust camshaft adjuster has been integrated. The high torque of 320 Nm at 1500 rpm delivers outstanding performance, but also in particular low consumption figures based on modified gearbox transmission ratios (downspeeding).

An entirely new cylinder head has been developed for the third generation EA888 and, for the first time in this power and torque class, the exhaust gas recirculation

is fully integrated to the turbocharger.

This water-cooled integrated exhaust gas cooling system makes it possible to reduce full-load consumption considerably.

To provide intelligent control of the engine's heat flows (thermomanagement), a new-style rotary slide module has been developed to provide fully electronic coolant control. In the engine's warm-up phase for example, it is able to completely block the coolant from entering the engine or set a minimal volumetric flow. When the engine is warmed up, the coolant temperature can be quickly and fully variably adjusted to various temperature levels according to the load demand and external conditions.

In order to comply with the future Euro 6 emissions standard, Audi has for the first time developed a dual fuel injection system with FSI and MPI injection. The ability to freely select the injection mode means that particulate emissions can be reduced significantly across wide map ranges and consumption can also be cut.

The weight of the new EA888 series has been significantly reduced again, despite numerous additional CO₂ measures. Key factors in this are the thin-walled engine block (3 mm thick), a weight-optimised crankshaft, the integrated exhaust gas cooling system cylinder head integrated exhaust manifold, a plastic oil pan, and the use of aluminium bolts.

② sets out the main dimensions and other characteristic data of the third generation 1.8 l TFSI engine compared to the predecessor second generation 1.8 l TFSI.

MAIN DIMENSIONS	UNIT	VALUE	
		1.8 l TFSI Gen.2	1.8 l TFSI Gen.3
ENGINE DIMENSIONS			
Capacity	l	1.798	
Stroke	mm	84.1	
Bore	mm	82.5	
Stroke/bore (ratio)	-	1.02	
Distance between cylinders	mm	88	
Block height	mm	220	
Con-rod length	mm	148	
Crankshaft bearing	-	5	
Main bearing diameter	mm	52	48
Con-rod bearing diameter	mm	47.8	
Piston pin diameter	mm	21	23
VALVE DIAMETER			
: Inlet	mm	33.85	
: Exhaust	mm	28	
VALVE STROKE			
: Inlet	mm	10.7	
: Exhaust	mm	8	6.35/9
TIMING WITH 1 MM VALVE STROKE			
IO retarded	°CA after TDC	38	30
IC retarded	°CA after BDC	48	40
EO advanced	°CA before BDC	28	39/24
EC retarded	°CA before TDC	8	-6
CAMSHAFT ADJUSTMENT			
Inlet camshaft adjustment range	°CA	60	
Exhaust camshaft adjustment range	°CA	-	30
Compression ratio	-	9.6	
Power output	kW at rpm	118 at 4500-6000	125 at 3800-6200
Torque	Nm at rpm	250 at 1500-4500	320 at 1500-3700
Fuel type	RON	95/91	95
Engine weight to DIN70020 GZ	kg	135	131.5
Initial oil charge	l	5.4	
Emissions standard	-	Euro 5	Euro 6

② Main dimensions of the new 1.8 l EA888 inline four-cylinder TFSI engine compared to its predecessor

BASE ENGINE

The focus of the latest development work on the base engine was on significantly reducing friction loss while at the same time cutting engine weight. Moreover, a maximum identical parts strategy was implemented in spite of the specified broad power and torque range (spread from entry-level to top-of-the-range engine).

ENGINE BLOCK

Based on the aim of further reducing the weight and blank tolerances of the engine block, the casting process was changed from the conventional flat pouring to upright pouring. The nominal wall thickness of the engine block has been

reduced from 3.5 mm \pm 0.8 mm to 3.0 mm \pm 0.5 mm and, thanks to greater freedoms in the core pack, additional functions could be integrated into the engine block. The function of the coarse oil separator has been integrated into the engine block casting, so eliminating the need for the bolted-on coarse oil separator and the flange face on the engine block. Adjusted to function, these engine block-related measures delivered a 2.4 kg weight saving. To further improve the comfort properties of the engine, the main bearing covers have been bolted to the top section of the oil pan.

CRANK DRIVE AND BALANCE SHAFTS

The main bearing diameters of the crankshaft have been reduced from 52 mm to 48 mm in order to cut friction, and the number of counterweights has been reduced from eight to four. This reduced the weight of the crankshaft by 1.6 kg. The pistons feature a newly developed, strength-enhanced alloy. In the course of this development, piston play was enlarged to optimise friction and piston wear was adapted based on a wear-resistant piston skirt coating with nanoparticles. The balance shaft concept has been changed to roller bearings, ③.

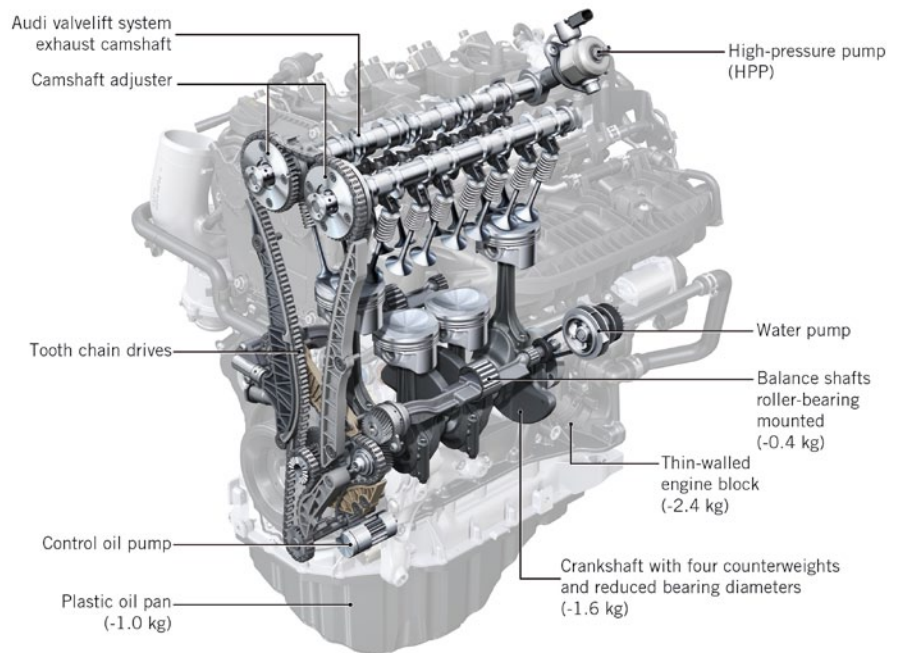
At low oil temperatures especially, the roller bearing mounting of the balance shafts results in substantially reduced friction loss. In addition, intensive optimisation of the topology helped reduce system mass by 20 % and rotational inertia by 30 %, while retaining the same mass balancing.

OIL CIRCULATION

The following measures were implemented on the engine in order to reduce the power consumption of the control oil pump:

- : reduction in displacement via oil temperature
- : optimised pressure losses in the pressurised oil ducts
- : reduction in oil pressure level in the low pressure stage to 1.5 bar
- : extension of the operating range of the low pressure stage to 4500 rpm.

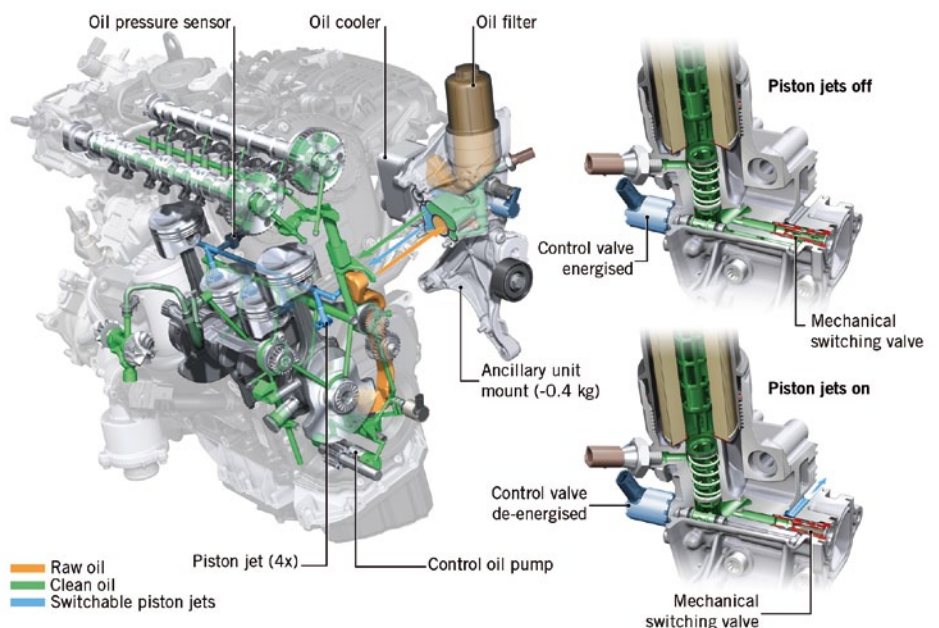
In addition to a further improvement in the efficiency of the control oil pump, the piston cooling has been changed from conventional spring-loaded spray nozzles



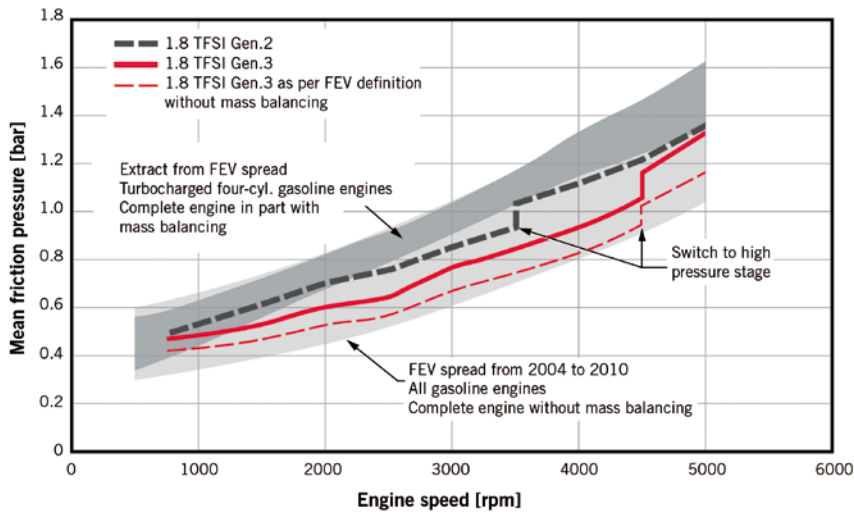
③ Crank drive with Lancaster balance as well as chain drives for camshafts, balance shafts and oil pump

to an electrically switchable system, ④. When current is applied to the electric control valve it releases a small control channel to the rear of the mechanical switching valve (piston spray nozzles off), allowing the electric control valve to be designed in a compact, low-cost manner. With no current applied, the mechanical switching valve is pushed up by the applied oil pressure, so releasing the sec-

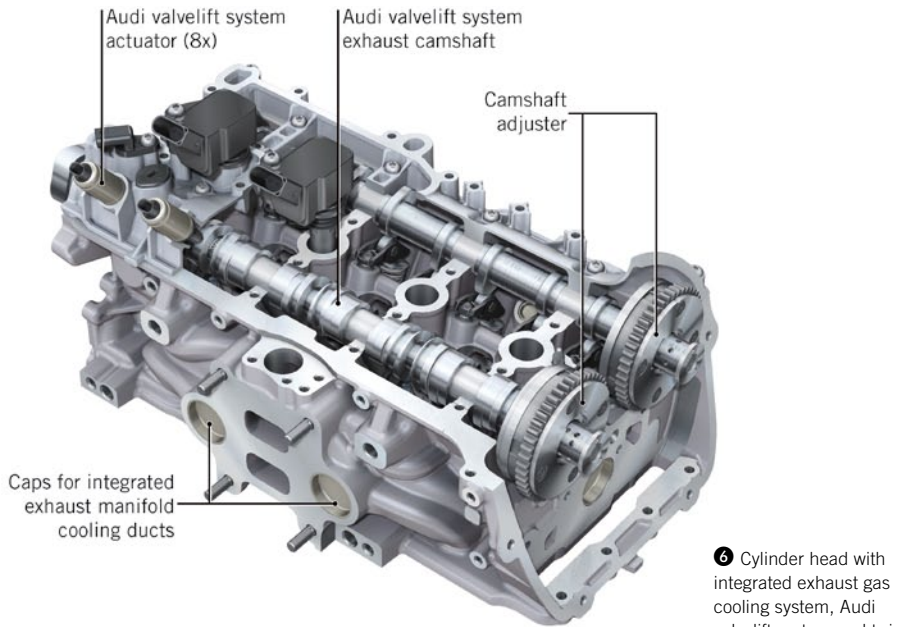
ond oil gallery to the piston cooling nozzles (fail-safe). Both valves are located directly downstream of the oil cooler and oil filter in the ancillary components holder. The new system enables needs-oriented data acquisition for piston cooling and with regard to thermomanagement and thermodynamics. System diagnosis is implemented by way of a dedicated oil pressure switch.



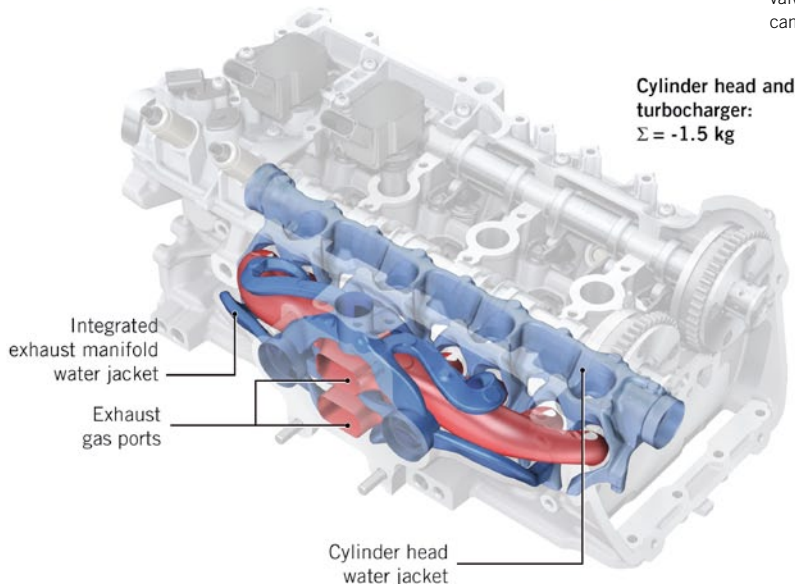
④ Pressurised oil circuit and section through the actuator system for the switchable piston spray nozzles



5 Mean friction pressure characteristic of the new 1.8 l TFSI engine; comparison with FEV spread



6 Cylinder head with integrated exhaust gas cooling system, Audi valvelift system and twin camshaft adjustment



Thanks to all the friction-reducing measures on the base engine, the new EA888 third generation engine series redefines the friction loss spread for turbocharged four-cylinder gasoline engines, 5.

CYLINDER HEAD

For the new EA888 third generation engine series, a cylinder head integrated exhaust gas cooling/routing system with ignition sequence separation has been implemented for the first time for turbocharged direct-injection gasoline engines, 6. This water-cooled exhaust manifold means that the need for full load enrichment is eliminated almost entirely. As a result, consumption can be greatly reduced both in normal customer driving and, especially, when employing a more sporty driving style. Moreover, the integrated exhaust manifold aids rapid heat-up of the coolant and so is a key component of the thermomanagement system. Another advantage lies in the convergence of the gas ducts while still in the cylinder head, which results in a comparatively compact and light turbocharger module. Consequently, the overall cylinder head/turbocharger balance resulted in a 1.5 kg weight reduction.

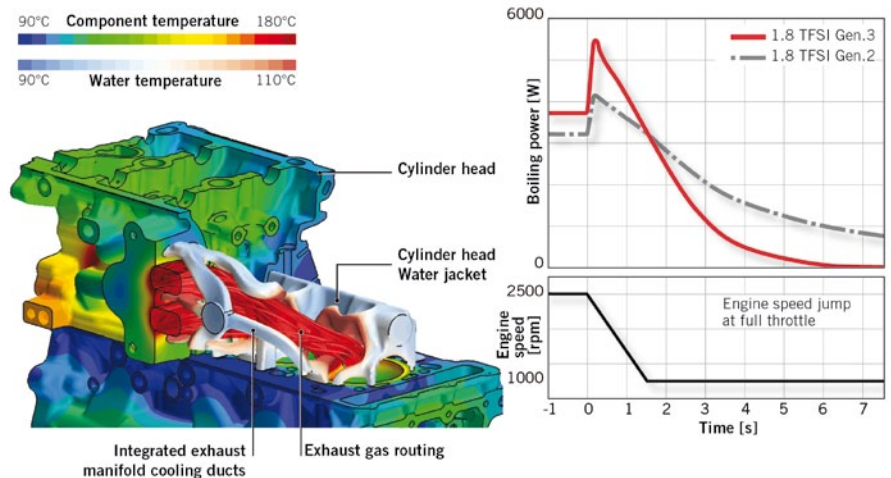
Achieving a thermodynamically and thermomechanically optimised package of gas ducts and integrated exhaust manifold cooling ducts posed a particular challenge during the development of the cylinder head, especially with regard to industrialisation and production castability. The cylinder head places extremely high demands on the casting process. A die with twelve sand cores is produced by the bottom casting method. To meet the high thermodynamic demands of the new third generation 1.8 l engine, the Audi valvelift system and a second camshaft adjuster have been integrated on the exhaust side and the inlet duct has additionally been revised. To control optimum engine heat-up and to improve monitoring of the temperatures in the cylinder head, the coolant temperature measuring point has been moved from the engine block into the cylinder head.

CYLINDER HEAD DESIGN

To simulate the integrated exhaust gas cooling system and its influence on the thermomechanics of the cylinder head, a

number of new simulation methods were also developed alongside established CFD and FEM methods. First, classic CFD simulations were used to produce the basic design of the gas and water cores and combined with FEM methods to thermo-mechanically optimise the cylinder head. As there is intensive coupling between the exhaust gas and cooling water flows and heat transport in the aluminium within a very confined area – that is to say, involving extreme temperature gradients – in this project, all three areas (gas, water, aluminium) were also calculated in a single simulation model for the first time, ⑦ (left). This methodology enables retroactive effects of the component temperatures on the fluid temperatures and the resultant heat flows to be simulated more accurately.

The development of the integrated exhaust manifold cylinder head revealed that, as well as the stationary cooling design, the load cycles involving negative load and speed changes are also a key factor. Immediately after such a change of operating state, firstly the large amount of heat stored in the material is discharged into the cooling water and, secondly, the cooling water volumetric flow and pressure decrease dramatically due to the slow water pump speed caused by the low engine revs. The hot water jacket areas



⑦ Simulation of the thermomechanics of the integrated exhaust gas cooling system: integrated CAE model with temperature distribution (left), boiling response in the cylinder head at full load with negative engine speed jump (right)

are particularly at risk of boiling in this context, which in the long term may result in damage to the cooling water.

Extreme cases of such load cycles, as well as rapid shutdowns, were analysed both on the test rig and by simulation. In the final integrated exhaust manifold configuration, from an integral viewpoint a comparable level to the predecessor engine was attained in terms of short-time boiling intensity, ⑧ (right). This simulation

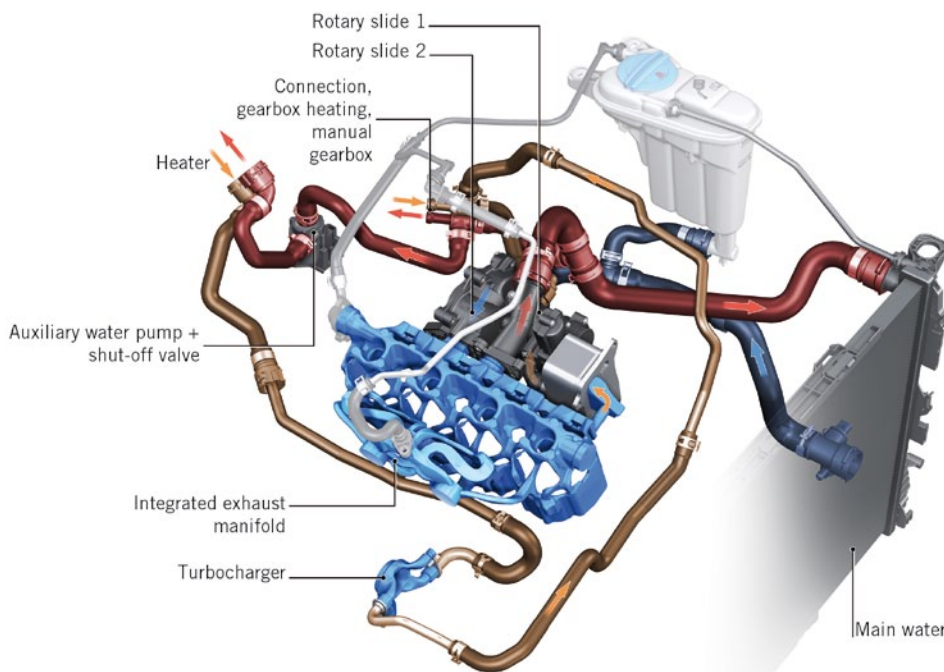
methodology, too, was deployed for the first time in the course of the integrated exhaust manifold development.

THERMOMANAGEMENT/COOLING

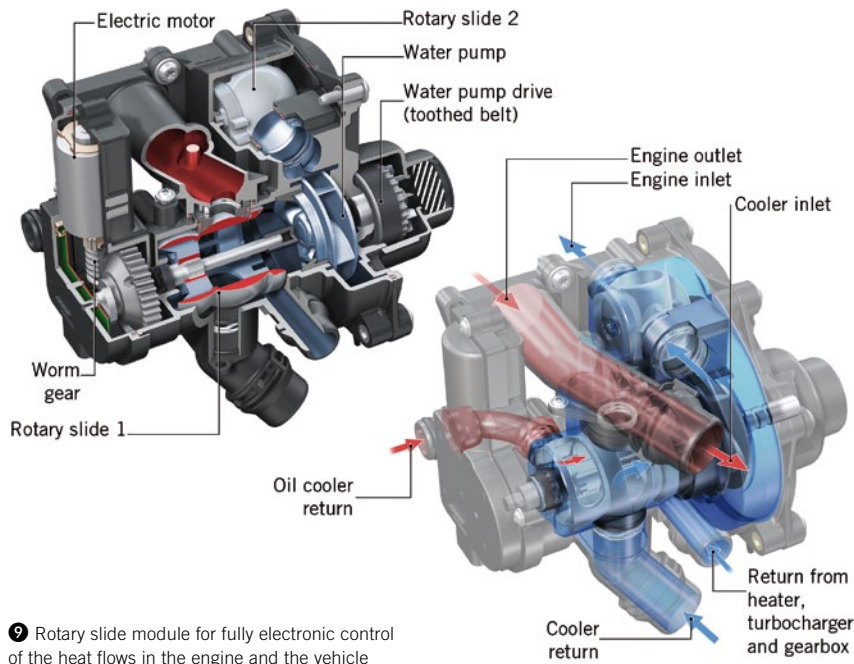
The complete cooling water circuit – both internally inside the engine and on the vehicle side – was designed throughout to provide innovative thermomanagement (ITM), resulting in rapid heat-up of the engine and, as required, of the vehicle interior. The two main components of the thermomanagement system are the integrated exhaust gas cooling system as already described and the rotary slide module for implementing fully electronic coolant control. The complete cooling circuit additionally features switching valves to activate or block the flow through the heater and the gear oil heat exchanger, ⑧.

FULLY ELECTRONIC COOLANT CONTROL

The central actuating element for the fully electronic coolant control and thermomanagement system is the plastic rotary slide module, housing two mechanically coupled rotary slides which regulate the cooling water flow, ⑨. An electric motor drives rotary slide 1 by way of a heavily downspeeded worm gear. This is in turn connected via lantern gear toothing to rotary slide 2. Rotary slide 1 replaces the conventional wax thermostat, and is able to vary the cooling water temperature



⑧ Engine cooling circuit with interface to passenger compartment heating, gearbox heating and main water cooler



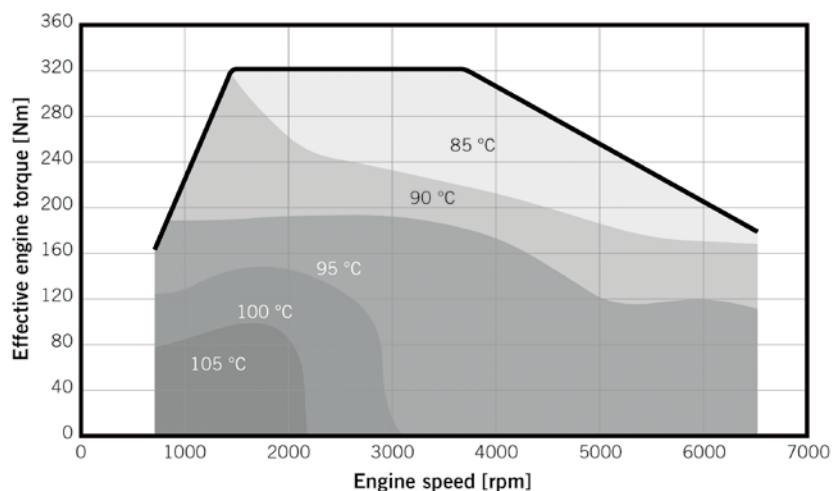
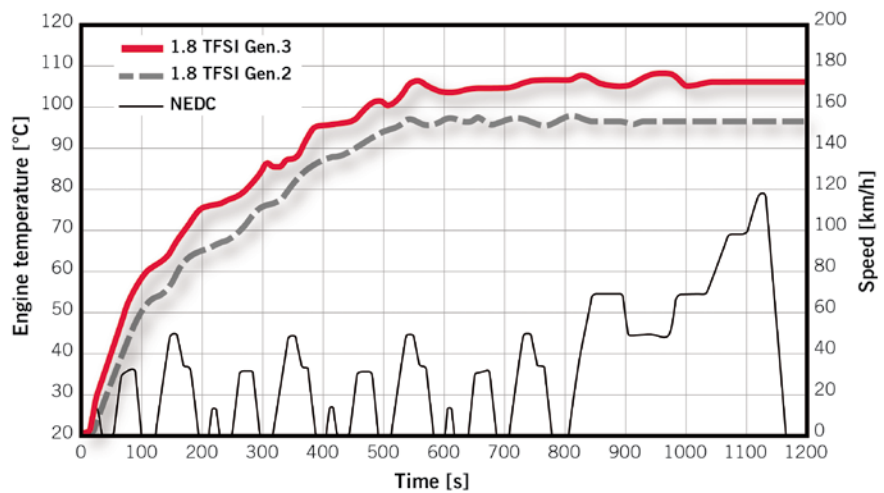
very rapid heat-up of the water further minimises friction in the warm-up phase. Ultimately, as from a specified water temperature, the engine oil is additionally heated by targeted activation of the engine oil cooler by way of rotary slide 1. Once the engine has been sufficiently warmed through, the switching valve to the gear oil cooler is finally opened so as also to warm up the gear oil with the surplus heat. The flow through the main water cooler entails heat loss to the surrounding environment and so, to deliver maximum fuel efficiency, occurs at the latest possible time. The integrated exhaust gas cooling system and the fully electronic coolant control thus provide the engine with a much shorter warm-up phase than its predecessor, and additionally speed up passenger compartment heating, 10 (top).

infinitely as required between 85 °C and 107 °C. Rotary slide 1 additionally regulates the cooling water return from the engine oil cooler.

HEAT-UP STRATEGY

During the warm-up phase, the cooling water flow into the engine is initially completely blocked by rotary slide 2. All external valves are closed, the water is standing throughout the engine. When heating is requested (in real-life customer operation), the standing water does not have to be completely used up. In this case there is an autonomous heating circuit with a dedicated auxiliary water pump via which the waste heat from the integrated exhaust manifold cylinder head is fed to the passenger compartment heater. The cooling water inlet into the engine block (rotary slide 2) remains closed, so maintaining the rapid heat-up function of the cylinder liners and reducing friction. The autonomous heating system means the customer's comfort demands can be met and at the same time the optimum heat-up strategy is implemented to minimise friction.

Finally, as the engine temperature rises further, rotary slide 2 is slowly opened. This generates the minimum necessary cooling water volumetric flow to ensure adequate cooling of the components. The



10 Thermomanagement properties: engine heat-up curve in the NEDC (top), cooling water temperature control across the map (bottom)

TEMPERATURE CONTROL

The innovative thermomanagement system permits optimum setting of the cooling water temperatures across the entire map so as to minimise friction and maximise thermodynamic efficiency. At low engine speeds and loads, the cooling water is adjusted to 107 °C in order to minimise engine friction. As the load and engine speed rise, the cooling water temperature is then lowered down to 85 °C, ⑩ (bottom).

This provides the best possible compromise between reduced friction and optimum ignition efficiency (and minimum knocking), so ensuring optimum overall engine efficiency. The high adjustment speed of the rotary slide module and the high dynamism of coolant control achieved as a result enable the coolant temperature to be lowered very rapidly for the jump to high loads. As a result, temperature overshoots in the components can be avoided.

The innovative thermomanagement system is rounded off by a special run-on function which is activated when the engine is switched off. The electric heating pump and a run-on setting of the rotary slide module then allow a targeted flow through the boil-sensitive cylinder head and turbocharger via the main water cooler, so enabling rapid discharge of the heat stored in those components.

There is no flow through the engine block in the run-on position, so as not to cool the cylinder liners unnecessarily. This function significantly reduced the run-on time, without generating excessive heat loss. Overall, the ITM delivers a consumption advantage of 2.5 g CO₂/km in the NEDC, with significant savings also in customer driving modes. It also provides high levels of comfort thanks to rapid heat-up of the passenger compartment.

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