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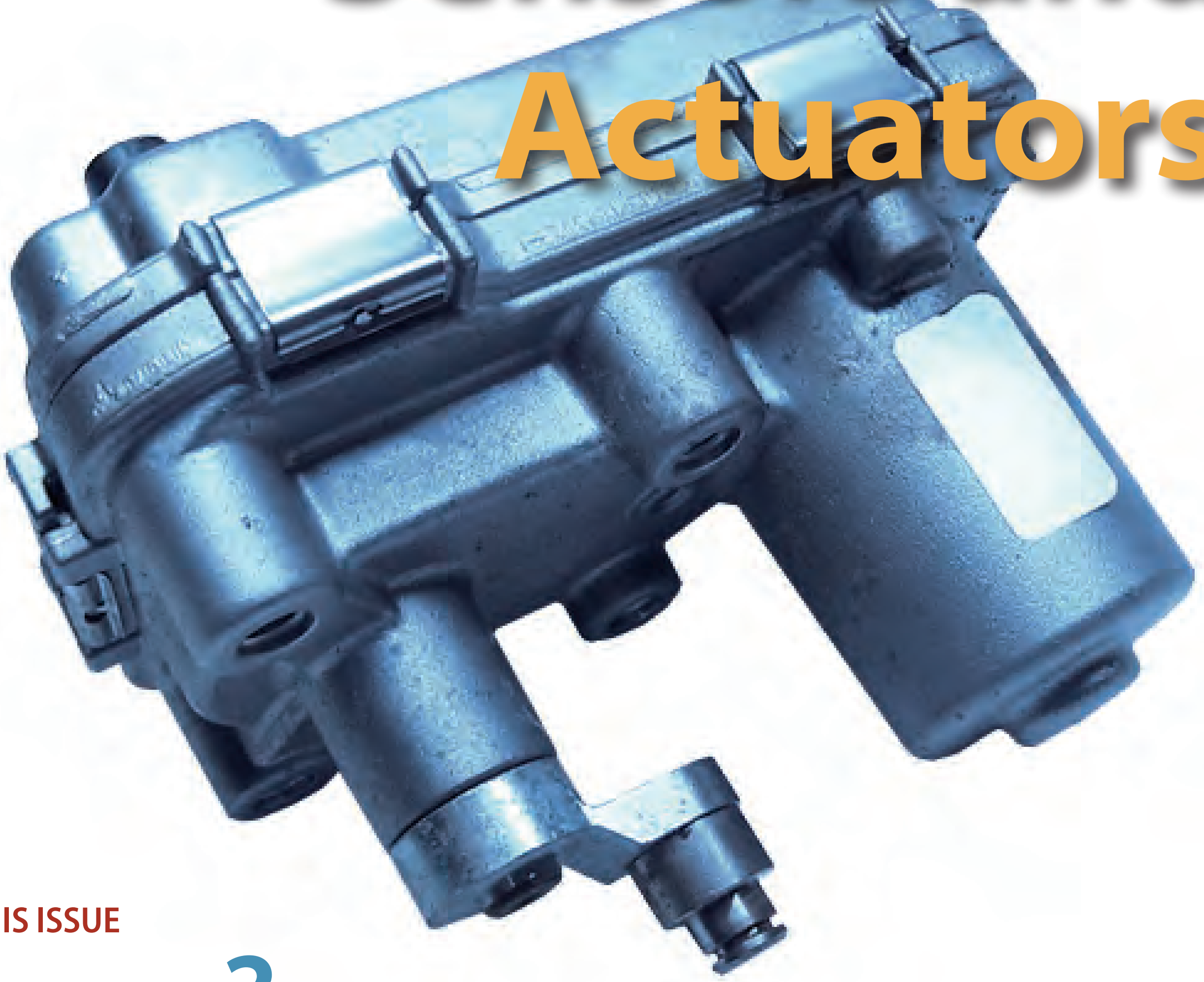
Eure!TechFLASH

THE UP-TO-DATE TECHNICAL INSIGHT IN AUTOMOTIVE TECHNOLOGY & INNOVATIONS

EDITION 24

State of the art Sensors and Actuators



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EureTechFlash is an AD International publication (www.ad-europe.com)

INTRODUCTION

The automotive industry undergoes constant technological development in order to produce more comfortable and higher performance vehicles, which are safer and more environmentally friendly at the same time. A large part of this evolution is achieved with incorporated electronics that improve the operation of traditionally mechanical systems and elements.

The interaction between the mechanical systems and the electronics is possible thanks to sensors, which are in charge of transforming all types of physical variables into electrical magnitudes, and actuators, which transform electrical magnitudes into physical work.

Electronic ignition and fuel injection systems were the first electronically controlled systems that were incorporated in automobiles in general. The work of both depends to a great extent on physical parameters that constantly vary (temperature, pressure, rpm, etc.), which have a direct influence on the operation and performance of the engine.

The traditional mechanical control systems are comparatively slow and not highly accurate, which results in variable, and sometimes ineffective, operation of the engine. The electronic control of the same functions increases both the speed of response and accuracy, and it also allows the construction of the mechanical elements to be simplified for greater reliability of the whole.

Furthermore, it reduces the need for joint work and interaction between purely mechanical components, which can be detrimental since the failure of one component can lead to others malfunctioning. Added to the above is the wear of certain mechanical components, which means that periodic adjustments must be made to maintain operation within acceptable limits.

In many cases, the use of electronic systems prevents the need for periodic adjustments, as they compensate for wear by means of continuous measuring and correction loops that compensate for wear and maladjustment throughout the useful life of the vehicles.

These systems also offer the intrinsic flexibility of the software, the programming of which allows the same control system to be applied in different vehicles, engines, etc. At more advanced levels, the logic functions and the self-diagnostic software report on possible component defects or poor performance of certain functions, and can even adapt in order to continue operating in an acceptable form until the fault is repaired.

SENSORS

A sensor is any component that is capable of detecting a physical or chemical magnitude (speed, position, temperature, etc.) and converting it into an electrical variable, called the signal, that a logic unit can interpret and convert into a mathematical value.

The electrical signal generated by the sensors may be analogue or digital, depending on the sensor and its function in the control system. While the values of analogue signals change continuously, like the magnitudes being measured, a digital sensor has electronics that encode the value of the measured magnitude into a sequence of electrical pulses. The electronic unit receives this sequence of pulses and decodes the signal in order to obtain the value of the magnitude in question.

Sensors can be classified into two large groups based on their electrical functioning:

- Passive: These are sensors that require an external electrical power supply to generate the signal.
- Active: Unlike passive sensors, active sensors do not require any power supply to generate the signal because they are able to create it due to their nature, so they are also referred to as generator sensors.

> Do not confuse the functioning of a sensor with the measuring principle, which may also be active or passive. The active measuring principle refers to the fact that the sensor carries out work prior to obtaining a variable result directly related to the magnitude to be measured. Prior electrical power is required for this.
>
> The passive measuring principle, on the other hand, does not require prior work to attain the measurement, therefore it does not require a power supply. In this type of measurement, the electrical energy is used directly as a measurement and signal element.

Lastly, sensors are also classified according to the physical principle that they use to make the measurement, which can be:

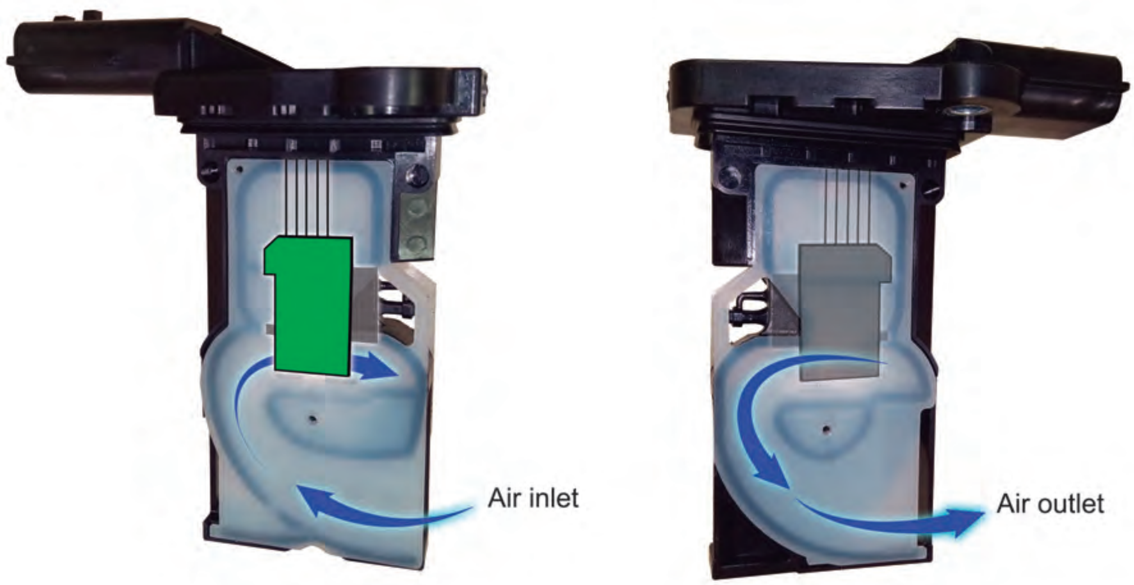
- Magnetic
- Hall effect
- By electrical conductivity
- Magnetoresistive
- Thermoresistive
- Piezoelectric
- Piezoresistive
- Capacitive
- Photoelectric
- Ultrasound and radio-frequency
- Breakers and switches

Described below are some of the sensors used in cars that have appeared most recently or have evolved significantly in recent times.

Digital air-flow meter

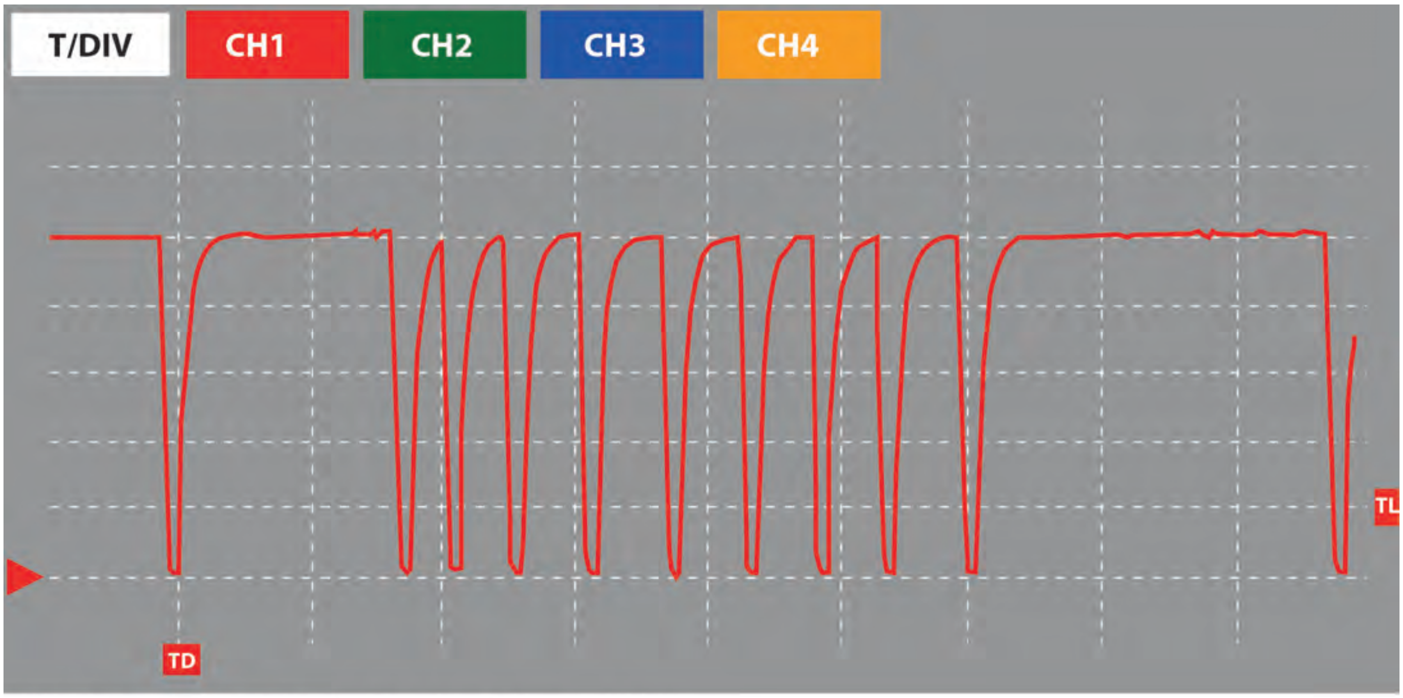
Normally located at the inlet to the intake system after the air filter, it reports the amount of air entering the engine. The engine control unit needs this information to calculate the amount of fuel that must be supplied during each working cycle, control the moment of ignition, the variable timing system, the exhaust gas recirculation rate, etc.

Current air-flow meters are usually the hot film type which use thermo-resistance as an active measuring principle. These have evolved from hot wire sensors and use, instead of a wire exposed to the air, a small sensitive film located in a small labyrinth. The labyrinth allows a flow of a quantity of air proportional to the total flow taken in by the engine, which reduces the amount of air incident on the sensitive element and the possible accumulation of dirt and other chemical contaminants on the sensor.



Its working principle is based on the resistance variation of two NTC elements positioned on the sides of a heated plate or film, which is kept at a constant temperature (about 100°C above ambient temperature). The air that flows through the labyrinth cools one of the resistors and heats the other depending on its direction and mass, so that the pulses and backflow caused by the closing of the throttle and the reciprocating work of the valves does not interfere in the measurement of the true amount of air that enters the engine. In Atkinson and Miller cycle engines, these backflows are much stronger than in the conventional Otto cycle.

The most recent versions of these types of sensors change their transmission format from analogue or digital to encoded digital, thus delivering a message and not a signal.



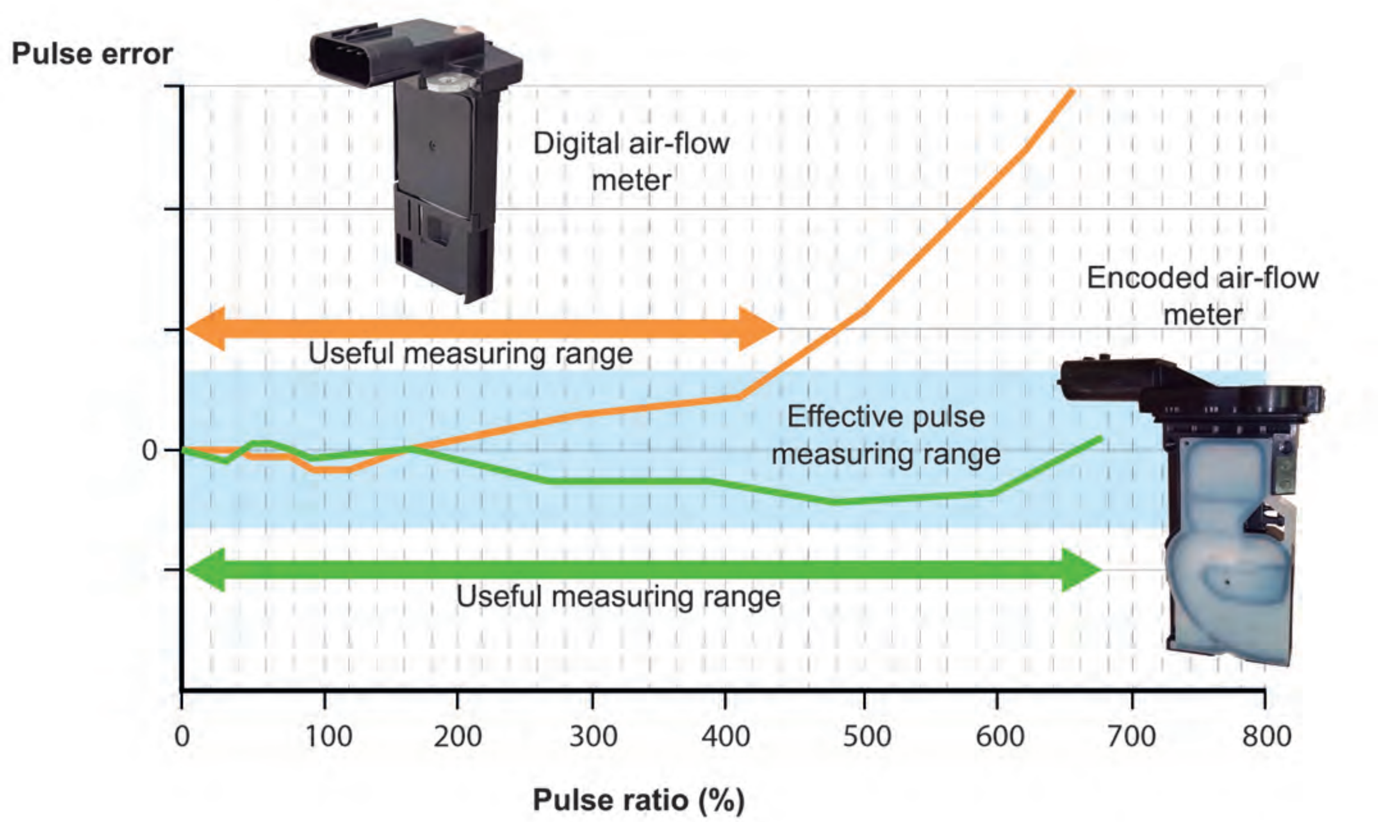
CH1 Frec: 4.08 kHz D.Cycle: 95% Nivel Trigger: 0.98 V
CH1 Min: +0.000 V Med: +34.149 V Max: +5.198 V

This characteristic prevents the direct checking of the measured value using a multimeter or oscilloscope, which we could consider a disadvantage, but it offers several advantages.

Digital signals are less sensitive to electromagnetic parasites and supply voltage variations and are therefore more secure.

The encoded transmission also allows several pieces of information to be sent along the same line, so that the sensors, in addition to the air flow, can communicate other information used for calculating it, such as temperature, pressure and relative humidity of the gas combination. This additional information allows the control unit to calculate the air density and oxygen concentration, essential values for the more accurate control of the boost pressure and of the stoichiometric ratio of the mixture.

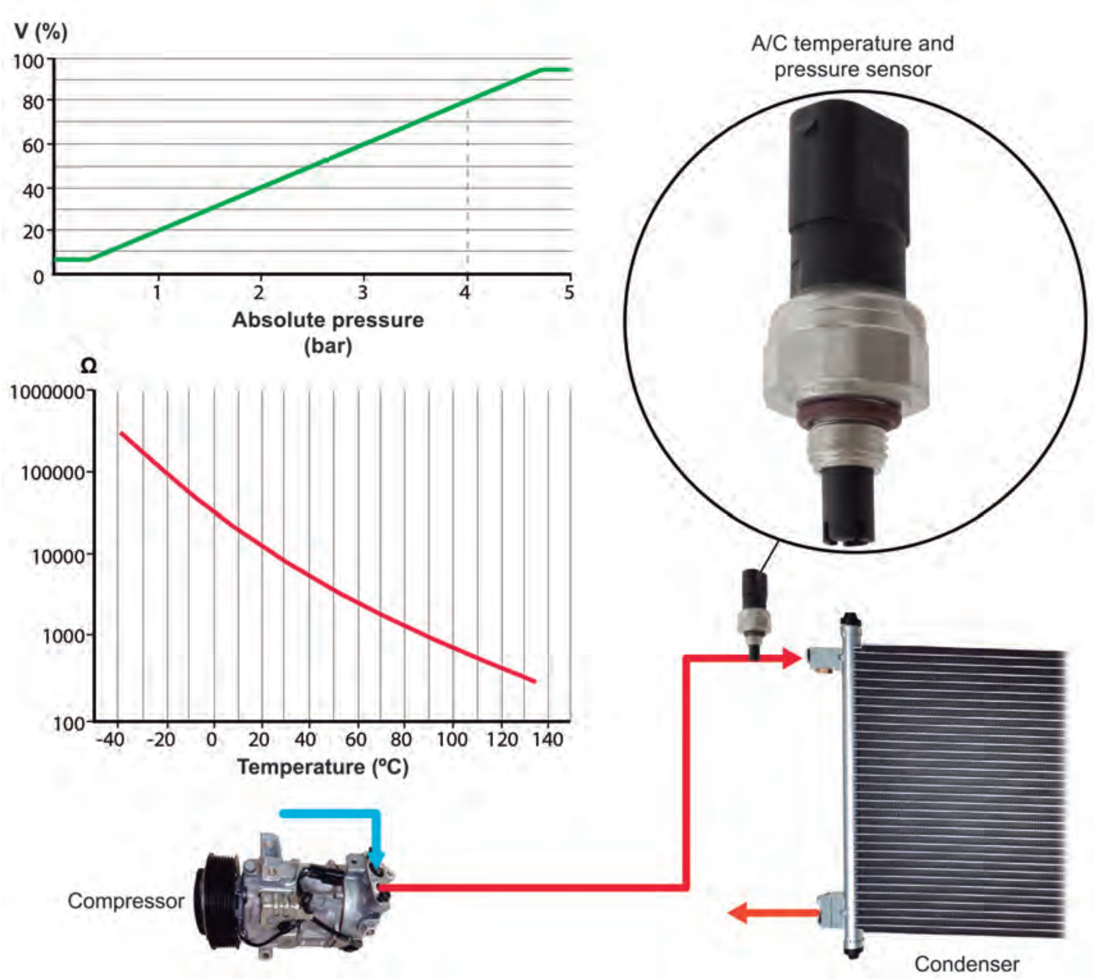
The following graph gives a functional comparison between a conventional digital signal air-flow meter and one that uses an encoded signal, demonstrating that the latter can operate under a wide range of pulse levels.



Refrigerant pressure and temperature sensor

The pressure sensors for the air-conditioning system are located in the high-pressure line, between the compressor and the condenser. Traditionally, their signal is used to prevent the compressor being switched on if there is a refrigerant gas leak in the circuit (insufficient pressure), and to manage the forced cooling of the fluid as it passes through the condenser in order to facilitate the change from gaseous to liquid phase. This is also necessary for shutting down the compressor due to excess pressure if the evaporator freezes, the expansion valve is blocked or there is an obstruction.

In their most recent evolution, these sensors incorporate a temperature sensor. The combination of both pieces of information increases the control and detection potential for more secure work and more consistent control.



With a conventional pressure sensor, if there is a considerable refrigerant gas leak during the operation of the AC system, this is detected as a result of the instantaneous reduction of pressure in the high-pressure circuit. In this case, the control unit recognises the problem through the sensor signal and shuts down the compressor, thus preventing its destruction and contamination of the circuit.

However, when the leak is slower or occurs in the low pressure section, the high-pressure information cannot be used to detect it, since a gradual reduction of this parameter can also be due to excessive cooling of the fluid that occurs when entering a tunnel, as a consequence of the sudden drop in the temperature of the air that flows through the condenser when travelling at high speed. In this case, the safety shutdown of the compressor does not occur with the consequent risk of contamination of the circuit and damage in the compressor. In these cases, the fluid temperature signal allows the consistency between it and the circuit pressure to be determined, it is compared with the reference value stored in the unit in order to recognise the existence of a leak and shut down the compressor.

The same comparison principle can even determine if there is an insufficient or excessive quantity of the refrigerant in the circuit, which results in the poor performance of the system.

The fluid temperature information also allows the work of the compressor and of the electric fan of the condenser to be reduced, thus cutting down the energy consumption of both and, thereby, fuel consumption and CO_2 emissions.

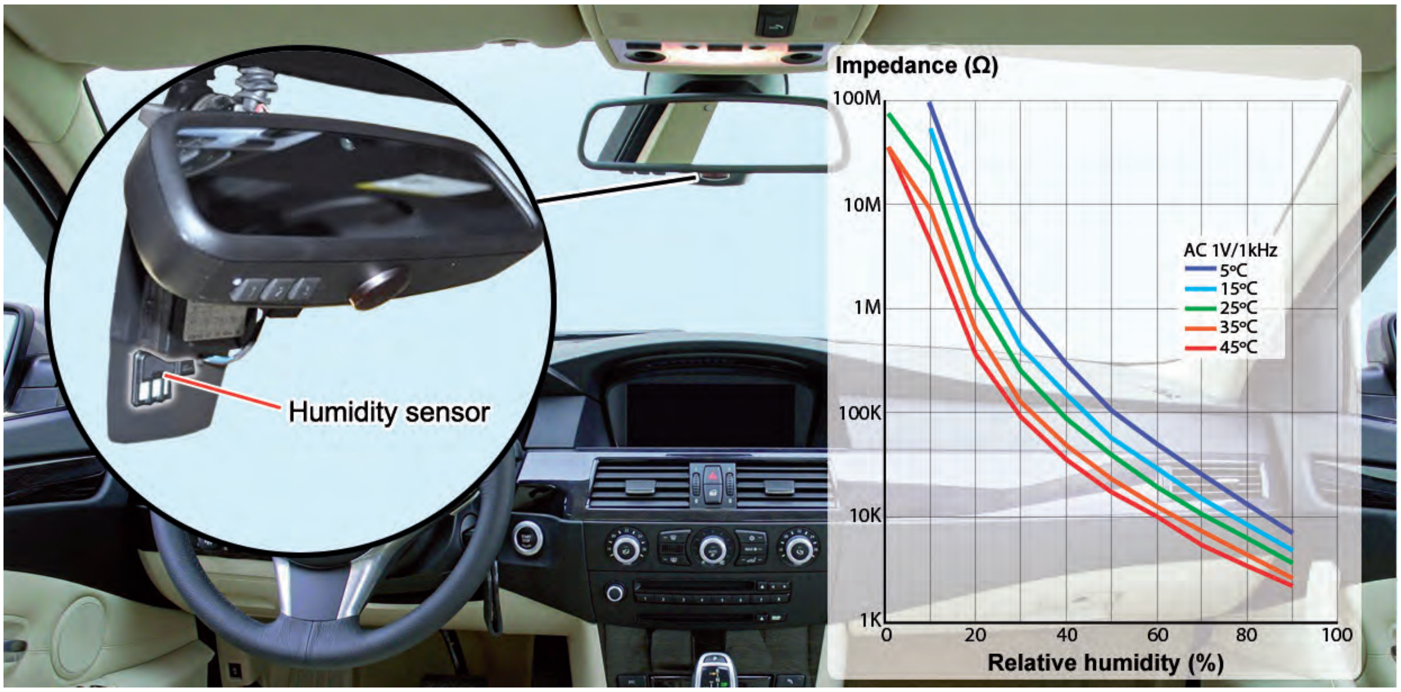
In vehicles with a Start/Stop system, it increases the automatic stop margin with the climate control system active, thus reducing emissions even more.

Air humidity sensor

The water vapour concentration in the ambient air influences concentration and fatigue while driving. Excessive relative humidity causes sweating and increases fatigue, and low relative humidity dries the respiratory tract and accelerates visual fatigue. The condensation of water vapour on the interior surface of the vehicle's windows hinders visibility while driving and is an added danger factor.

The humidity sensor is an element capable of evaluating the proportion of water vapour in the air inside the cabin, a parameter that is used for maintaining the thermal comfort of the occupants at a maximum level. This value is sufficiently low to prevent the misting of the front windscreen, which is directly exposed to the air flow as the vehicle moves forward causing condensation to form very easily due to thermal contrast.

The humidity sensor for the cabin is usually located behind the central rearview mirror on the front windscreen.



It detects the humidity through the condensation of water vapour on windows by means of a capacitive element. For this, a fine polymer film is used that increases its electrical capacitance when it absorbs water vapour.

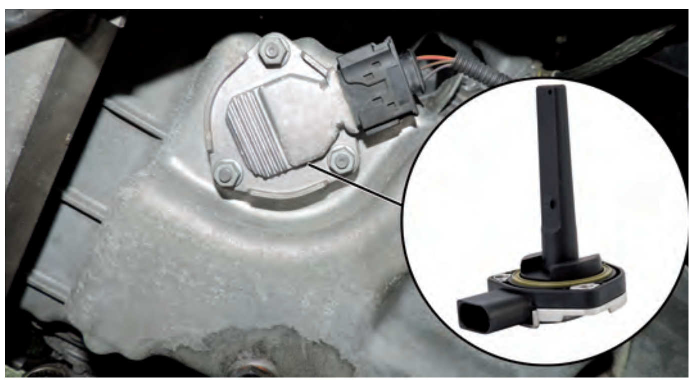
The air's capacity for retaining water vapour varies according to the temperature of the gas, therefore this sensor is usually combined with another thermoresistive type sensor. The humidity value together with the temperature are sent in the form of a signal to the system's control unit to calculate the condensation point and thus prevent the windows misting up.

For the demisting function, the direction of the temperature, mixing and air distribution flaps is adjusted, directing dry air to the windscreen. The humidity in the cabin is reduced by recirculating the air over the air-conditioning evaporator that, due to its low temperature, causes the vapour to condense, and this is then expelled as liquid through the drainage duct of the heater assembly.

Oil quality and level sensor

The extension of maintenance periods and widespread use of particulate filters requires full control of the engine oil level and degradation in order to ensure the adequate lubrication, longevity and performance of the engine.

The oil level and quality sensor is usually capacitive and is located on the sides or at the bottom of the engine crankcase. Their measurement principle is based on their ability to vary their electrical capacitance when elements approach the sensor's active surface.

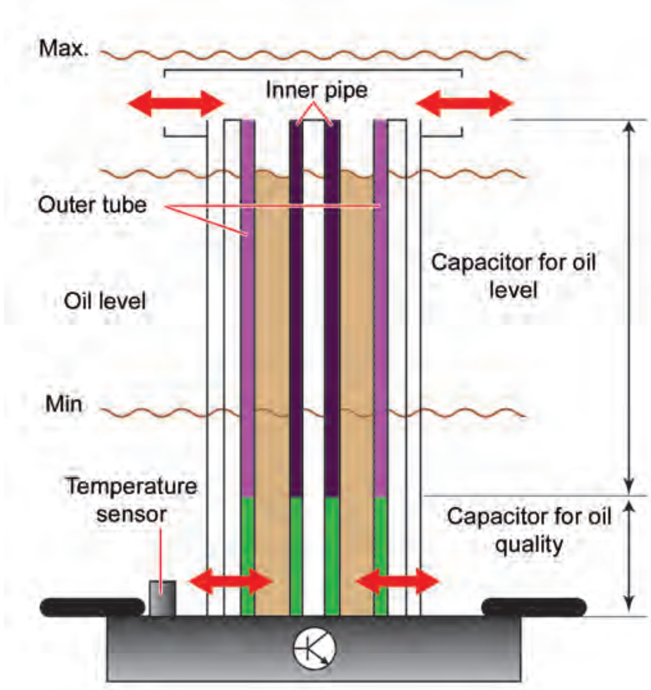


As just a level sensor, they work as a capacitor that varies its capacitance depending on the level of the oil which acts as a dielectric element. Some sensors, in addition to measuring the level, measure the quality of the lubricant with a second completely submerged capacitor.

The electrical properties of the oil vary according to the decomposition of its additives and on the concentration of contaminating substances or combustion residues, which changes the capacitive response of the sensor.

Furthermore, these sensors may include another NTC type sensor for measuring the oil temperature.

Ultrasonic oil level sensors also exist which look very similar to the above. They have an electronic module inside them that emits an ultrasonic signal to the boundary surface of the oil in the crankcase. A sensor detects the echo of the signal when it rebounds off the free metal surface of the crankcase and sends it back to the module, which calculates the oil level from the variation of the amplitude and speed of the sound.

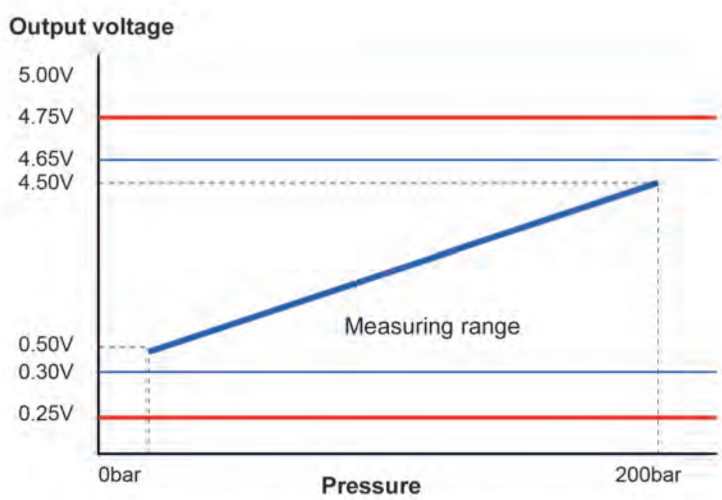


Combustion pressure sensor

The glow plugs incorporate a pressure sensor, which is both a sensor element and actuator. In addition to heating the combustion chamber for starting or during operation of the engine to improve combustion, they detect the pressure in the chamber in order to prevent the production of polluting emissions, as far as is possible, particularly nitrogen oxides.

The glow plug incorporates a retractable heating rod which, when exposed to the combustion chamber pressure, transmits its movement to a measuring diaphragm. This diaphragm has several incorporated extensometer strips that change their electrical resistance as they are deformed, characteristic behaviour known as piezoresistance.

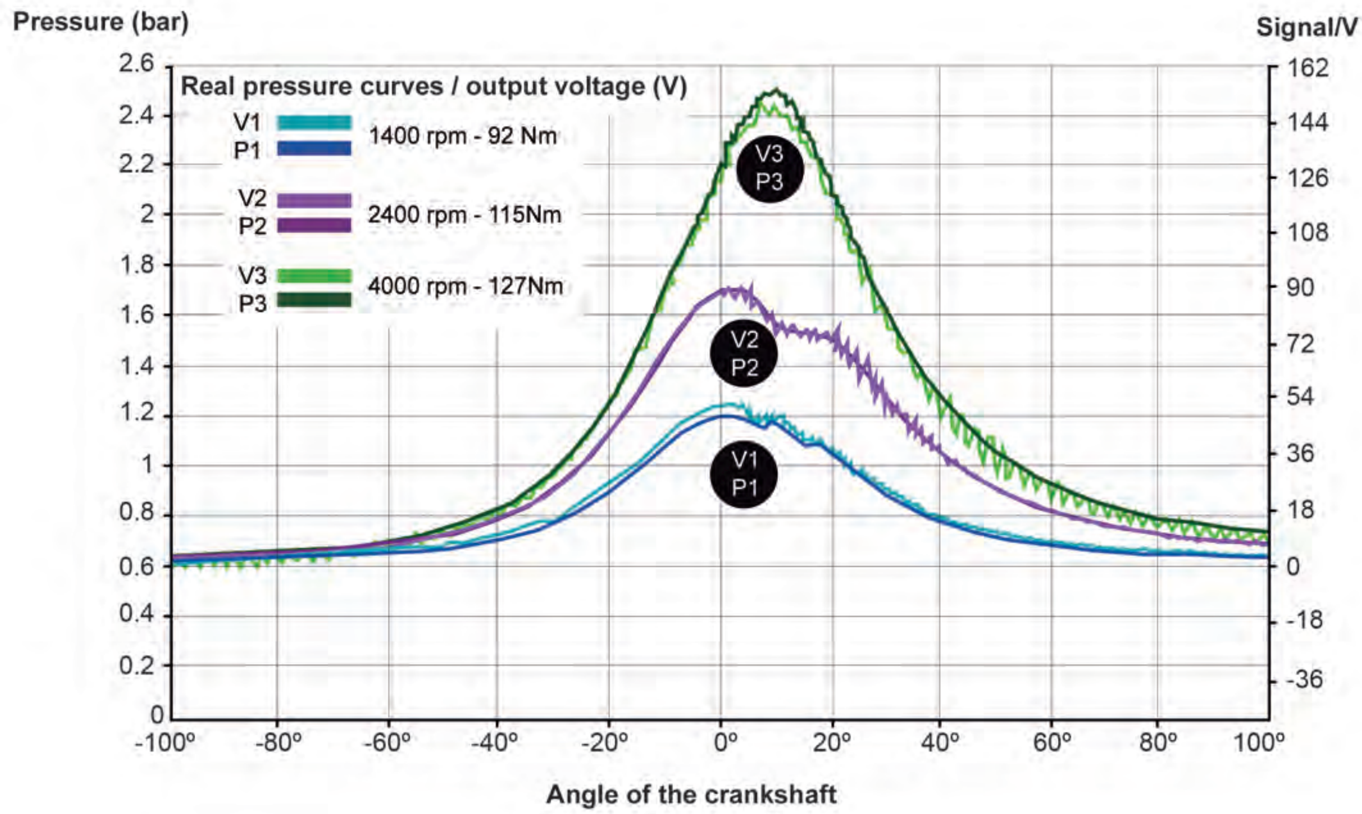
An integrated electronic circuit evaluates the deformation of the diaphragm and generates an analogue signal proportional to the pressure in the combustion chamber, which it then sends to the engine control unit.



The engine control unit software analyses the pressure increase due to combustion according to the engine load and engine speed signal. Comparing the values obtained from the various cylinders with each other and in relation to the reference maps programmed in the unit, new values are calculated for the correction of the injection advance and duration of the excitation of the injector.

This control system provides the following advantages:

- Accuracy in the control of the moment and quantity of the fuel to be injected.
- Adaptation of the injection to the mechanical wear of the engine during its useful life.
- Smooth and stable operation of the engine in all its cylinders.
- Fuel quality compensation.
- Adaptation of the injection in accordance with recirculated gas and different fuel qualities.
- Optimal operation of the engine in case of injection regulation for regeneration of the DPF and of the NOx catalytic converter-trap.



The glow plugs with pressure sensor are fitted in all the engine's cylinders so that control/regulation is carried out during all the operating cycles, which allows mechanical compression problems to be detected as well as faults in the injectors. The parameters generated in each glow plug can be read using a diagnostic tool.

Cylinder 1 combustion chamber pressure 0.8 MPa
Cylinder 2 combustion chamber pressure 19.2 MPa
Cylinder 3 combustion chamber pressure 14.8 MPa
Cylinder 4 combustion chamber pressure 20.9 MPa

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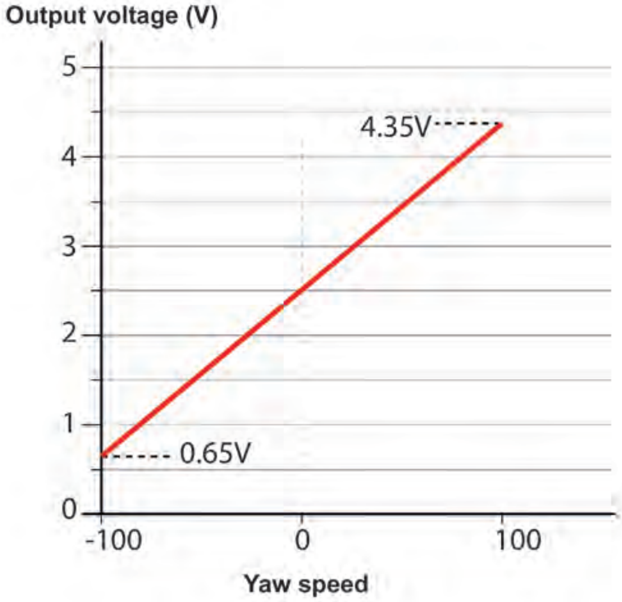
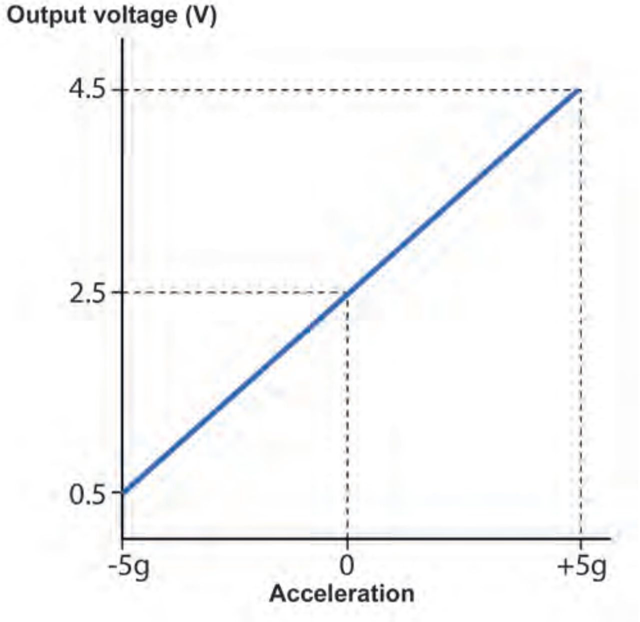
Yaw and acceleration sensors

Their function is to detect and evaluate the forces and the movements of the vehicle relating to a loss of trajectory or stability.
They can be micromechanical, piezoresistive or Hall type. The independent elements are known as yaw, transverse acceleration and longitudinal acceleration sensors, or together as a single component they are known as a combined sensor. They are usually integrated into the electronic stability control unit in more recent vehicles.



The purpose of the yaw or yaw rate sensor is to measure the speed of rotation of the vehicle about its vertical axis. This signal is used by the control unit to calculate the yaw torque, the force that must be counteracted to recover the stability of the vehicle.
Its measuring principle requires it to be mounted as close as possible to the centre of gravity of the vehicle, normally next to the parking brake lever, under the front seats or on the dashboard, although it may also be integrated into the control unit itself.



The purpose of the transverse acceleration sensor is to detect and measure the lateral forces caused by the lateral movement of the vehicle, that is, skidding perpendicular to the direction of travel. Together with the vehicle's yaw and speed sensor signals, it allows the control unit to recognise if the car is following the path indicated by the driver or if it has deviated from it and is in an unstable situation.

It may be located next to the yaw sensor, inside the control unit or under the dashboard.

The longitudinal acceleration sensor has a structure and operation similar to the transverse acceleration sensor, the main difference being the force detection direction (longitudinal instead of transverse). Its purpose differs depending on the type of vehicle on which it is mounted. The main application of this signal is in four-wheel-drive vehicles, where it is used to calculate the true speed of the vehicle in low grip conditions. Nevertheless, this sensor can also be found in two-wheel-drive vehicles, for the differential management of the automatic gearbox during overrun and acceleration, for example.

When these elements are replaced, they must be mounted in the same original position (detection direction), and in many cases the initial calibration must be carried out using diagnostic equipment.

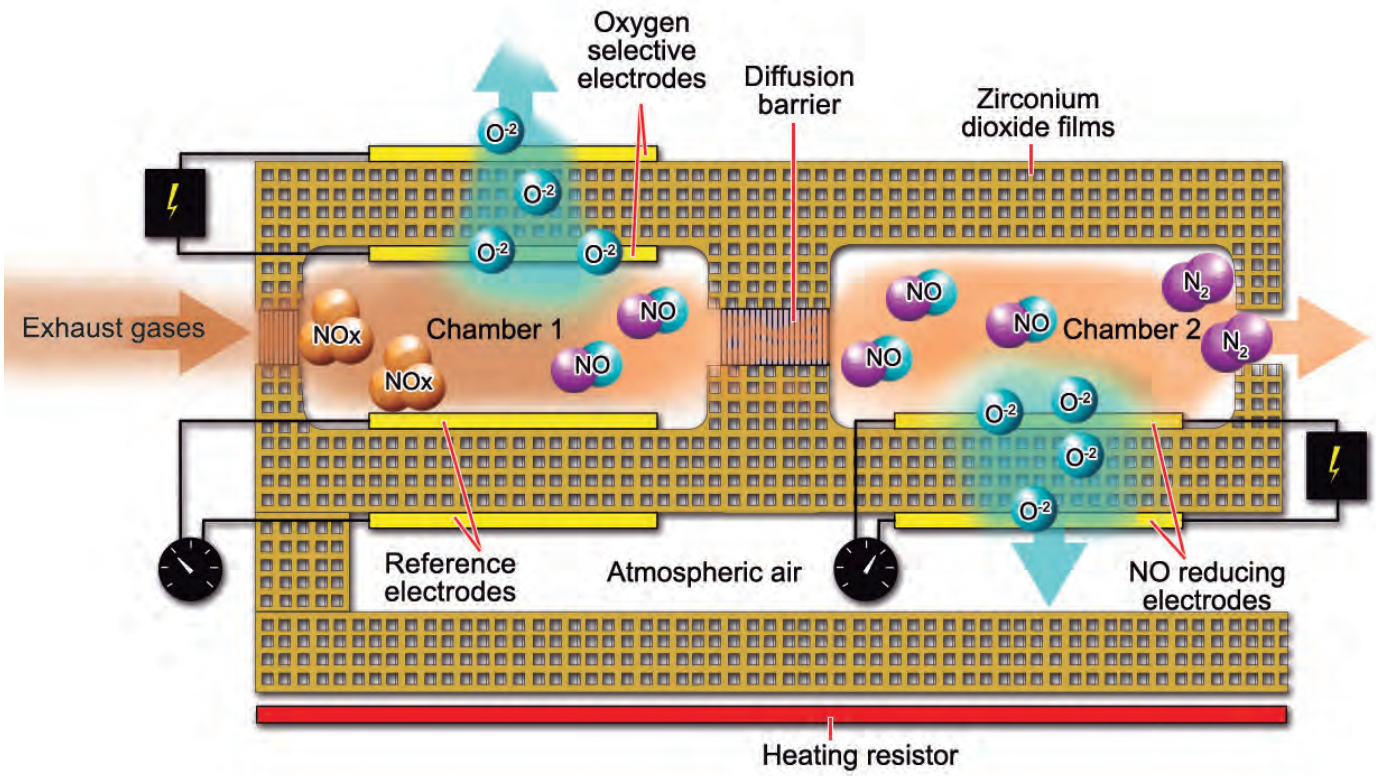
NOx sensor

This is responsible for determining the percentage of nitrous oxides contained in the exhaust gas. There are normally two sensors: one in front of the SCR catalytic converter and the other behind. Each sensor has its own control unit with which it forms an indivisible mounting assembly that is located under the vehicle.

The reason why the NOx sensor needs its own control unit is because of the low electrical power of the detection signals. Conventional connection of the sensor element with the engine control unit is not possible via the electrical installation, as the resistance of the wiring and possible electromagnetic parasites would affect the measurement.

The NOx sensor units share the information resulting from the active measuring work with the engine's control unit via the CAN-Bus in order to calculate the performance of the reduction catalytic converter and monitor the operation of the SCR system.
Structurally, the sensor is made up of:

- A set of zirconium dioxide films.
- Two work chambers.
- Three pairs of electrodes with different functions.
- Two diffusion barriers (one at the inlet and another between the two chambers).
- One heatable resistor.



The operation of the NOx sensor has similarities with that of the broad-band lambda sensors. When the exhaust gas enters chamber 1, the NOx control unit applies a variable voltage difference between the selective electrodes for O2 reduction to attract them towards the outside. The free oxygen ions (O-) are attracted by the external electrode (+), and move through the zirconium dioxide. In this way, the oxygen inside the NOx sensor is reduced to a stable minimum concentration value, a value that is obtained from the potential difference that occurs at the reference electrodes.
The remaining gas goes to the second reaction chamber through the diffusion barrier, where the NOx is disassociated into N and O ions on coming into contact with the interior reducing electrode. The NOx sensor control unit applies a stable electrical voltage difference between the NOx reducing electrodes. The oxygen ions disassociated from the NOx, attracted by the positive potential of the external electrode, cross the zirconium dioxide and recombine to form O2 in the ventilation channel of the sensor. The flow of ions is proportional to the amount of disassociated NOx, which, when the voltage is kept stable, gives rise to an electrical current of a magnitude equivalent to the proportion of NOx in the exhaust gas.
The magnitude of this resulting current allows the proportion of NOx to be calculated, the value is then communicated from the control unit to the engine ECU together with the temperature, oxygen concentration and other working data from the sensor.

ACTUATORS

An **actuator** is defined as a device that is able to convert hydraulic, pneumatic, or electrical energy into a physical process in order to generate a particular effect or work.
Actuators can be classified in different ways. The most common way is to group them based on the energy used to activate them, and they are organised as follows:

- **Hydraulic**: These are actuators that use hydraulic pressure to carry out the functions for which they were designed. An example of this type of actuator in a vehicle are the brake callipers, which convert the pressure of the brake fluid into movement and force to press the brake pads against the disc.
- **Pneumatic**: These are actuators that use the pressure of a gas (normally air) to carry out their functions. An example of this type of actuator in a vehicle are the pneumatic diaphragms often used in variable-geometry turbochargers, which convert pneumatic pressure into the movement of the vanes of the turbo.
- **Electrical**: These are actuators that use electrical energy to carry out the functions for which they were designed. This is the most common and numerous type of actuator used in vehicles, and they vary widely depending on the needs of the system. Some examples are solenoid valves and electric motors.

Although all of these types of actuators are used in a vehicle, this magazine will focus on electrical actuators because they are the only ones that can be governed directly by an electronic control unit. The electrical actuators used in vehicles can be classified based on their operating principle as follows:

- Electromagnetic
- Electric motors
- Piezoelectric
- Heaters
- Pyrotechnic
- Optical / Visual

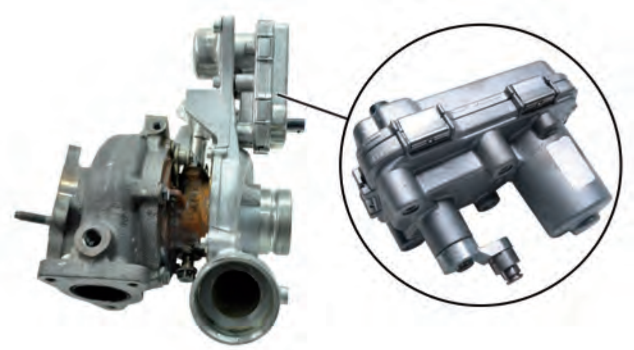
During the operation of the vehicle's electrical systems, the control unit continually receives information from the sensors and sends the output signals to control the actuators. This means that it is constantly regulating the functioning of the system until the information that is received matches the theoretical value stored in its internal memory. The values programmed in the internal memory correspond to the optimum performance of the system, which is obtained by programming or by calculation. Since the values vary constantly, the activation of the actuators by the unit also varies, in order to correct and self-adapt the system.
Some of the more notable actuators are described below.

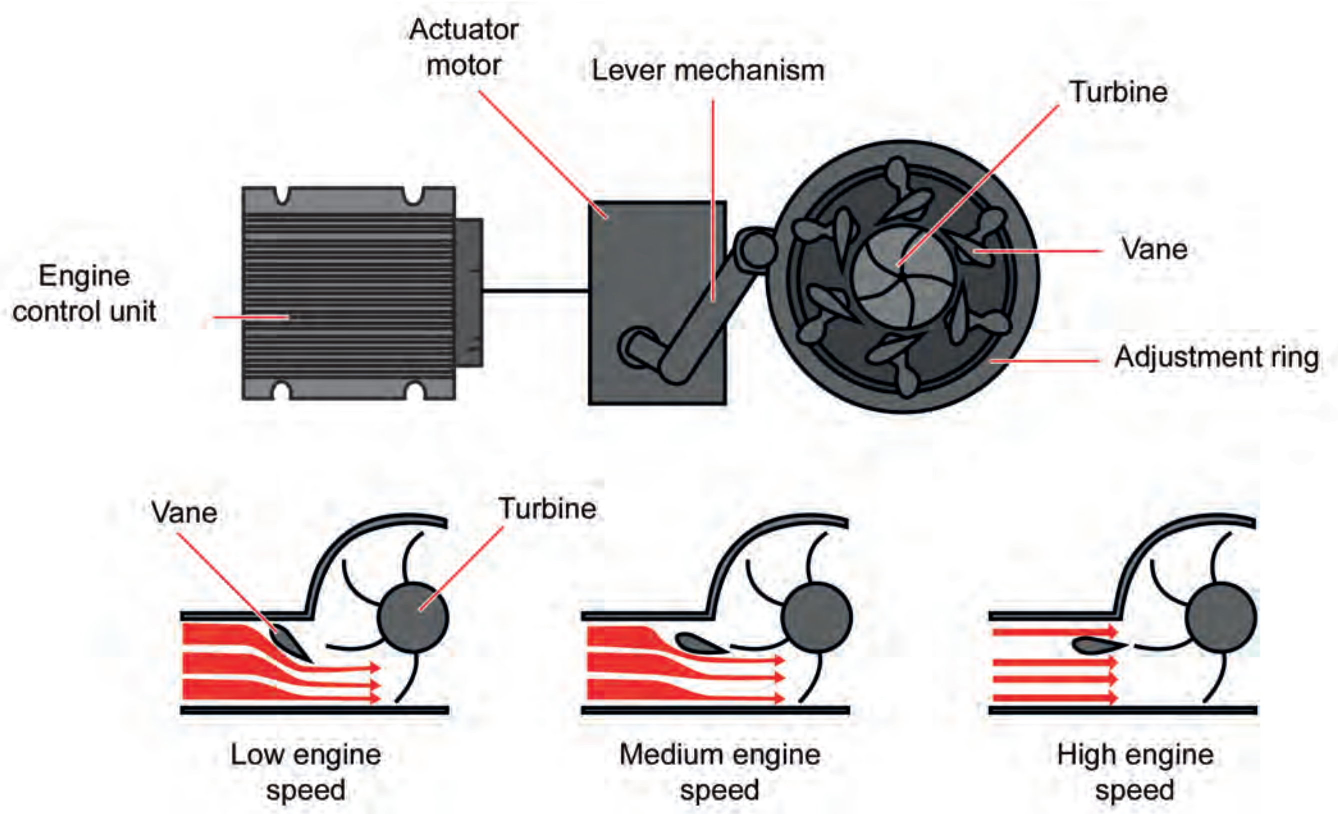
Electric actuator for turbocharger

This device controls the speed of the turbocharger turbine in order to regulate the boost pressure of the engine.
The electric actuator that controls the geometry replaces the pneumatic solenoid valve and actuator diaphragm systems, and has the following advantages:

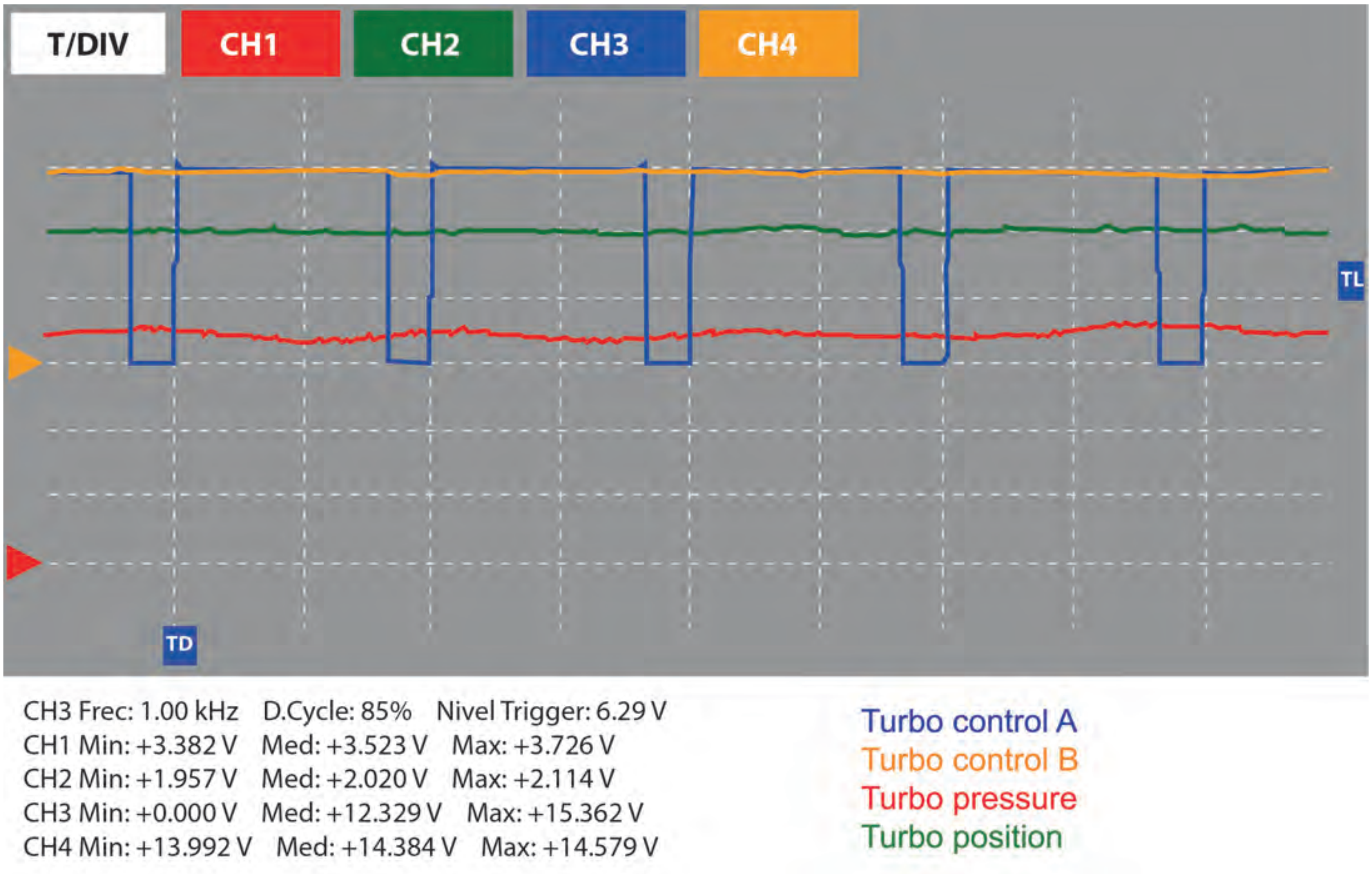
- Shorter control time and faster turbocharger response.
- More effective and secure actuation of the geometry as it is able to develop a higher actuation force and accuracy in the position.
- Direct control with possibility of feedback of position, travel and defect detection.

The electric actuator is made up of an electric motor and a reduction gear that positions the vanes that regulate the cross-section and angle of incidence of the exhaust gas on the turbine's impeller. It also incorporates an electronic unit that carries out the safety functions in case of loss of communication with the control unit, by placing the assembly in the minimum output position.

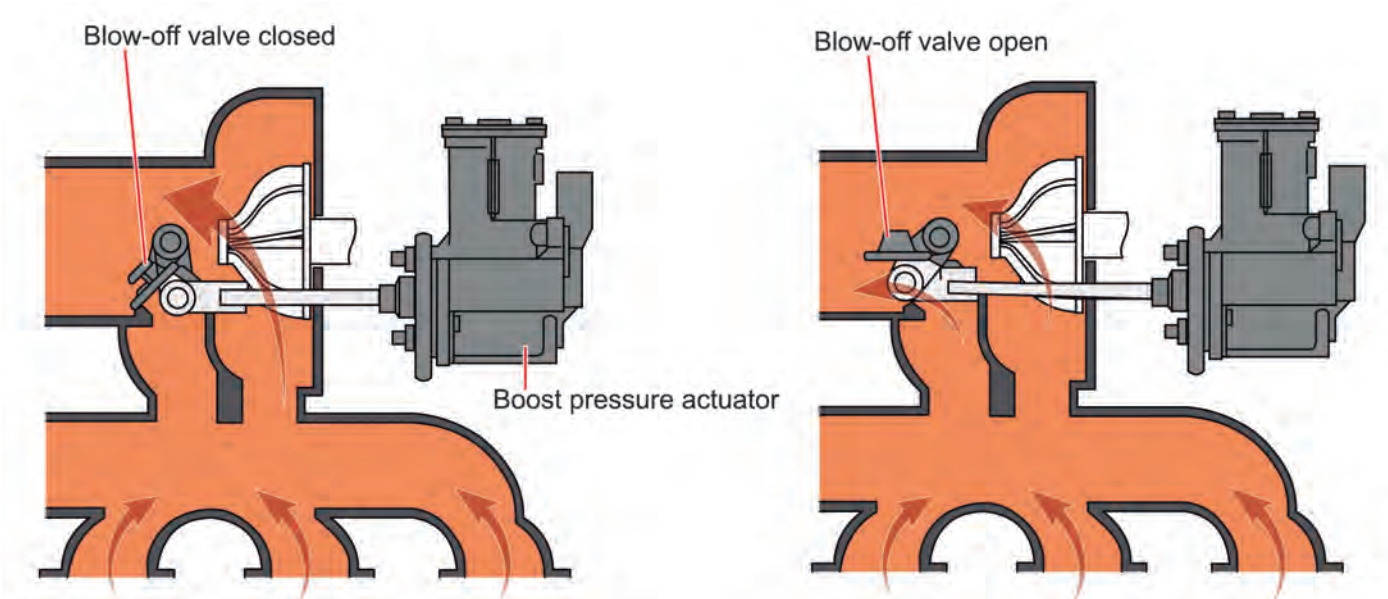




The motor is controlled at a variable work percentage by means of a fixed frequency square signal and polarity inversion to reverse the rotation direction. The vane position feedback signal is obtained by means of a Hall sensor that provides an analogue voltage proportional to the advance angle of the final component that moves the geometry guide ring.



In systems with a blow-off valve, the engine control unit calculates the theoretical boost pressure according to the requested torque. If the theoretical pressure is not reached, the blow-off valve closes completely and the entire exhaust gas flow is conducted to the turbine on the turbocharger exhaust side. To reduce the rotation speed of the turbine and the boost pressure, the control unit commands the actuator to open the blow-off valve at a certain percentage. In this way, some of the exhaust gas that is incident on the turbine is conducted through the new opening, thus reducing the working speed of the turbocharger and the compression force.



In the case of an electrical fault, the blow-off valve is opened by the flow of the exhaust gas. If the fault is mechanical, the actuator opens the valve or closes the butterfly valve. A boost pressure cannot be generated in either case.

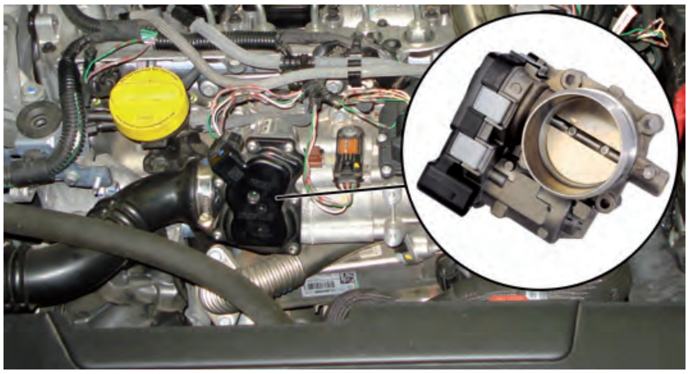
Motor-driven throttle

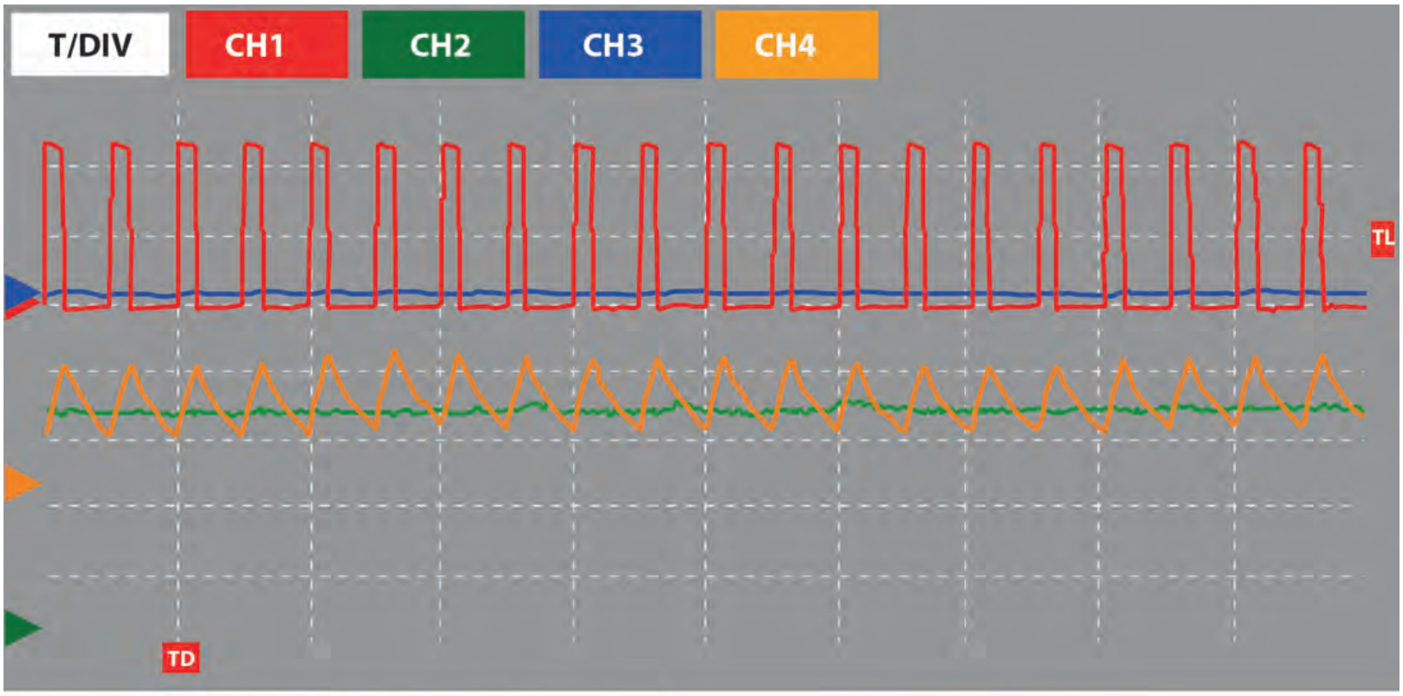
The flow of air to the intake manifold is regulated through a gas throttle located at the inlet to this manifold.

Nowadays, normally open throttles are used instead of the traditional throttles closed by a return spring. The throttle position potentiometers are also replaced by contactless Hall sensors. As they are based on an electric motor and a reduction gear, the electrical consumption of the throttles is considerably reduced at the same time as the control speed is increased.

In addition to the energy saving that they provide, they are notable for much more effective regulation of the engine torque control functions necessary for electronic traction and stability control.

The active control of the electric motor for both opening and closing is carried out by inverting its connection polarity, which achieves more accurate management of the engine overrun and the combined work with the electronic control systems for automatic or sequential gear change.





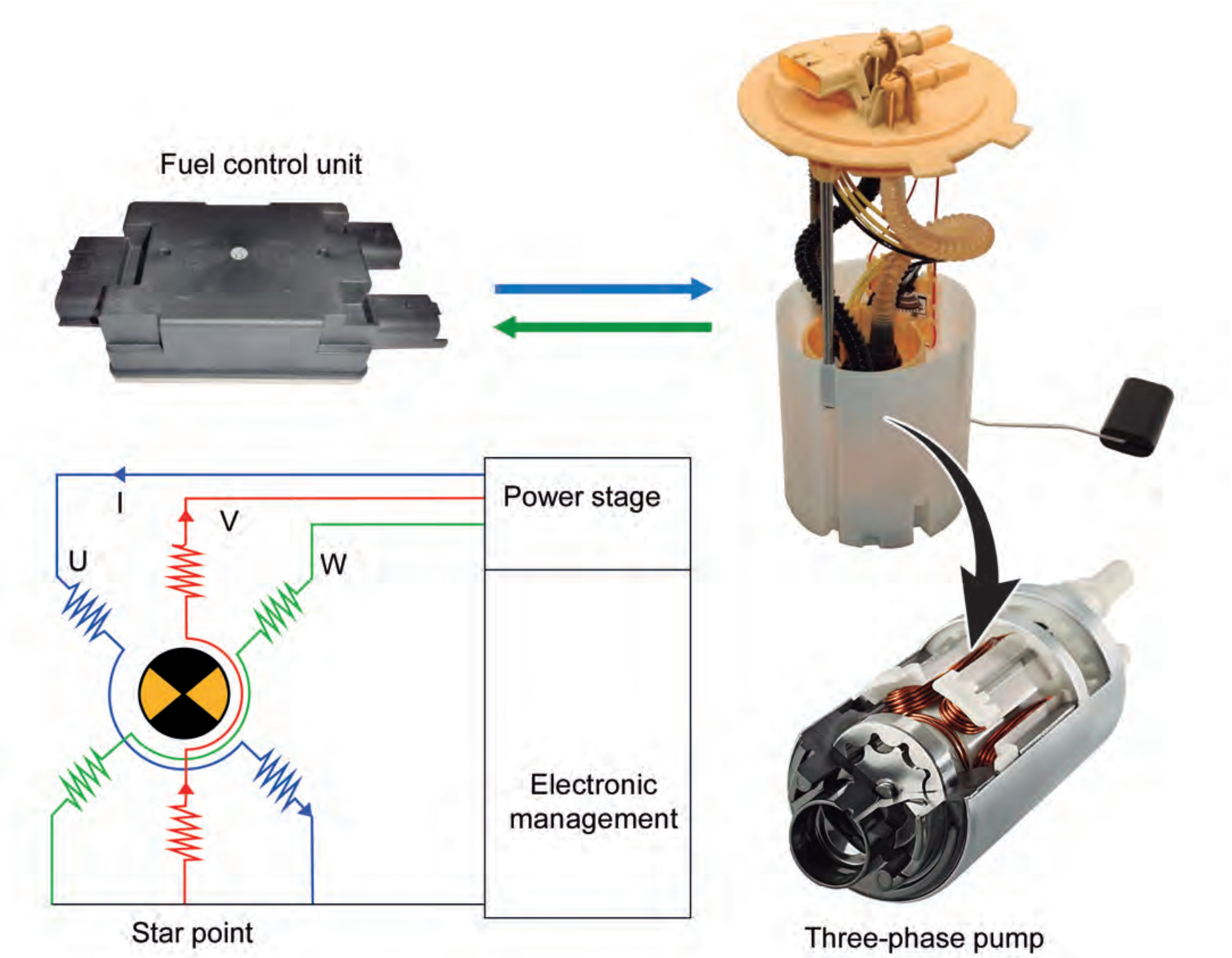
CH1 Frec: 2.00 kHz D.Cycle: 32% Nivel Trigger: 4.43 V
CH1 Min: -0.587 V Med: +3.131 V Max: +11.644 V
CH2 Min: +1.957 V Med: +2.098 V Max: +2.286 V
CH3 Min: +0.196 V Med: +0.294 V Max: +0.489 V
CH4 Min: +1.205 A Med: +1.785 A Max: +2.568 A

Close control signal
Open control signal
Working current
Throttle position signal

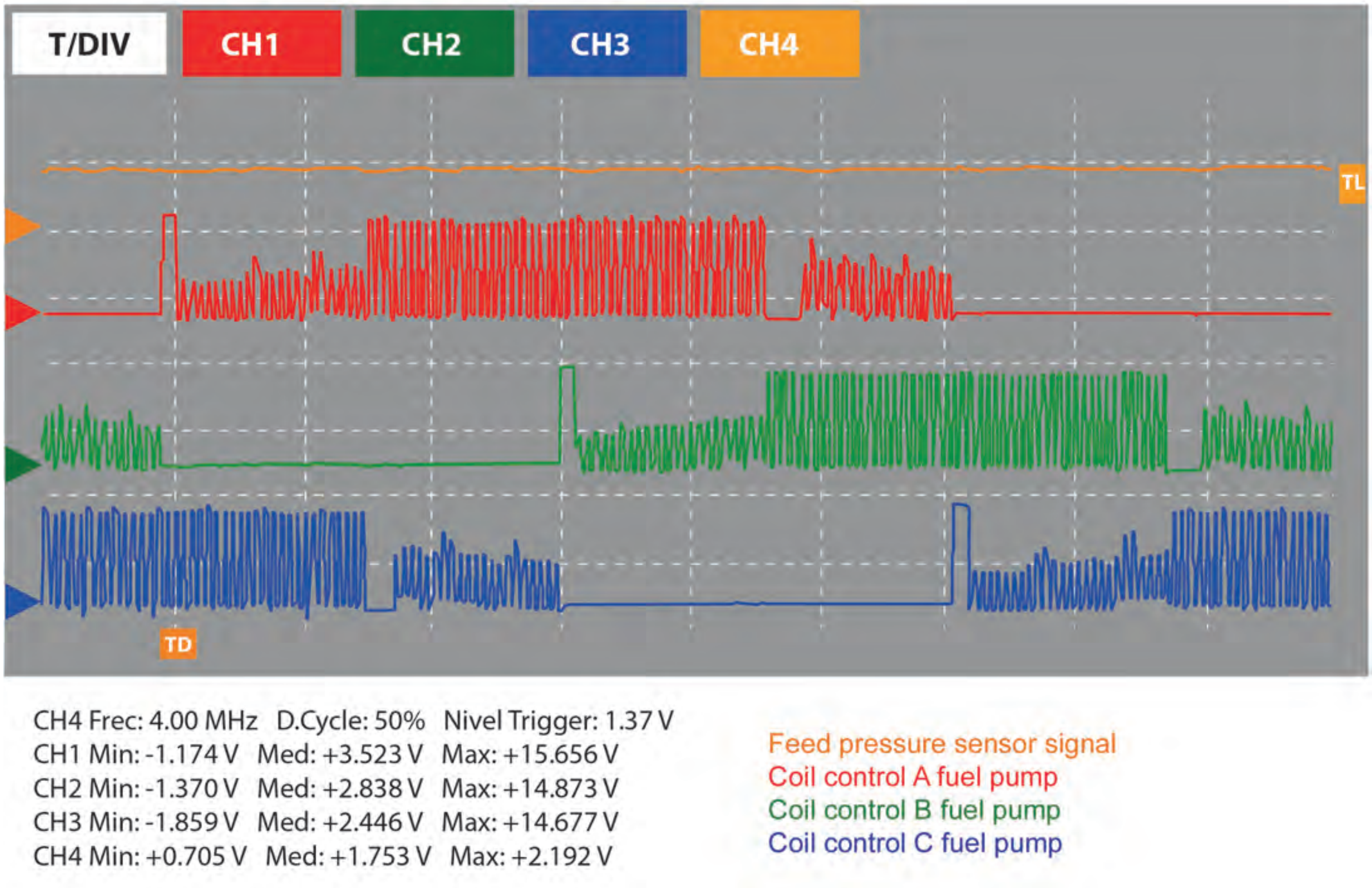
Three-phase fuel pump

Supplies the fuel drawn from the tank to the high-pressure pump at a variable pressure of between 4 and 7 bar depending on the requirements of the engine. This is an electric gear pump driven by a three-phase permanent magnet and brushless electric motor.

The electric pump is managed by the ECU through a specific control unit. This unit receives the "nominal fuel pressure" signal from the ECU and compares it with the voltage measured by the low fuel pressure sensor to activate, accordingly, the three motor phases and obtain the required feed pressure value at all times with the lowest electrical consumption possible.



The fuel pump's control unit recognises the position of the pump rotor's magnetic field and supplies the stator coils sequentially to attain the correct rotation direction and desired rotation speed, by varying the voltage and frequency applied to the coils.

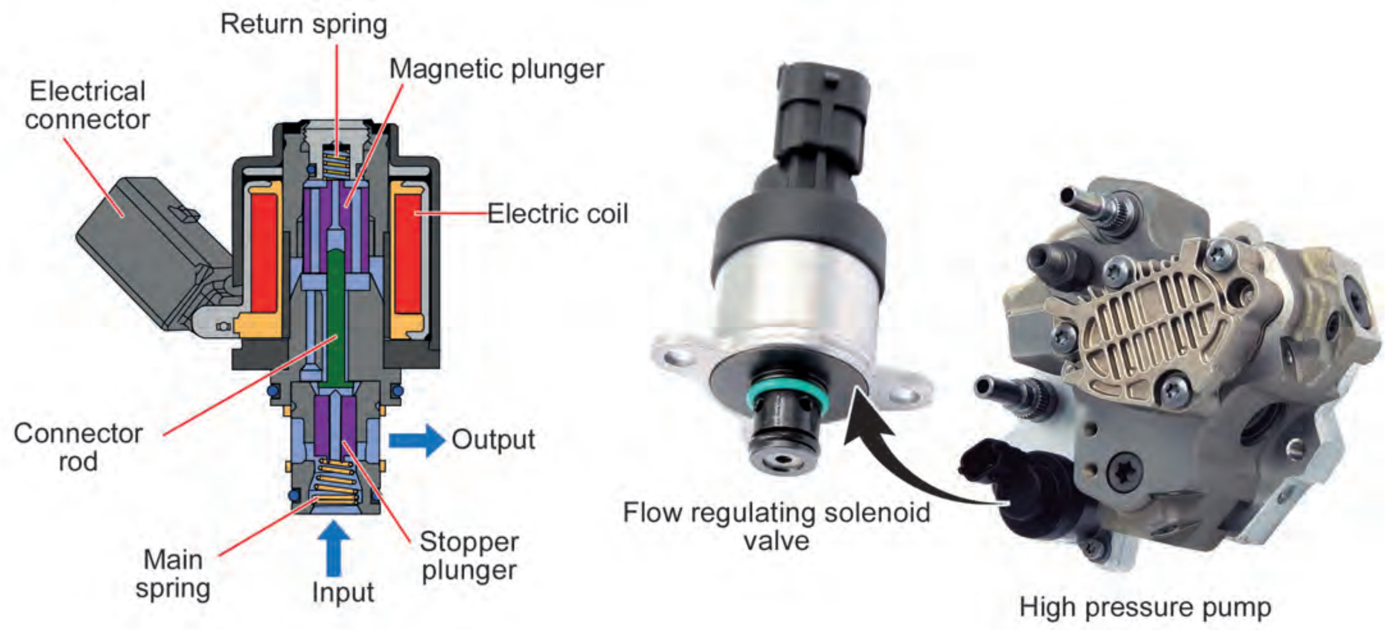


The individual signal for each coil is modulated by means of a magnetic activation pulse and subsequent progressive regulation by rising followed by falling voltage.
The frequency of the excitation cycles is variable in order to modify the pump rotation speed, and in this way adapt the fuel flow to maintain the necessary fuel pressure irrespective of the amount of injected fuel. The unit independently controls each coil by positive modulation and sequential activation of the coils by common ground.

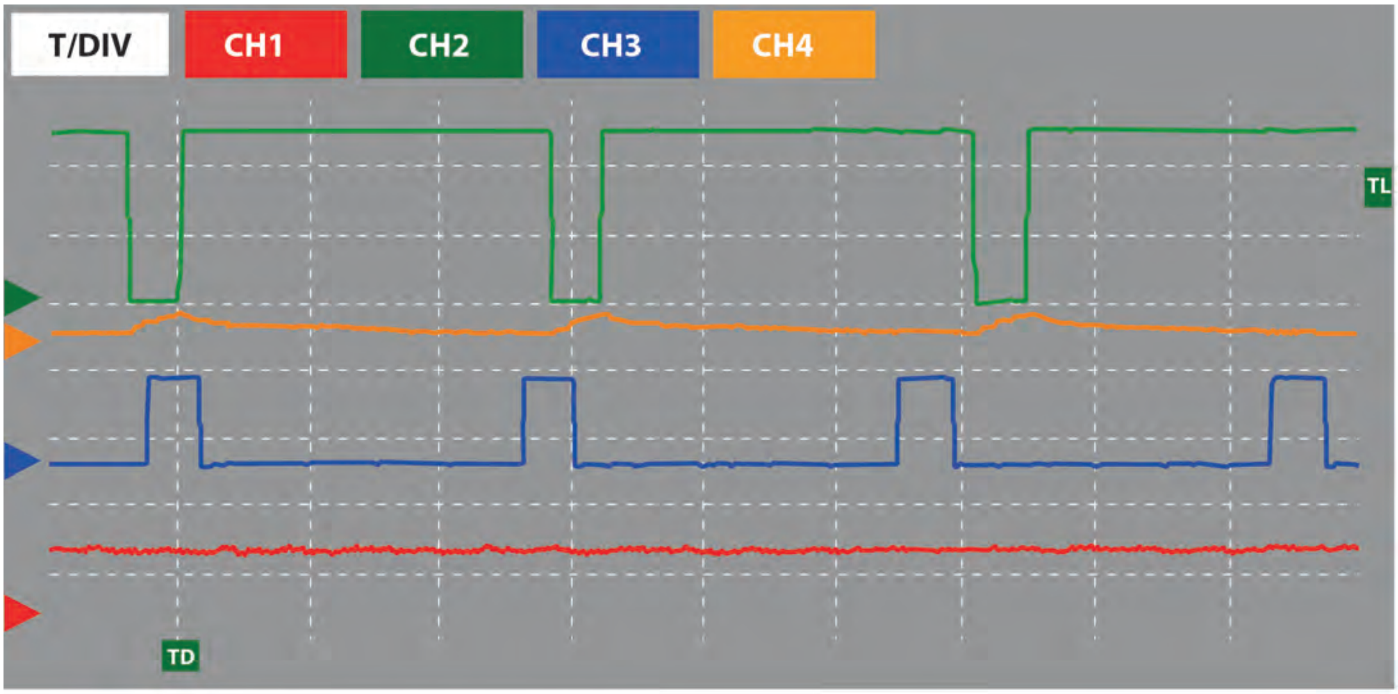
This electronic control standard for the pressure dispenses with the mechanical pressure regulators, which achieves a significant energy saving as only the flow necessary for the engine feed is pressurised.

Flow regulating solenoid valve

This is responsible for modulating the fuel flow to the pump elements in accordance with the engine control unit's signal. Among its functions is stopping the engine by cutting off the fuel supply and the basic control of the rail pressure.



This is a solenoid valve with a variable flow cross-section, which depends on the intensity of the magnetic field created by a copper wire coil. This rest position is open, allowing full fuel flow to the pump. The engine control unit modulates the electrical current applied to the flow rate control solenoid valve by means of a variable frequency OCR signal from 300 to 600 Hz.



CH2 Frec: 311 Hz D.Cycle: 88% Nivel Trigger: 1.37 V
CH1 Min: +0.892 V Med: +1.018 V Max: +1.127 V
CH2 Min: -0.196 V Med: +11.448 V Max: +12.818 V
CH3 Min: -0.881 V Med: +1.076 V Max: +12.133 V
CH4 Min: +0.078 A Med: +0.172 A Max: +0.391 A

Flow regulating solenoid valve control
Rail pressure solenoid valve control
Rail pressure signal

This solenoid valve receives a power supply positive from the injection system and control ground modulated by the engine control unit in variable percentage and frequency. The positive voltage of the signal is variable depending on the working voltage value of the alternator. The rising ground percentage increases the current applied to the component and with it, its magnetic field.

The amount of pressurised fuel reduces as the average applied current increases. The flow regulating solenoid valve is deactivated after starting when fuel temperatures are lower than 10°C, in order to force the rapid heating of the fuel and improve its fluidity. The rail pressure is regulated by means of the high pressure regulator in these circumstances, leading to a large quantity of pressurised fuel in the return circuit.

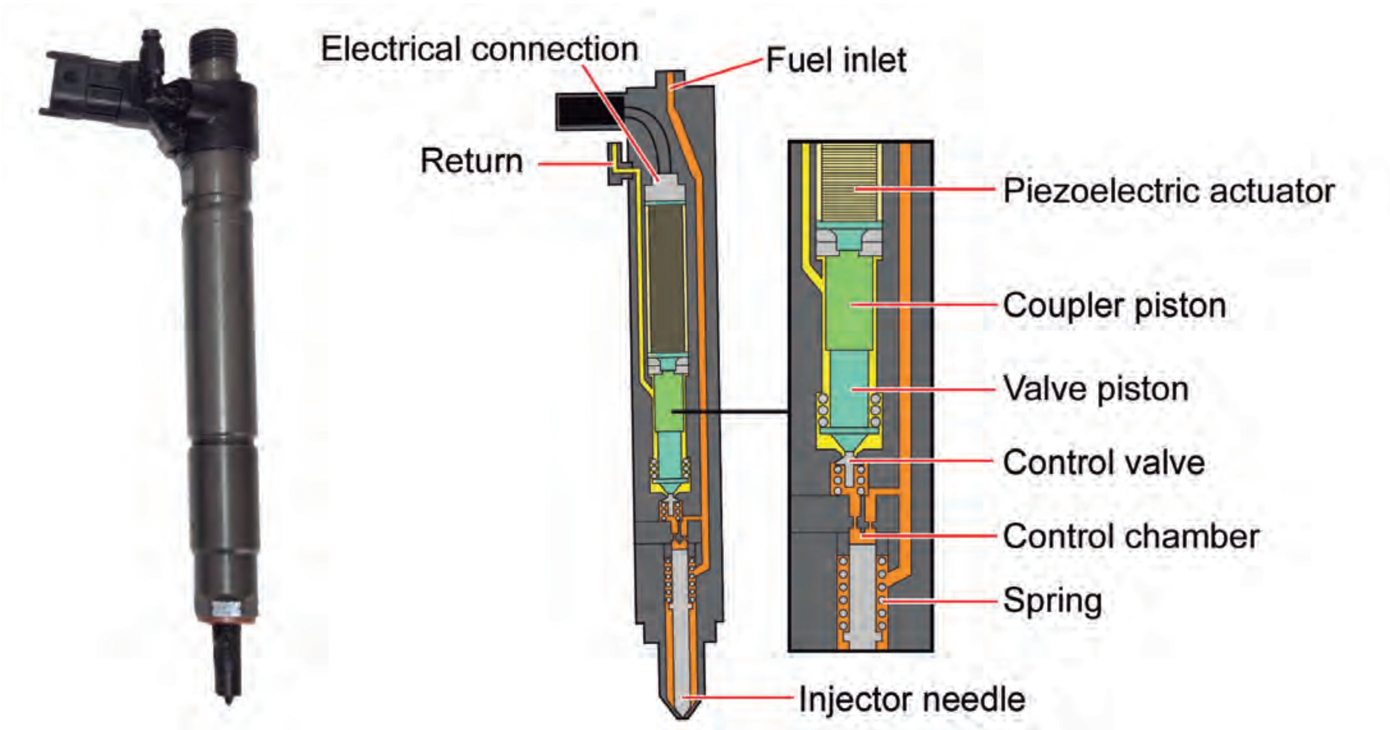
In case of an electrical failure of the circuit or component, the fuel pressure is fully regulated by the fuel pressure regulator with certain operation and performance limitations.

Piezoelectric injector

The function of the injector is to introduce and atomise the required amount of fuel into the combustion chamber during each one of the injection cycle phases. Depending on the operating state and engine load, the engine control unit determines the optimal injection sequence for each situation, and establishes the number of injections and the amount of fuel for each engine cylinder in each working cycle.

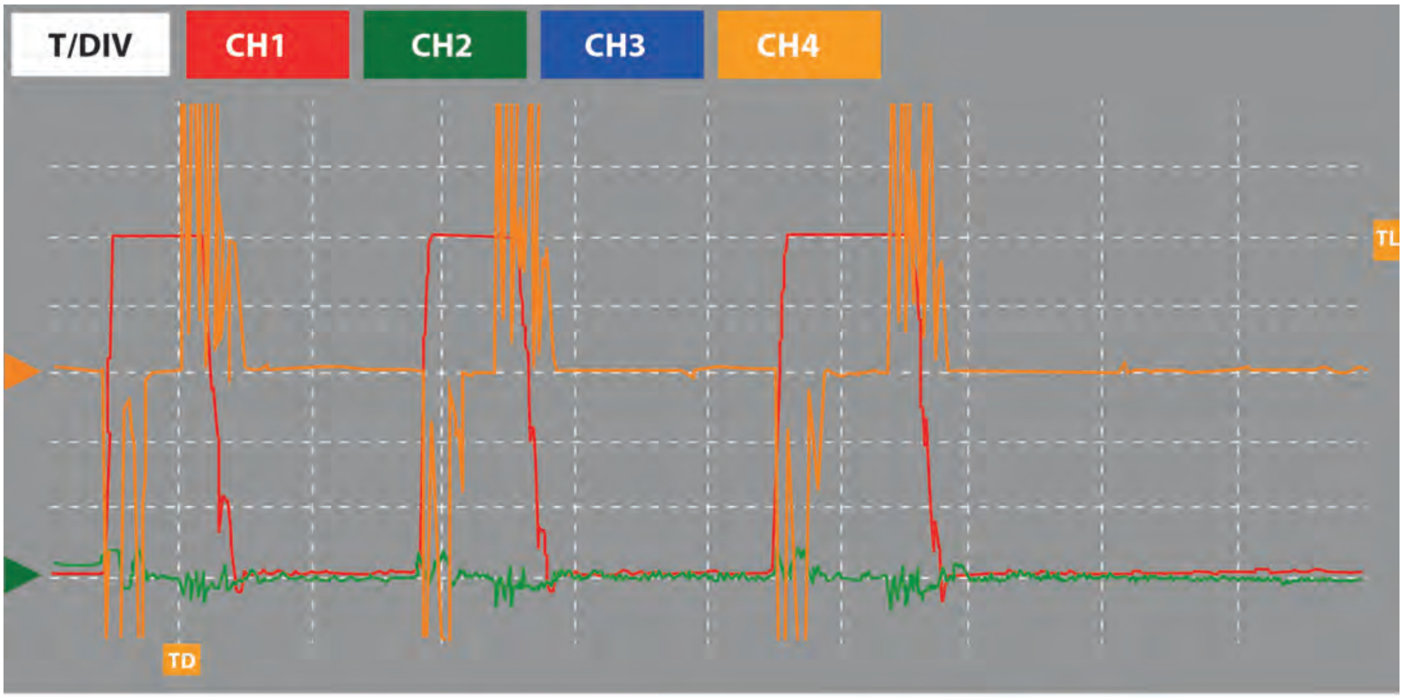
The use of piezoelectric elements in the injectors considerably increases the response speed of the injector needle when compared to electromagnetic systems. The physical response or deformation of piezoelectric materials is instantaneous, although it is also very small. Their high capacity for changing state makes them ideal for modern diesel injectors that must open and close several times in a single combustion cycle.

The injector's internal hydraulic functioning is very similar to a coil injector. It uses the hydraulic pressure of the fuel to control the opening of the injector. While the injector is idle, the high pressure of the fuel in the control chamber, along with the needle spring, generate a force that is greater than the force in the opposite direction that is exerted by the pressure of the fuel located around the needle, keeping the injector closed.



When the control unit energizes the injector, the piezoelectric actuator expands, moving the coupling piston, the valve piston, and the control valve. This movement causes the opening of the fuel path between the control chamber and the return chamber. This releases the pressure in it because the outgoing fuel flow is greater than the incoming flow. When the pressure in the control chamber has been released, the force exerted by the fuel on the needle is higher than the force exerted by the closing spring, so the needle is raised, allowing fuel to exit through the injection openings.

To complete the injection, the control unit acts as a load instead of electrically energizing the injector, by changing the direction of the current. This change causes the piezoelectric actuator to discharge (recover its internal electrical balance) and contract, which returns to its initial size. Both the coupling piston as well as the valve piston and the control valve return to their original positions due to the effect of a series of springs. The flow of fuel to the return is thus closed which increases the pressure in the control chamber. The pressure increase in the chamber, along with the force of the spring, cause the needle to drop, closing off the injector again and cutting off the injection of fuel into the cylinder.



CH4 Frec:73.5 kHz D.Cycle: 49% Nivel Trigger: 1.92 A
CH1 Min: -5.284 V Med: -41.194 V Max: +50.000 V
CH2 Min: -5.088 V Med: -28.376 V Max: +50.000 V

CH4 Min: -8.016 A Med: -5.479 A Max: +7.984 A

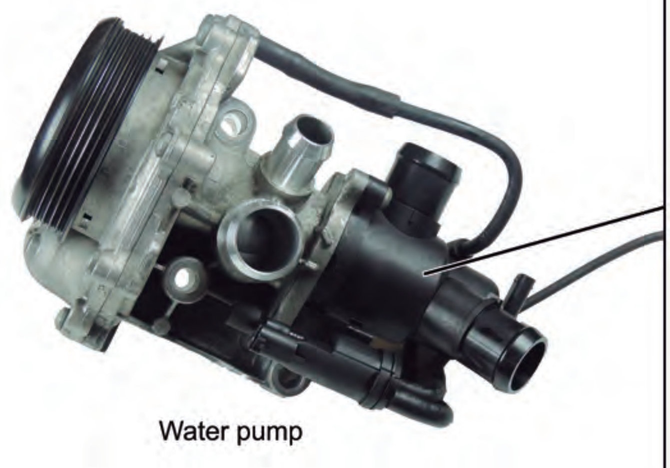
Injector ground
Injector current
Injector positive

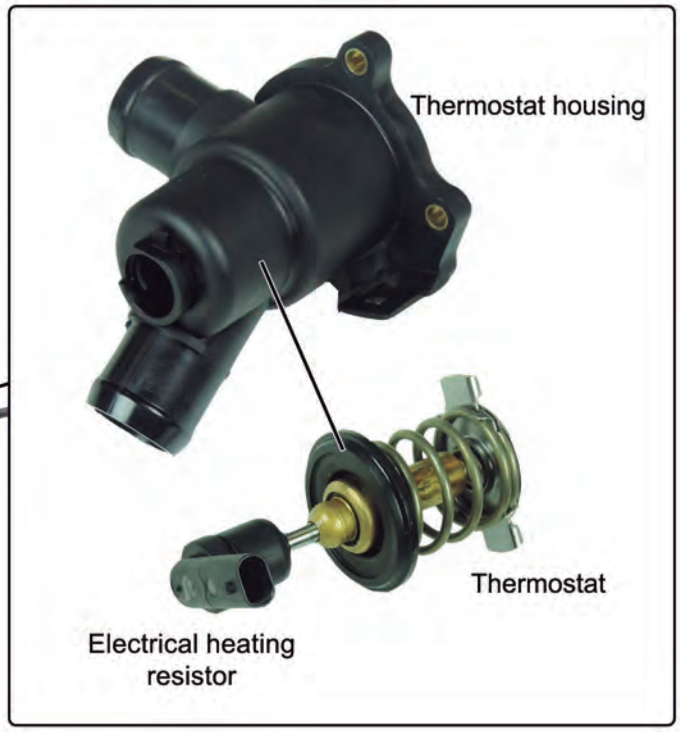
The work of the injectors is activated by polarising the element in one direction that expands it and then allowing it to discharge so it contracts; therefore there is no reversing of the polarity but there is a current change. The excitation is carried out in this case through the positive which is maintained until the component is discharged. A proper check must be based more on the inversion of the current than on the voltage values, as this is an indicator of the work and change of state of the expandable element.

Electronic thermostat

Also known as the piloted thermostat. It is usually located in the thermostat housing, whether at the outlet of the cylinder head or at the lowest part of the engine next to the water pump.

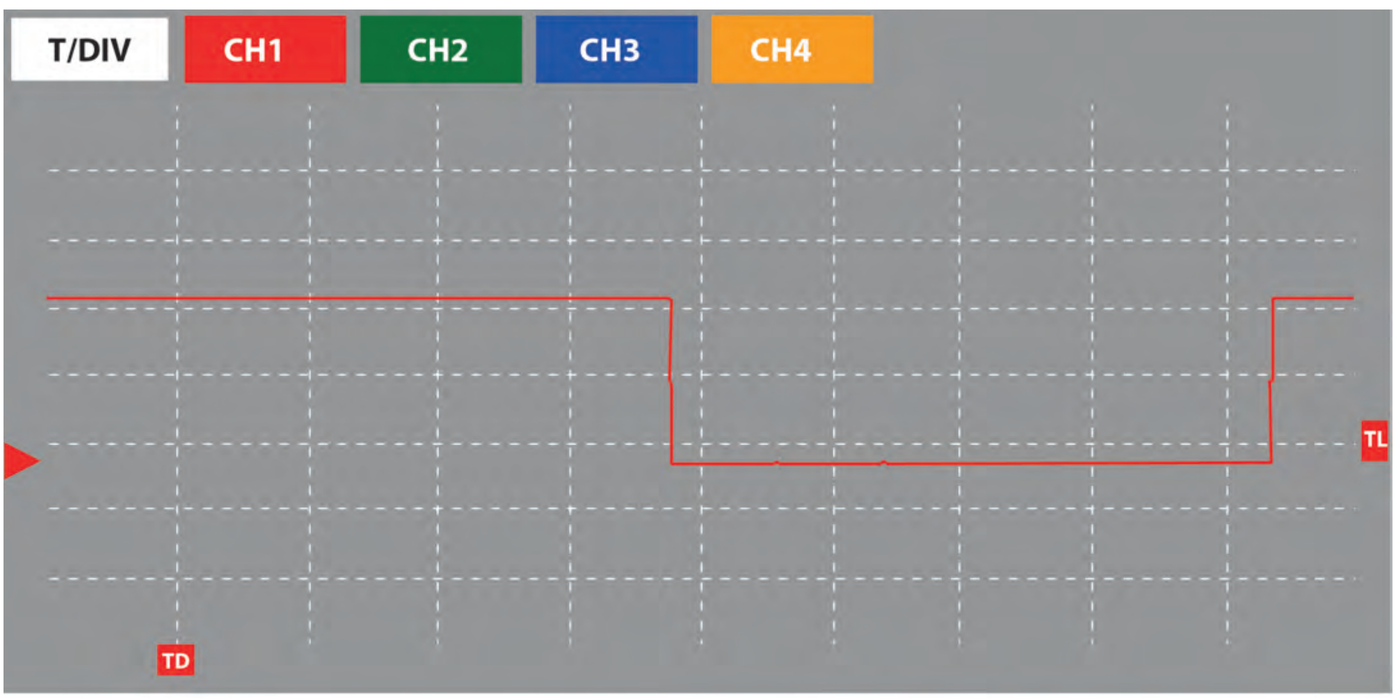
It is usually double acting, with an electrical heating resistor that penetrates the wax capsule. The activation of the thermoresistor raises the temperature of the capsule above that of the coolant so that the thermostat opens at lower temperatures than its presetting.





This type of thermostat is used to control the coolant flow according to the engine load and vehicle speed in advance. Power is supplied to the resistor in order to change the opening cross-section in expectation of a considerable increase in the accumulation of heat in the cylinder head and in the engine block.

The natural working temperature, somewhat higher, reduces the possibility of excessive cooling under low load conditions.



CH1 Frec: --- Hz D.Cycle: --- % Nivel Trigger: 1.37 V
CH1 Min: -0.098 Med: +6.751 V Max: +12.133 V

Ground activation of the thermostat resistor

The engine control unit activates and regulates the forced opening of the thermostat in order to modulate the coolant flow that is sent to the cooling radiator. The thermostat's heatable resistor receives a power supply positive from the injection system and control ground from the control unit. The control ground can be both continuous and modulated depending on the current that must be applied to the heating element.

TECHNICAL NOTES

This section includes examples of the most common faults that can be found in some of the aforementioned sensors and actuators. Depending on the manufacturer and the different models, the number of faults occurring over the years may vary.

These faults are selected from the online platform: www.einavts.com. This platform has a series of sections that specify: make, model, line, system affected, and subsystem, which can be selected independently depending on the desired search.

VOLKSWAGEN

TOURAN (1T1, 1T2) 2.0 TDI (BMM), (1T1, 1T2) 2.0 TDI 16V (BKD), (1T1, 1T2) 2.0 TDI (BMN), VW PASSAT (3C2) 2.0 TDI (BMP), (3C2) 2.0 TDI 16V 4motion (BKP), (3C2) 2.0 TDI 4motion (BMP), (3C2) 2.0 TDI (BMR)	
Symptom	**Error codes**: 17448 - P1040 - Supply injector valves A. Electrical malfunction in circuit. 17672 - P1264 - Valve for pump/injector, cylinder 2 (N241), adjustment limit exceeded. 17675 - P1267 - Valve for pump/injector, cylinder 3 (N242), adjustment limit exceeded. 17925 - P1517 - Main relay (J271). Fault in the electrical circuit. 18009 - P1601 - Relay for supply voltage terminal 30 (J317). Signal implausible. 18578 - P2146 - Supply injection valve(s) A - Open circuit. Engine does not start after shutting down while driving on the road. Improper operation of the dashboard, no warning lights illuminate intermittently.
Cause	Defect in the piezoelectric injectors. This type of management installs piezoelectric injectors; when a short-circuit occurs in any of them, the engine management unit cancels the excitation of the rest of the injectors for safety reasons. Said short-circuit occurs when the electrical part of the injector comes in contact with ground.
Solution	**Repair procedure:** • Carry out a test of the injectors to determine which injector is faulty. • Remove the cover to the camshaft. • Disconnect one of the injectors. • Attempt to start the engine with three cylinders. • Replace the injector we have disconnected at this time if the engine starts; otherwise, continue disconnecting one injector at a time until we find the one that is crossed.

TOYOTA

TOYOTA AVENSIS Sedan / Family estate car (_T27_)	
Symptom	Error code: C1336 - Zero point calibration of G sensor undone. Parking brake warning lamp on. Dashboard warning message: 'check parking brake system'.
Cause	G sensor calibration, undone.
Solution	Calibrate G sensor (side force, yaw sensor, etc.) with the diagnostic tool. NOTE: Once the zero point calibration of the sensor has been carried out, it may not solve the problem and the actuator assembly of the electric parking brake (EPB) will have to be replaced.

CITROËN

CITROËN C3 I (FC_, FN_) 1.4 16V HDi (8HY (DV4TED4))	
Symptom	Fault code recorded in the engine control unit (P1163 - Engine control module. Injector control). Engine stalls. Engine chattering noise when cold. Not enough engine power. NOTE: The fault code P1136 must not be accompanied by other fault codes. The fault code and symptoms may appear after reprogramming or replacement of the engine control unit.
Cause	Defective injector calibration.
Solution	Repair procedure: • Read the fault codes recorded in the engine control unit with the diagnostic tool. • Confirm that the cited fault code is recorded in the symptom field of this technical note. • Confirm that the symptoms indicated in the symptom field of this note occur. • Note the classification number of the 4 injectors (16-digit code) and compare them with the codes indicated in the diagnostic tool on the injector classification menu. • Exit the injector classification menu and disconnect the diagnostic tool. • Turn off the ignition and wait 1 minute. • Switch on the ignition and connect the diagnostic tool. • Re-code the 4 injectors in the injector classification menu of the diagnostic tool and validate. • Exit the injector classification menu and disconnect the diagnostic tool. • Turn off the ignition and wait 1 minute. Carry out an injector learning with a dynamic test on the road in accordance with the following process: • With the engine service temperature at or more than 70°C, accelerate at least 8 times every 30 seconds with the pedal fully depressed in 5th gear at a speed of between 60 and 90 km/h.

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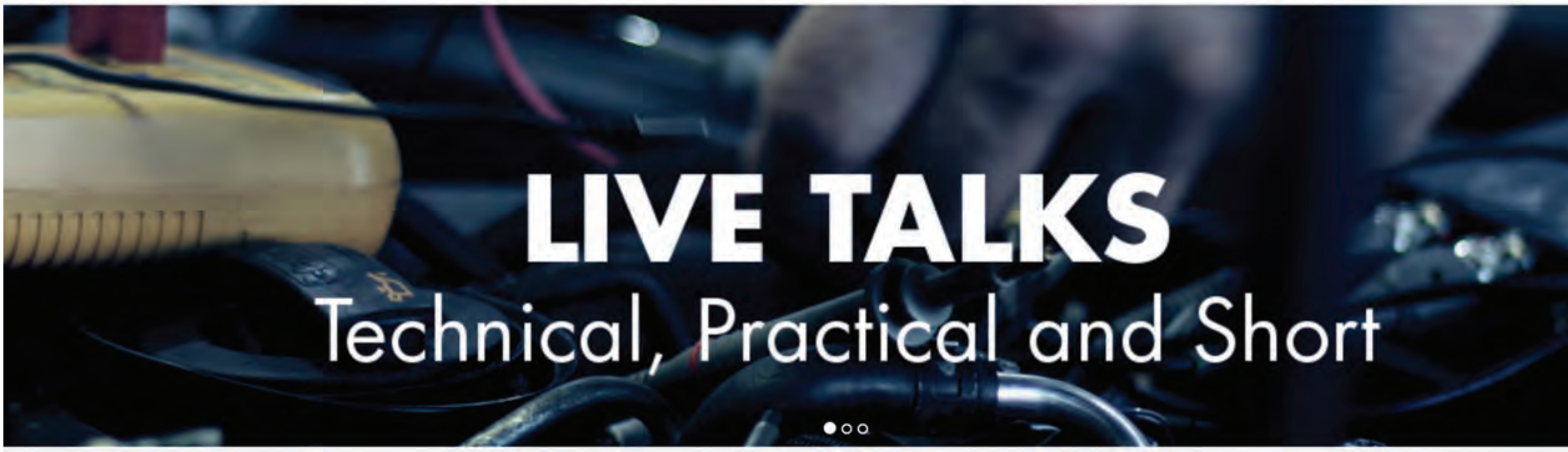

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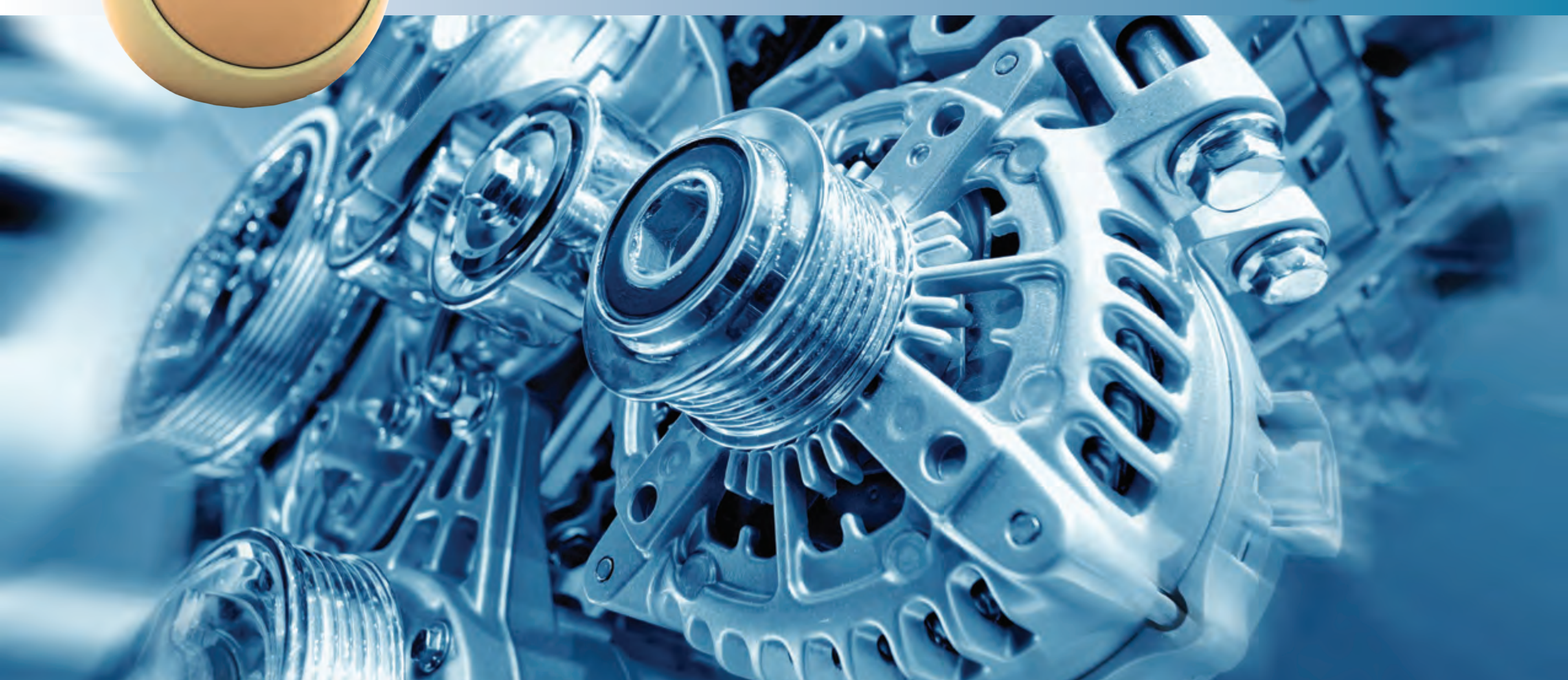
Gas Analysis in internal combustion engines



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