Control of Diesel engines

System overview

Electronic control of a diesel engine enables precise and differentiated modulation of fuel-injection parameters. This is the only means by which a modern diesel engine is able to satisfy the many demands placed upon it. Electronic diesel control (EDC) is subdivided into three system blocks: sensors/setpoint generators, ECU, and actuators.

Requirements

The lowering of fuel consumption and exhaust emissions (NO_X, CO, HC, particulates) combined with simultaneous improvement of engine power output and torque are the guiding principles of current development work on diesel-engine design. Conventional indirect-injection engines (IDI) were no longer able to satisfy these requirements.

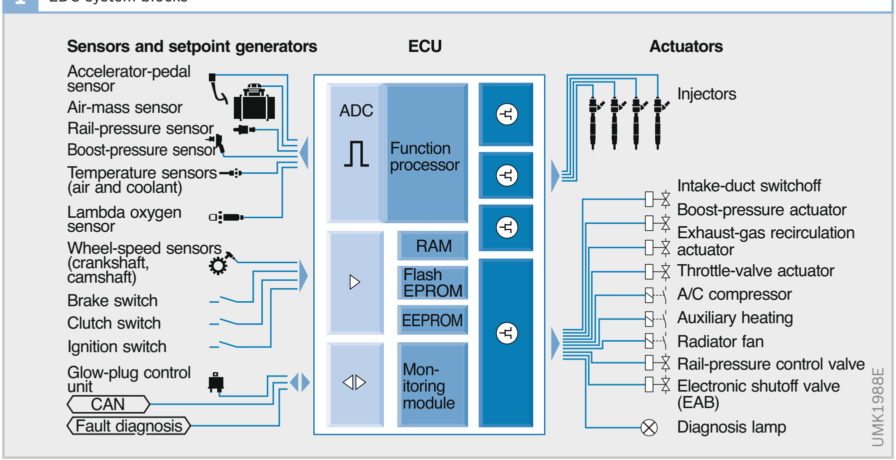
State-of-the-art technology is represented today by direct-injection diesel engines (DI) with high injection pressures for efficient mixture formation. The fuel-injection systems support several injection processes: pre-injection, main injection, and secondary injection. These injection processes are for the most part controlled electronically (pre-injection, however, is controlled mechanically on UIS for cars).

In addition, diesel-engine development has been influenced by the high levels of driving comfort and convenience demanded in modern cars. Exhaust and noise emissions are also subject to ever more stringent demands.

As a result, the performance demanded of the fuel-injection and management systems has also increased, specifically with regard to:

- High injection pressures
- Rate shaping
- Pre-injection and, if necessary, secondary injection
- Adaptation of injected fuel quantity, boost pressure and start of injection at the respective operating status
- Temperature-dependent excess-fuel quantity
- Load-independent idle speed control
- Controlled exhaust-gas recirculation
- Cruise control
- Tight tolerances for start of injection and injected-fuel quantity and maintenance of high precision over the service life of the system (long-term performance)
- Support of exhaust-gas treatment systems

1 EDC system blocks



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Conventional mechanical RPM control uses a number of adjusting mechanisms to adapt to different engine operating statuses and ensures high-quality mixture formation. Nevertheless, it is restricted to a simple engine-based control loop and there are a number of important influencing variables that it cannot take account of or cannot respond quickly enough to.

As demands have increased, EDC has developed into a complex electronic engine-management system capable of processing large amounts of data in real time. In addition to its pure engine-management function, EDC supports a series of comfort and convenience functions (e.g. cruise control). It can form part of an overall electronic vehicle-speed control system ("drive-by-wire"). And as a result of the increasing integration of electronic components, complex electronics can be accommodated in a very small space.

Operating principle

Electronic diesel control (EDC) is capable of meeting the requirements listed above as a result of microcontroller performance that has improved considerably in the last few years.

In contrast to diesel-engine vehicles with conventional in-line or distributor injection pumps, the driver of an EDC-controlled vehicle has no direct influence, for instance through the accelerator pedal and Bowden cable, upon the injected fuel quantity. Instead, the injected fuel quantity is determined by a number of influencing variables. These include:

- Driver command (accelerator-pedal position)
- Operating status
- Engine temperature
- Interventions by other systems (e.g. TCS)
- Effects on exhaust emissions, etc.

The ECU calculates the injected fuel quantity on the basis of all these influencing variables. Start of injection can also be varied. This requires a comprehensive monitoring concept that detects inconsistencies and initiates appropriate actions in accordance with the effects (e.g. torque limitation or limp-home mode in the idle-speed range). EDC therefore incorporates a number of control loops.

Electronic diesel control allows data communication with other electronic systems, such as the traction-control system (TCS), electronic transmission control (ETC), or electronic stability program (ESP). As a result, the engine-management system can be integrated in the vehicle's overall control system, thereby enabling functions such as reduction of engine torque when the automatic transmission changes gear, regulation of engine torque to compensate for wheel slip, etc.

The EDC system is fully integrated in the vehicle's diagnosis system. It meets all OBD (On-Board Diagnosis) and EOBD (European OBD) requirements.

System blocks

Electronic diesel control (EDC) is divided into three system blocks (Fig. 1):

1. *Sensors and setpoint generators* detect operating conditions (e.g. engine speed) and setpoint values (e.g. switch position). They convert physical variables into electrical signals.

2. The *ECU* processes the information from the sensors and setpoint generators in mathematical computing processes (open- and closed-loop control algorithms). It controls the actuators by means of electrical output signals. In addition, the ECU acts as an interface to other systems and to the vehicle diagnosis system.

3. *Actuator*s convert the electrical output signals from the ECU into mechanical variables (e.g. solenoid-valve needle lift).

Data processing

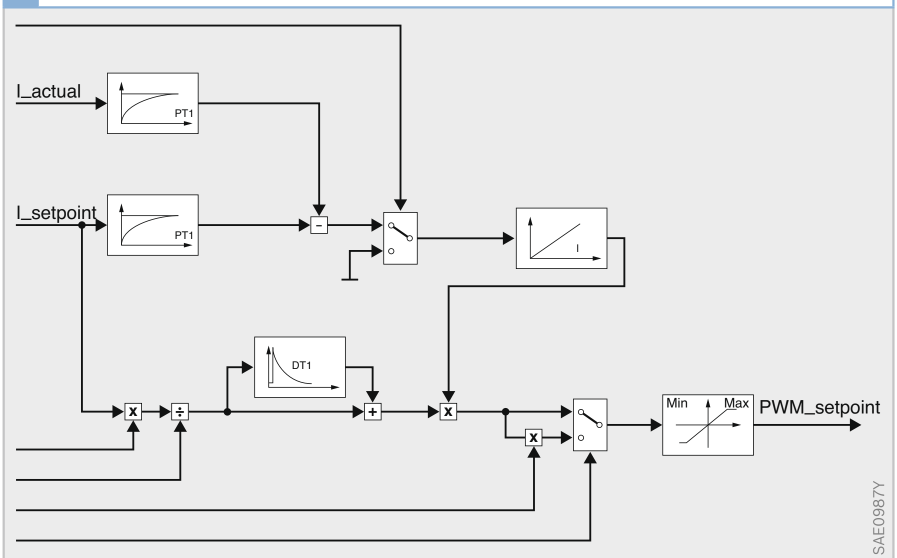
The main function of the electronic diesel control (EDC) is to control the injected fuel quantity and the injection timing. The common-rail accumulator injection system also controls injection pressure. Furthermore, on all systems, the engine ECU controls a number of actuators. The EDC functions must be matched to every vehicle and every engine. This is the only way to optimize component interaction (Fig. 3).

The control unit evaluates the signals sent by the sensors and limits them to the permitted voltage level. Some input signals are also checked for plausibility. Using this input data together with stored program maps, the microprocessor calculates the position and duration for injection timing. This information is then converted to a signal characteristic which is aligned to the engine's piston strokes. This calculation program is termed the “ECU software”.

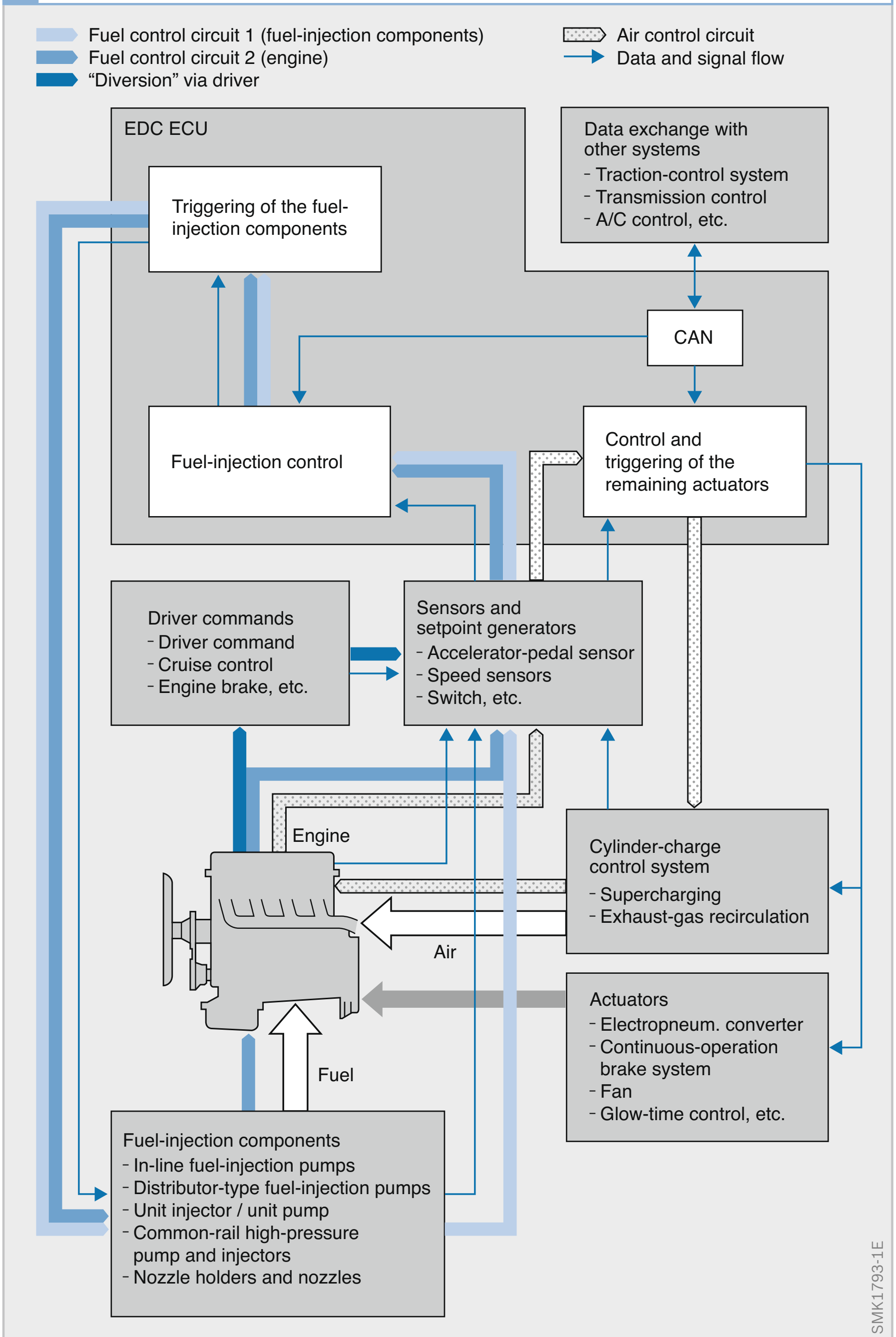
The required degree of accuracy together with the diesel engine's outstanding dynamic response requires high-level computing power. The output signals are applied to driver stages which provide adequate power for the actuators (for instance, the high-pressure solenoid valves for fuel injection, exhaust-gas recirculation positioner, or boost-pressure actuator). Apart from this, a number of other auxiliary-function components (e.g. glow relay and air-conditioning system) are triggered.

The driver-stage diagnosis functions for the solenoid valves also detect faulty signal characteristics. Furthermore, signals are exchanged with other systems in the vehicle via the interfaces. The engine ECU monitors the complete fuel-injection system as part of a safety strategy.

2 Schematic using the example of a current regulator



3 Basic sequence of electronic diesel control



Fuel-injection control

Table 1 provides an overview of the EDC functions which are implemented in the various fuel-injection systems. Figure 4 shows the sequence of fuel-injection calculations with all functions, a number of which are optional extras. These can be activated in the ECU by the after-sales service when retrofit equipment is installed.

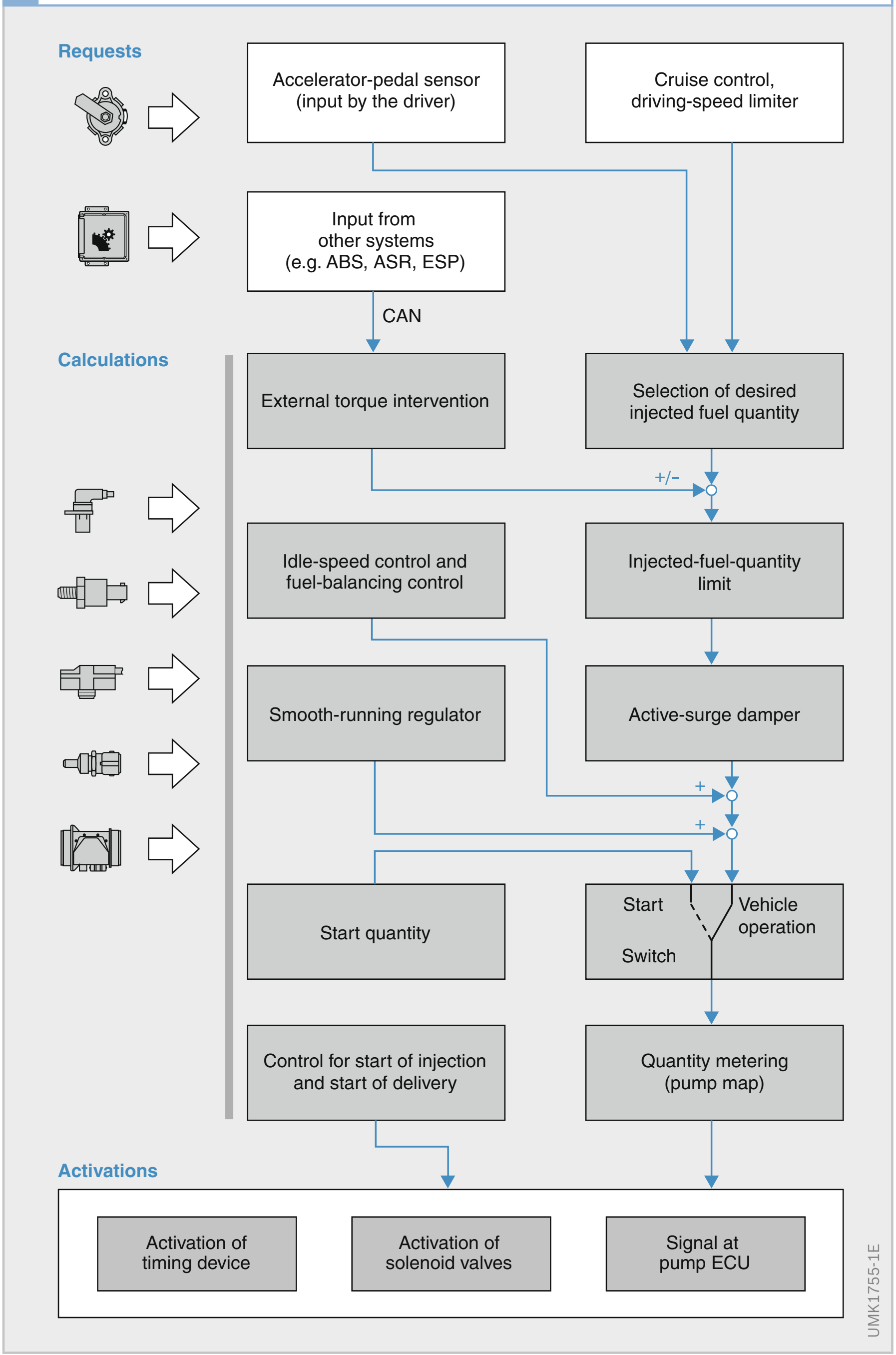
In order that the engine can run with optimal combustion under all operating conditions, the ECU calculates exactly the right injected fuel quantity for all conditions. Here, a number of parameters must be taken into account. On a number of solenoid-valve-controlled distributor-type injection pumps, the solenoid valves for injected fuel quantity and start of injection are triggered by a separate pump ECU.

1 Overview of functions of EDC variants for motor vehicles

Fuel-injection system	In-line fuel-injection pumps PE	Helix-controlled distributor-type injection pumps VE-EDC	Solenoid-valve-controlled distributor injection pumps VE-M, VR-M	Unit injector system and unit pump system UIS, UPS	Common-rail system CR
Function					
Injected-fuel-quantity limit	•	•	•	•	•
External torque intervention	• 3)	•	•	•	•
Driving-speed limitation	• 3)	•	•	•	•
Cruise control	•	•	•	•	•
Altitude correction	•	•	•	•	•
Boost-pressure control	•	•	•	•	•
Idle-speed regulation	•	•	•	•	•
Intermediate-speed regulation	• 3)	•	•	•	•
Active surge damping	• 2)	•	•	•	•
BIP control	–	–	•	•	–
Intake-port shutoff	–	–	•	• 2)	•
Electronic immobilizer	• 2)	•	•	•	•
Controlled pre-injection	–	–	•	• 2)	•
Glow control unit	• 2)	•	•	• 2)	•
A/C switch-off	• 2)	•	•	•	•
Auxiliary coolant heating	• 2)	•	•	• 2)	•
Smooth-running control	• 2)	•	•	•	•
Fuel-balancing control	• 2)	–	•	•	•
Fan activation	–	•	•	•	•
EGR control	• 2)	•	•	•	•
Start-of-injection control with sensor	• 1) 3)	•	•	•	•
Cylinder shutoff	–	–	• 3)	• 3)	• 3)
Increment-angle learning	–	–	–	•	•
Increment-angle rounding	–	–	–	• 2)	–

Table 1
1) Control-sleeve in-line fuel-injection pumps
2) Cars only
3) Commercial vehicles only

4 Calculation of fuel-injection process in ECU



Torque-controlled EDC systems

The engine-management system is continually being integrated more closely into the overall vehicle system. Vehicle-dynamics systems (e.g. TCS), comfort and convenience systems (e.g. cruise control/Tempomat), and transmission control influence electronic diesel control (EDC) via the CAN bus. Apart from this, much of the information registered or calculated in the engine-management system must be passed on to other ECUs via the CAN bus.

In order to be able to incorporate EDC even more efficiently in a functional alliance with other ECUs, and implement other changes rapidly and effectively, it was necessary to make radical changes to the newest-generation controls. These changes resulted in torque-controlled EDC, which was introduced with the EDC16. The main feature is the changeover of the module interfaces to the parameters as commonly encountered in practice in the vehicle.

Engine characteristics

Essentially, an engine's output can be defined using the three characteristics: power *P*, engine speed *n*, and torque *M*.

Figure 5 compares typical curves of torque and power as a function of the engine speed of two diesel engines. Basically speaking, the following formula applies:

$$P = 2 \cdot \pi \cdot n \cdot M$$

It is sufficient therefore, for example, to specify the torque as the reference variable while taking into account the engine speed. Engine power then results from the above formula. Since power output cannot be measured directly, torque has turned out to be a suitable reference variable for engine management.

Torque control

When accelerating, the driver uses the accelerator-pedal (sensor) to directly demand a given torque from the engine. Independently of the driver's requirements, other external vehicle systems submit torque demands via the interfaces resulting from the power requirements of the particular component (e.g. air-conditioning system, alternator). Using these torque-requirement inputs, the engine-management system calculates the output engine torque to be generated and controls the fuel-injection and air-system actuators accordingly. This has the following advantages:

- No system has a direct influence on engine management (boost pressure, fuel injection, preglow). The engine management system can thus also take into account other higher-level optimization criteria for the external requirements (e.g. exhaust-gas emissions, fuel consumption) and then control the engine in the best way possible.
- Many of the functions which do not directly concern the engine management system can be designed to function identically for diesel and gasoline engines.
- Expansions to the system can be implemented quickly.

5 Example of the torque and power-output curves as a function of engine speed for two car diesel engines with approx. 2.2 *l* engine displacement

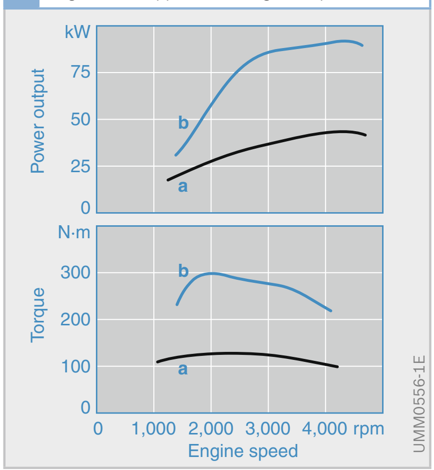


Fig. 5
a Build year 1968
b Build year 1998

Sequence of engine management

The setpoint values are processed further in the engine ECU. In order to fulfill their assignments efficiently, the engine management system's control functions all require a wide range of sensor signals and information from other ECUs in the vehicle.

Propulsion torque

The driver's input (i.e. the signal from the accelerator-pedal sensor) is interpreted by the engine management system as the request for a propulsion torque. The inputs from the cruise control and the vehicle-speed limiter are processed in exactly the same manner.

Following this selection of the desired propulsive torque, should the situation arise, the vehicle-dynamics system (TCS, ESP) increases the desired torque value when there is the danger of wheel lockup and decreases it when the wheels show a tendency to spin.

Further external torque demands

The drivetrain's torque adaptation must be taken into account (drivetrain transmission ratio). This is defined for the most part by the ratio of the particular gear, or by the torque-converter efficiency in the case of automatic transmissions. On vehicles with an automatic transmission, the transmission control stipulates the torque demand during the gearshift. This is reduced in order to produce a comfortable, smooth gearshift, thus protecting the engine. In addition, the torque required by other engine-powered auxiliary systems (e.g. air-conditioning compressor, alternator, servo pump) is determined. This torque demand is calculated either by the auxiliary systems themselves or by the engine management system. Calculation is based on the required power and engine speed, and the engine management system adds up the various torque requirements.

The vehicle's driveability remains unchanged notwithstanding varying requirements from the auxiliary systems and changes in the engine's operating states.

Internal torque demands

At this stage, the idle-speed control and the active surge damper intervene.

For instance, if demanded by the situation, in order to prevent mechanical damage, or excessive smoke due to the injection of too much fuel, the torque limitation reduces the internal torque demand. In contrast to previous engine-management systems, limitations are no longer only applied to the injected fuel quantity, but instead, depending on the required effects, also to the particular physical quantity involved.

The engine's losses are also taken into account (e.g. friction, drive for the high-pressure pump). The torque represents the engine's measurable effects to the outside. However, the engine management system can only generate these effects in conjunction with the correct fuel injection together with the correct injection point, and the necessary marginal conditions as apply to the air system (e.g. boost pressure and exhaust-gas recirculation rate). The required injected fuel quantity is determined using the current combustion efficiency. The calculated fuel quantity is limited by a protective function (e.g. protection against overheating), and if necessary can be varied by smooth-running control. During engine start, the injected fuel quantity is not determined by external inputs such as those from the driver, but rather by the separate "start quantity" control function.

Actuator triggering

The resulting setpoint value for the injected fuel quantity is used to generate the triggering data for the injection pumps and/or the fuel injectors, and for defining the optimum operating point for the intake-air system.