THE NEW 1.0-L THREE-CYLINDER MPI ENGINE FOR THE UP!

Various demands were placed on the engine of the up!. The primary objective is to ensure efficient consumption values yet also enable dynamic performance. In addition to this, considerable demands were placed on the compact measurements of the engine to allow for a correspondingly small engine compartment. An entirely newly developed three-cylinder engine with two performance classes and with a natural gas variant successfully achieves this careful balancing act.

DEVELOPMENT OBJECTIVES

With a vehicle in the size category of the up!, a compact engine design directly influences the interior space and is of great benefit to the passengers. Further development objectives were as lightweight a design as possible as well as low-cost manufacturability all over the world. To fulfill these requirements, the new three-cylinder engine EA211 was designed. The only thing in common with the familiar EA111 engine is the cylinder spacing of 82 mm. The new 1-l engine is offered in the two performance classes 44 kW and 55 kW, which, in each case, are also available as BlueMotion variants; a natural gas variant (CNG) with 50 kW is also available. The two gasoline versions and the CNG variant, which will be introduced somewhat later, comply with the Euro 5 standard. The key basic data for the three variants is shown in ❶.

The compact full aluminum engine with four valves per cylinder has been consistently designed for low weight and low friction. The diameter of all plain bearings has been minimised. All radial shaft seals to the outside are equipped with wear-optimised seal rings. The valve train is operated by means of roller-type finger followers with low frictional resistance, and the camshafts are driven by a low-friction toothed belt drive. The drive runs in a dust-proof toothed belt cover and is designed to be maintenance-free for the service life of the vehicle.

The intake camshaft adjustment enables perfect control times for each load and speed, hence increasing the efficiency of the engine. Dual circuit cooling and the integrated water-cooled exhaust manifold ensure a short engine heating phase and, with that, operation within the optimum temperature range.

Ultimately, these consistent features of the components and systems, in line with load and requirement, achieved the set objectives: Mean engine pressure when externally driven which is considerably below that of the existing comparable three-cylinder engine from the EA111 series and at the lower end of the competitive environment, ❷.

The two MPI engine variants are taken from one component toolbox and differentiate only slightly from one another. The BlueMotion versions of the MPI engines have an additional start-stop function and a further wear-optimised front end accessory drive. For continuous natural gas operation, the CNG engine deviates from the MPI variants in some components. Piston compression has been increased to 11.5 so as to ensure optimum efficiency of the natural gas. The valves and the seat rings have been

reinforced in order to counter the greater loads occurring during natural gas combustion. The intake manifold also has separate mounting points for the additional stainless steel gas distributor. The quasi-monovalent CNG engine can also be easily operated using gasoline. A 10-l gasoline tank is integrated in the vehicle for this purpose.

CYLINDER BLOCK AND CRANKCASE

The cylinder block and crankcase (ZKG) is designed as an open deck structure made of die cast aluminum. To realise the desired weight savings, the fastening points of the ancillaries are mainly fitted directly to the crankcase. This eliminated the need for the additional support usually required for the accessory drive. Three individually gray cast iron cylinder liners enable reliable engine operation with all types of fuel available around the world.

To ensure that the heat is optimally forwarded, the bushings on the outer diameter are provided with a gray iron surface, ❸. This increases the surface to the surrounding aluminum and produces a positive clamp system. The cylinder block and crankcase is characterised by a multitude of pre-cast channels for supplying hydraulic fluid and returning the oil, and for ventilation. This reduces the number of individual components and the machining scope, enabling low-cost production.

CRANK MECHANISM

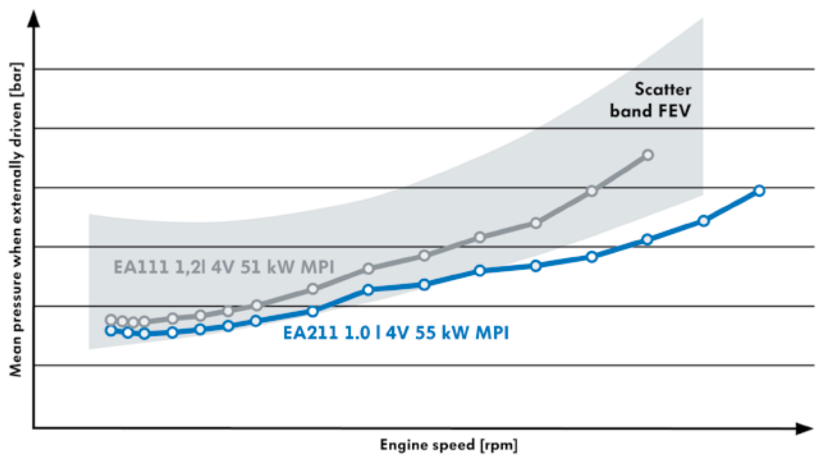
When designing the crank mechanism, the moving masses were reduced and the friction in the system minimised. The downwards guided connecting rod and the piston are weight-optimised to such an extent that it was possible to eliminate the balance shaft that is usually required in a three-cylinder engine while sustaining the same level of comfort. Together with the small main and connecting rod bearings (diameter 42 mm), the engine weight and the powertrain friction have been further reduced and consumption positively influenced. The six counterweights reduce the

AUTHOR

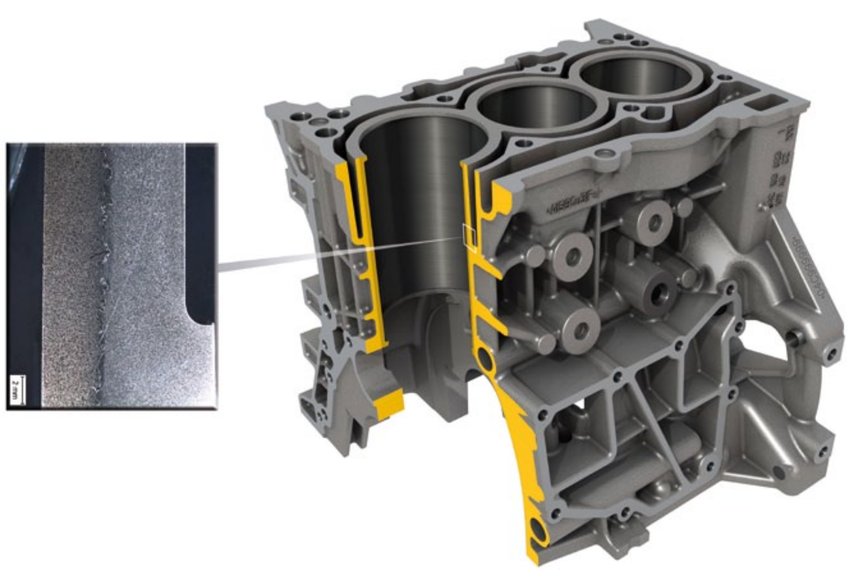
DIPL.-ING. NORBERT BECKER
is Head of EA211 3-Cylinder Design Engineering at Volkswagen AG in Wolfsburg (Germany).

	MPI 44 kW	MPI 55 kW	CNG 50 kW
Engine type	Three-cylinder SI engine	Three-cylinder SI engine	Three-cylinder SI engine
Mixture formation	Port fuel injection	Port fuel injection	Port fuel injection
Engine control unit	Bosch ME 17.5.20	Bosch ME 17.5.20	Bosch ME 17.5.20
Valves per cylinder	4	4	4
Displacement [cm³]	999	999	999
Bore/stroke [mm]	74.5/76.4	74.5/76.4	74.5/76.4
Cylinder spacing [mm]	82	82	82
Compression ratio	10.5	10.5	11.5
Maximum power output [kW]	44	55	50
At engine speed [rpm]	5500	6200	6200
Maximum torque [Nm] / [rpm]	95 at 3.000 – 4.300	95 at 3.000 – 4.300	90 at 3.000 – 4.300
Fuel	Premium gasoline 95 RON	Premium gasoline 95 RON	CNG (Premium gasoline 95 RON)
Gearbox	MQ-5F	MQ-5F	MQ-5F
Axle drive ratio	3,895 : 1	4,167 : 1	4,167 : 1

❶ Basic engine characteristics



❷ Competitive comparison of the mean pressure of the new three-cylinder engine when externally driven



❸ Cylinder block and crankcase with gray cast iron bushings

inner forces in the camshaft and, with that, the main bearing stress.

CYLINDER HEAD

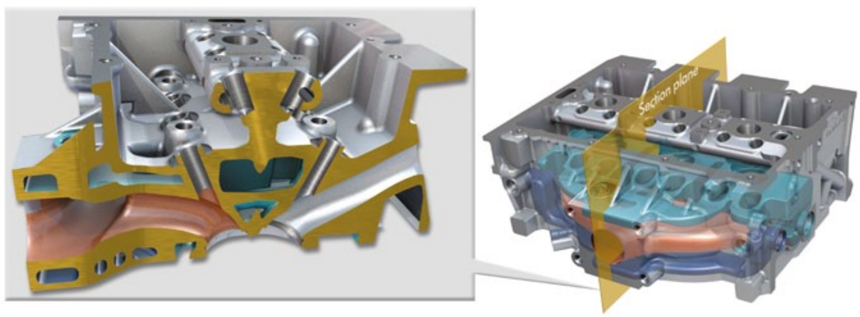
The four-valve cylinder head of the EA211 R3 MPI is cast from a standard aluminum cast alloy. The valves suspended in the roof combustion chamber are arranged at an angle of 21° to the inlet or 22.4° to the outlet and are activated by means of roller-type finger followers. The valve stems have a diameter of 5 mm. The valve seat angle on the inlet side is at 90°, on the outlet side however 120°, so as to ensure wear resistance when alternative fuels are used.

The cylinder head is designed with an integrated exhaust manifold (IAGK). The reason for this is that, by using this technical structure, the engine reaches optimum operating temperature more quickly. By combining the three exhaust ports within the head to a central flange, the coolant is heated up more quickly during the cold starting phase. That said, in normal operation, the exhaust gas flow is cooled down more quickly, enabling the engine to be operated using a favorable fuel-air ratio of $\lambda = 1$. This further improves the consumption and exhaust gas values.

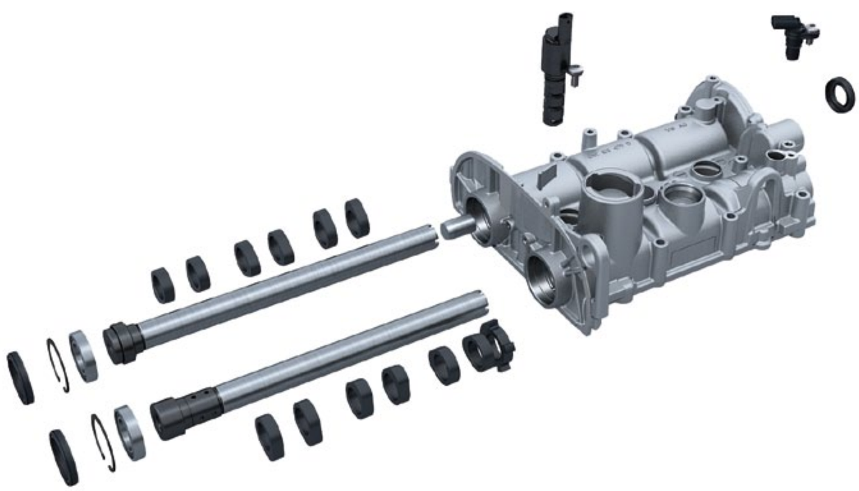
The water core is designed to draw off the heat generated from the exhaust gas flow and forward it to the cooling water. The cooling system above the combustion chambers is designed as a cross-flow cooling system. From there, the water travels between the outlet valves via channels to the upper area of the main water casing, which then cools the area above the integrated exhaust manifold. A separate water core is used to reduce the temperature in the lower section of the IAGK, ❹. This chamber is also supplied with cooling water via the main water chamber.

MONOLITHIC COVER MODULE

A monolithic cover module with camshafts inserted into the valve hood has been used in the manufacture of the new 1.0-l MPI engine, ❺. To this end, the die-cast hood is mounted in a fixture, and the ground, heated cam elements plus trigger wheel are held in position by a cassette attached in the valve hood. The camshaft shafts, which are provided with the end pieces and subcooled, are then fed through the



❹ Cylinder head with cross section through the integrated exhaust manifold



❺ Components of the cylinder head hood module

mounting locations of the hood and through the heated cam elements. After cooling down the cam elements and/or heating up the shafts, the two camshafts are fitted to the module hood in such a manner that they cannot be removed.

This procedure allows for a very stiff but also low weight design of the camshaft support. Compared to conventional tunnel shaft bearings, the bearing diameter is kept small. A further advantage is the elimination of system-related misalignments of the bearing cap and additional threaded joints, which are otherwise common, for example, with the mounting bracket/cover bearing. Small plain bearings also reduce the friction losses. The rigid and compact design of the bearings has a positive effect on the dynamics of the valve train.

For friction reasons, the first bearing from the inlet and/or exhaust camshaft, which is stressed by the additional forces from the timing drive, has been changed to a deep groove ball bearing. Due to the previously described friction measures in the camshaft bearings, fuel consumption and CO_2 emissions in the MVEG cycle have been reduced by 1.5 g/km CO_2, compared with conventional systems.

WATER PUMP MODULE WITH INTEGRATED DUAL CIRCUIT COOLING

In the concept phase, considerable demands were placed on the internal engine coolant circuit. The development focus was to accommodate the entire circuit with as few components as possible on the engine in a space-saving manner and, for consumption reasons, to integrate full-performance dual circuit cooling. To ensure a compact design, the drive of the coolant pump was not positioned in the timing drive or the accessory drive, which is often the case.

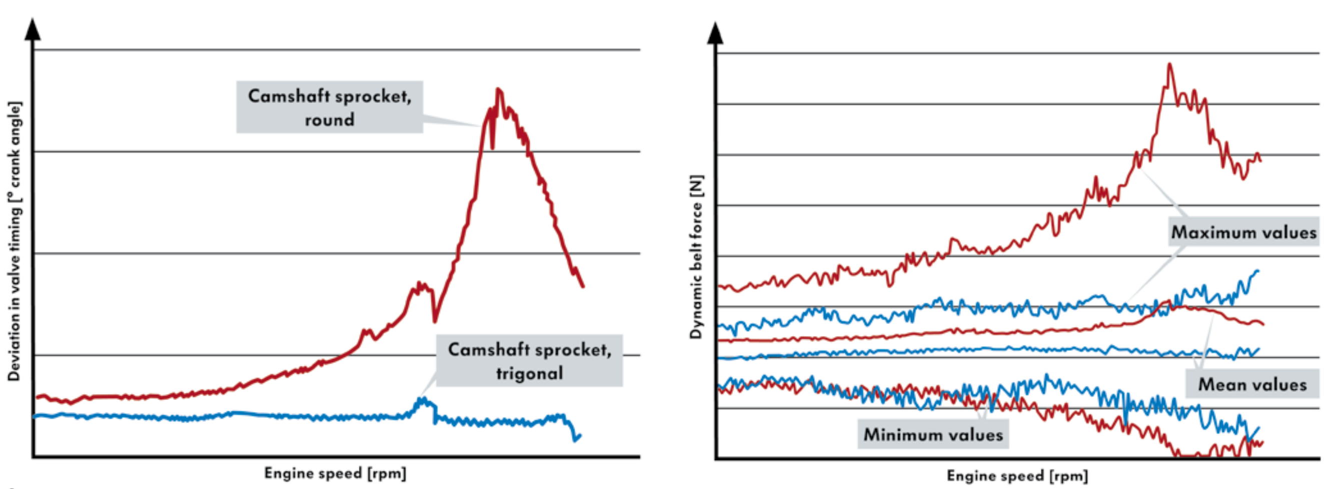
❻ Water pump thermostat module with water circuit

❼ Timing drive of the 1.0-l three-cylinder engine

Intead, the coolant pump is integrated in the gearbox-side on the thermostat housing which is flange-mounted to the cylinder head. The drivetrain is generated via a separate toothed belt from the exhaust camshaft. This arrangement boasts the advantage that the coolant circuit design can also be compact, as external, engine-fixed piping is not required.

The module, ❻, is made up of a die-cast aluminum base body which is flange-mounted to the cylinder head. It includes both the water feed as well as the two water return channels. The water pump shaft bearing is also incorporated. The thermostat housing made of PA 6.6 is bolted to the die-cast part and accommodates both thermostats, the pipe unions for the radiator supply and return, respectively, as well as the heating system fittings.

Starting from the coolant pump, the cooling water is fed through a connecting passage in the cylinder head into the water gallery. This is located in the cylinder block and crankcase. From here, one main flow is fed through the head gasket to the cylinder head for the cross-flow cooling system of the combustion chambers, a second to the parallel cooling system of the integrated exhaust manifold. Both partial flows connect with each other again upstream of the thermostat housing and flow into the mixing chamber upstream of the main thermostat.



❽ Minimization of control time fluctuations and dynamic belt forces by means of trigonal camshaft drive wheels

At the end of the water gallery in the ZKG there is an opening to the water jacket of cylinder 1. This is where the block-side second cooling circuit begins, which flows past and along cylinders 2 and 3 and back to the thermostat housing and through a third connecting passage in front of the crankcase thermostat. This opens at a temperature of 105 °C and allows the water then to flow into the mixing chamber upstream of the main thermostat. The main thermostat in turn controls the quantity that flows via the vehicle radiator.

The dual circuit cooling system enables a faster heating up of the engine, and the powertrain friction is reduced due to the greater temperature of the liners. MVEG testing documented an improvement of 2 g/km CO_2.

POSITIVE CRANKCASE VENTILATION SYSTEM

During the development phase, particular attention was also given to the design of the positive crankcase ventilation system: The oil separation must work efficiently under all operating conditions, and ensure sufficient condensed water discharge even on short trips. To comply with these boundary conditions, the decision was made to use a pressure-regulated system with forced ventilation. The blow-by gases are removed splash-oil-protected in the cylinder block and crankcase downstream of bearing block 2. From here, the gas reaches the separating chamber which is formed from the cylinder block and crankcase and the plastic separator lid. This area is divided into a coarse and a fine separator, each with its own exhaust air system. Here the gas is de-oiled by means of baffle plates and nozzle inserts and then fed to the pressure relief valve which is integrated in the separator lid. The outlet from the fine separator area leads to below the oil level in the oil pan.

Due to its positioning, the pressure relief valve has the function of keeping the vacuum virtually constant across the entire load and speed range of the engine. The de-oiled gas is forwarded in an air rise duct in the ZKG, which allows the gas to flow over the cylinder head and directly into the intake manifold beneath the throttle valve. Channeling the gas entirely within the engine guarantees the operation of the system, even under extreme conditions.

To ensure the condensed water discharge, the vacuum in the ZKG continuously sucks in fresh air through the engine from the filtered air side of the air filter via a check valve in the cylinder head cover. If water vapor then escapes while the engine is heating up, this is caught by the fresh air flow and fed via the oil separator to the engine for combustion.

TIMING DRIVE

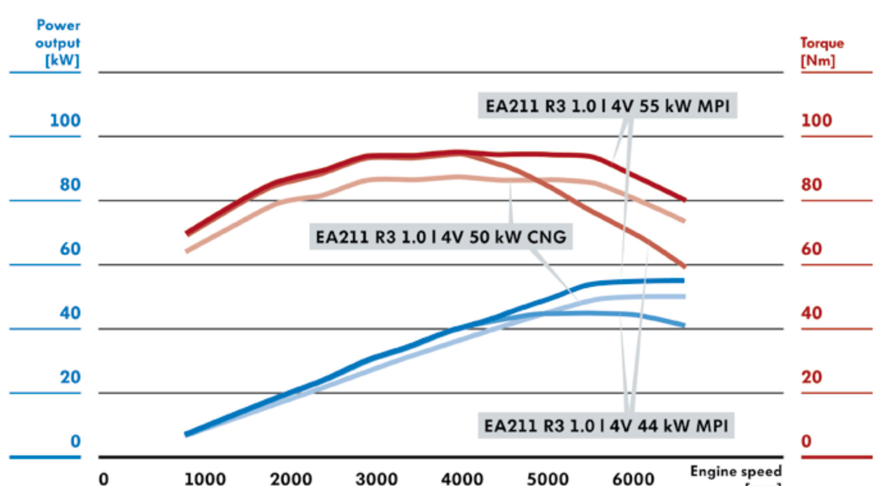
The camshafts are driven directly by a toothed belt from the crankshaft. The toothed belt is guided through thrust surfaces on the roller of the toothed belt tensioner in the low loaded slack span. A rigid idler pulley is positioned on the tension span side in order to guarantee smooth running of the belt, ❼.

The harmonised design of the control times was a stated objective in the development of the timing drive. To minimise the vibrations which are typical of three-cylinder engines, the drive gears of the exhaust camshaft and/or those of the camshaft phaser of the inlet shaft are not round. Instead, they protrude at three equally divided points in the radius (trigonal). It is these local changes to the transmission ratio that have almost completely eliminated the specific peak forces and angle of rotation deviations in the toothed belt drive of a three-cylinder engine. This has made it possible to significantly reduce the tensioning force and, with it, the span forces. Nevertheless, it remains ensured that the minimum dynamic belt forces are always in a positive range and, as a result, friction locking is guaranteed between the timing belt and toothed belt wheels, ❽. This reduces the load of the toothed belt tensioner. In addition, the harmonised forces of the toothed belt system result in less friction with a positive effect on the consumption and durability of the system.

INTAKE SYSTEM

When designing the long-stroke engine, the aim was to provide the driver with considerable elasticity over a broad engine speed range. This is why the maximum torque of 95 Nm lies in the range between 3000 rpm and 4300 rpm. In the 55-kW engine, more than 90 % of this lies between 2000 rpm and 6000 rpm, ❾. Due to the low heating value of natural gas, the maximum values of the CNG engine are slightly below the gasoline variants.

The entire intake stroke is designed for high volumetric efficiency. The four-part plastic intake manifold is designed as snail shell type intake manifold with internal collector, so as to maintain the length of 550 mm which is necessary for a good torque curve. After a number of optimisations, the intake ports have the desired ratio between good load movement and minimum flow resistance. The central air filter, which is located above the intake manifold and cylinder head cover, complies with acoustic requirements in conjunction with the raw air intake with integrated bypass resonator.



❾ Performance and torque

MIXTURE FORMATION

The intake manifold injection system of the 1.0-l engine with its sensors and actuators is shown in ❿. The air enters the intake manifold by means of an electrically-controlled throttle body with a diameter of 44 mm. A dual sensor for measuring temperature and vacuum is integrated in the intake manifold to measure the filling level (engine load). The installation location of the sensor has been chosen in such a manner that the vacuum values of all cylinders are recorded. The fuel vapors from the tank system are fed through a fuel tank ventilation valve to the intake manifold. The inlet point in the intake manifold lies directly behind the throttle valve, ensuring an equal distribution of the induced fuel vapors on the three cylinders.

By fixing the fuel rail to the plastic intake manifold, the three injection valves are thermally decoupled from the "hot" cylinder head. This "cold" installation location prevents a build-up of vapor bubbles in the valves, keeping the system pressure at just 3 bar. This has noticeably reduced the energy consumption of the fuel pump.

A camshaft phaser is used on the inlet shaft in order to reduce emissions and consumption. The phaser is a vane-type camshaft phaser which is controlled by a proportional valve. This is positioned upstream of phaser in the oil supply channel in the module hood. The respective position of the intake camshaft is recorded by a phase sensor at the end of the camshaft.

The engine is equipped with single-spark coils. The ignition coils sit directly above the spark plugs and are fixed to the cylinder head. To record the engine temperature, the temperature sensor is positioned in the water jacket of the integrated exhaust manifold. The position has been chosen because this is where the highest water temperatures occur in the cooling system.

The directly connected knock sensor is located on the cylinder block and crankcase beneath the water jacket in the area of the second cylinder. To ensure optimum registration of the knock signals of all cylinders, the fixing point is linked with the two external cylinders by means of ribs.

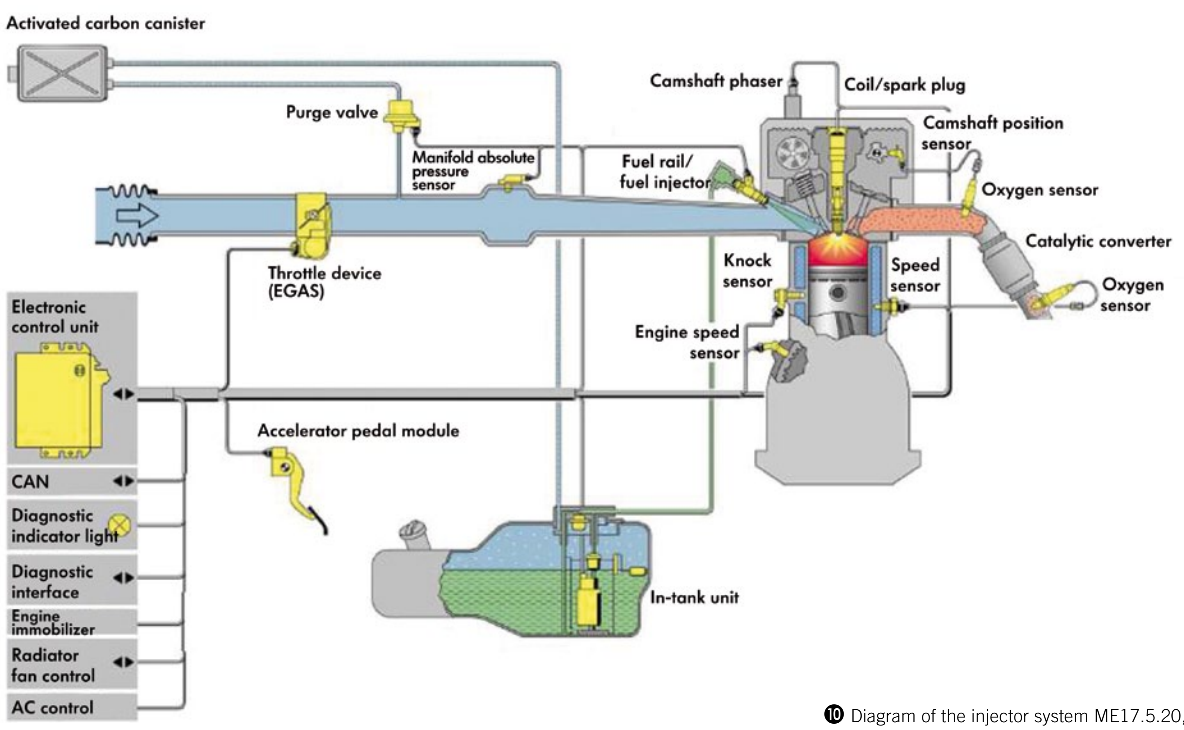
The speed of the engine is measured using a sealing flange trigger module on the flywheel-side end of the crankshaft on which the flywheel is also located. When assembling the module, the 60-2 trigger wheel is simultaneously pressed onto the crankshaft stump with the aid of a tool. Its location at the lower end of the crankshaft assures a low torsional vibration measurement of the speed signal.

Two discrete-level sensors control the fuel mixture and monitor the catalytic converter. Thanks to further-developed software procedures, it is now possible to replace the pre-catalytic converter probe, which is usually always built in, with a simple and lower-cost discrete-level sensor. The rear discrete-level sensor is usually used to monitor the conversion control.

The engine control unit represents improvements in terms of function, cost and space optimisation. Alongside the actual engine control management, it also controls the air-conditioning compressor and the fan module.

SUMMARY

The new three-cylinder fuel injection engine with 44/55 kW and/or the 50 kW CNG drive represents a state-of-the-art and efficient development for the up! which includes all the typical Volkswagen features. The engines have been designed to be consistently friction- and weight-optimised. The two fuel injection engines prove that the up! can literally measure up with the competition in terms of environmental protection concerns. Particularly the BlueMotion and CNG variants set standards in consumption and CO_2 emissions.



❿ Diagram of the injector system ME17.5.20, Figure © Bosch

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