The third-generation passenger car common rail system with piezo inline injectors introduced by Bosch in May 2003 presents a leap in technology in the field of common rail diesel injection technology. A special feature is the injector with its fast switching piezo actuator integrated into the injector body. Compared to the best systems with solenoid or piezo technology up to now, the third-generation passenger car common rail system reduces harmful emissions by up to 20%. The exact metering of the injection quantity by the piezo inline injector is supported by new types of control functions.
2 System Overview of the Third-Generation Common Rail System

2.1 Fuel Quantity-Controlled High-Pressure Pump
The fuel quantity-controlled high-pressure pump CP3.x for the third-generation common rail injection system is a radial piston pump with three high-pressure pistons and a polygon drive unit in a steel mono-block housing. Figure 3. Injection pressures of up to 1600 bar and pump speeds of up to 4000 rpm can be utilized.

The rail pressure is controlled by feeding exactly that quantity of fuel to the rail that is necessary for the system consumption. Thus, the fuel quantity pressurized by the pump is reduced, as is the power consumption of the pump.

The CP3.x is available with different displacements to suit all requirements, starting from small-displacement passenger car engines and ending with heavy-duty trucks. The pump programme varies the delivery volume through the diameter of the piston and the piston stroke rating in different housing sizes.

2.2 Rail with Injection Lines and Pressure-Regulating Valve
In its basic concept, the high-tensile, modular laser welded rail (LWR) is prepared to meet future requirements. The surface layering is Cr6+-free and already fulfils the legal requirements that come into force in 2007.

For pressure regulation, a pressure sensor and a pressure-control valve of the latest generation are axially mounted to the rail. Figure 4.

The electro-magnetic pressure-control valve is actuated via the duty cycle of the electric power supply. Due to the optimised solenoid circuit and minimised hysteresis, the pressure in the rail can be quickly and precisely set, so that a constant pressure is possible at varying fuel volume flows.

The rail volume needs to be sufficiently large in order to minimise pressure fluctuations and repercussions on the injection. On the other hand, the volume should be sufficiently small in order to ensure a fast pressure build-up at engine start. During the design phase, the optimisation is carried out by means of simulation calculations using the program AMESim.

2.3 The Piezo Inline Injector
In order to take optimum advantage of the highly dynamic characteristics of the piezo actuators in common rail injectors, certain design criteria should be adhered to. In the following, the functionality of the piezo inline injector in comparison to a conventional common rail injector will be briefly explained.

2.3.1 Fundamentals of the Bosch Piezo Inline Injectors (CR13)
Operation:
In the Bosch piezo inline injectors, the nozzle needle in the injection valve is controlled by a servo valve. The injection quantity is regulated via the control duration. The functional principle is shown schematically in Figure 5. The main assembly groups for the injector functions are the piezo actuator, the hydraulic coupler, the servo valve and the nozzle.

When deactivated, the actuator is in the starting position with the servo valve closed and the high-pressure domain is separated from the low-pressure domain. A hydraulic coupler cancels out any play that might occur (e.g. due thermal expansion). The nozzle is kept closed by the rail pressure in the control volume.

Activation of the piezo actuator opens the servo valve; thus reducing the pressure in the control volume and opening the nozzle. Closing the servo valve increases the pressure in the control volume again and the nozzle needle closes.

Characteristics of Piezo Actuators:
In operation, piezo actuators generate forces and actuating paths. The actuators are characterised by the idle stroke and the lockup force. These parameters are the stroke in the loaded state without force generation and the maximum force without generating a stroke. Depending on the design and the piezo ceramics used, these are in the range of several micrometres or some kN.

When used in an injection valve, different switching positions, i.e. combinations of stroke and force, must be achieved. A hydraulic coupler with the transmission ratio i increases the actuator stroke. As a consequence, the maximum theoretically available force is reduced by the same factor i for energy reasons. In dynamic operation, a reduction in the total stiffness of the system by i must be taken into account.

The lockup force $F_{AB}$ that can be generated by a piezo actuator in linear approximation is proportional to the active cross-sectional area. The idle stroke is proportional to the active length of the piezo actuator and is thus in good approximation to the number of layers.

The mechanical characteristics of the actuator can be presented in a force/distance diagram as shown in Figure 6.

Generally, a linear voltage dependency can be assumed. In fact, the piezo-electric coefficient additionally depends on the electric field strength and therefore also on the voltage applied.

The lockup force is calculated in linear approximation as per Eq. (1).

In order to minimize the loss of energy, the lowest possible values are required for the lockup force and idle stroke. Furthermore, the power requirement is dependent only on material properties. As a consequence, the requirements for the valve to be switched result in a low stroke and the lowest possible hydraulic force.

In real conditions, the stiffness $c_K$ within the switching chain leads to a reduction in the lockup force $F_{AB}$ of the actuator that is available at the valve side. In combination with the transmission ratio $i$, the valve force $F_V$ can be calculated according to Eq. (2). The lockup force $F_{AB}$ on the valve side follows Eq. (3) and its theoretically maximum possible value is calculated according to Eq. (4).