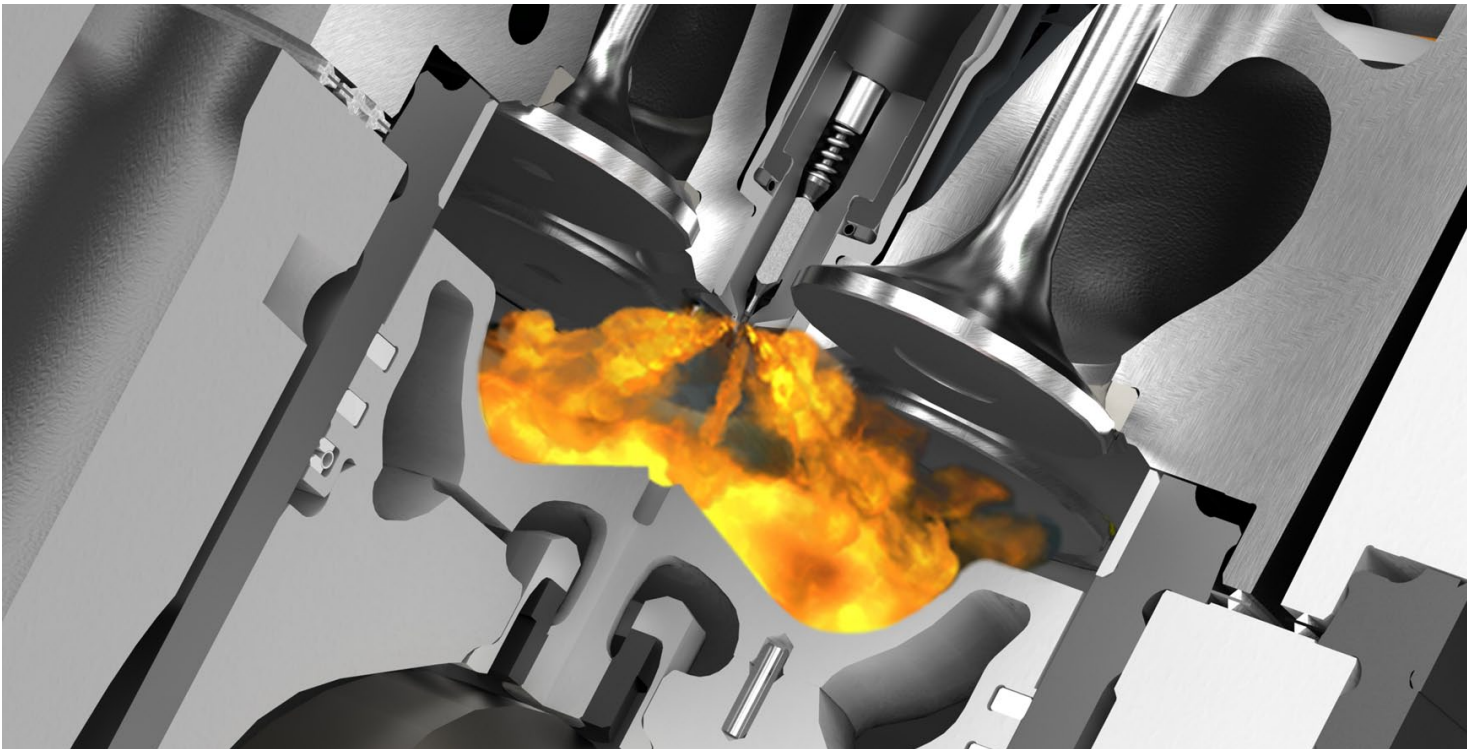


Common Rail Fuel Injection: Key technology for clean and economical combustion



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With common rail fuel injection, the combustion process can be optimized to achieve low pollutant levels combined with lower fuel consumption. Fuel is injected into the combustion chamber from a common rail under high pressure. The electronic control system ensures that the start of injection, the quantity and time are independent of the engine speed. In 1996, with the Series 4000 engine, MTU was the first manufacturer of large diesel engines to introduce common rail fuel injection as a standard feature.

Pioneer of the common rail fuel injection system

The emissions regulations for diesel engines in applications such as ships, trains and heavy-duty off-road vehicles and gensets worldwide are becoming more stringent and make extensive modifications to the power units necessary. At the same time, customers are constantly calling for more economical engines. Exhaust after treatment systems such as SCR catalytic con-

verters (selective catalytic reduction, short: SCR) or diesel particulate filters are one way of lowering emissions, but also have a greater space requirement and potentially increase the engine's maintenance needs. For these reasons, MTU primarily pursues a policy of reducing emissions by internal engine enhancements. Fuel combustion inside the engine is improved so that, if at all possible, emissions are not produced in the first place. If necessary, MTU introduces a

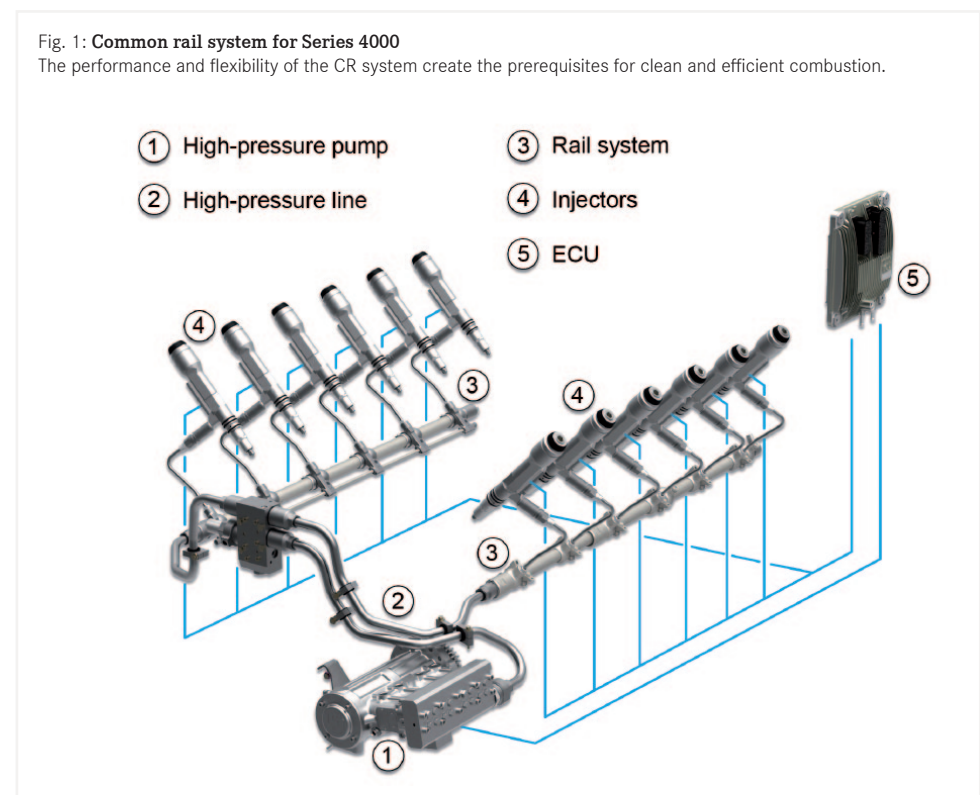
second phase of emission control whereby remaining harmful emissions are removed by exhaust aftertreatment systems.

As part of the internal engine enhancements, one of the major means of control for obtaining clean fuel combustion, besides exhaust gas recirculation, is the fuel injection system. It is designed to inject the fuel at high pressure at precisely the right moment, while also accurately metering the quantity of fuel injected in order to create the conditions required for low-emission combustion inside the cylinder. With precise control of fuel volume delivery at high pressure, fuel consumption can also be dramatically reduced. This is the reason why MTU implemented a technology change from conventional mechanical injection systems to the flexible, electronically controlled common rail system at a very early stage – at the time mainly with a view to producing more economical engines. In 1996, MTU equipped the Series 4000, the first large diesel engine, with a common rail system as a standard feature.

A common fuel pipeline – the so-called rail that gives the system its name – supplies all the engine's fuel injectors with fuel. When fuel is to be injected into a cylinder, the system opens the nozzle of the relevant injector and the fuel flows from the rail into the combustion chamber, is atomized by the high pressure in the process, and mixes with the air. The common rail system components have to be extremely precisely and flexibly controlled. For this purpose, MTU uses its ECU (Engine Control Unit, see Figure 1), a proprietary engine management system that was developed in-house. Due to the increasingly stringent emissions standards for engines of all power classes and all types of application, MTU in future will be fitting all newly developed engines with common rail fuel injection.

Lower emissions due to combination with other key technologies

With combustion optimization by internal engine design features there is a three-way interaction between nitrogen-oxide formation, the produc-



tion of soot particulates and fuel consumption: the more intensive the combustion and thus the energy conversion, the lower the particulate emissions and consumption and the higher the nitrogen oxide emissions. Conversely, retarded combustion leads to lower nitrogen oxide formation, but also to higher fuel consumption and particulate emission levels. The job of the engine developers is to find a compromise between these extremes for every point on the engine performance map. When doing so, they must harmonize the effect of the fuel injection system with that of other internal engine measures such as exhaust gas recirculation, which primarily reduces nitrogen oxide emissions, and external exhaust aftertreatment systems. As a pioneer in this field, MTU can draw from many years of experience with fuel injection systems produced by Rolls-Royce Power Systems brand L'Orange and other suppliers. In the course of this period, MTU has acquired comprehensive expertise in

the integration of the common rail fuel injection system into the engine. This has enabled the company to fully utilize the potential of the fuel injection system in combination with other key technologies for refining the combustion process. The two key parameters in fuel injection that affect fuel consumption and emissions are injection rate and injection pressure.

Injection rate: pre-, main and post injection

The injection rate determines when and how much fuel is injected into the cylinder. In order to reduce emissions and fuel consumption, the present evolution stage of the injection system for MTU engines divides the fuel injection sequence into as many as three separate phases (see Figure 2). The timing of the start of injection, the duration and amplitude are user-defined in accordance with engine performance map. The main injection phase supplies the fuel for generating the engine's power output. A pre-

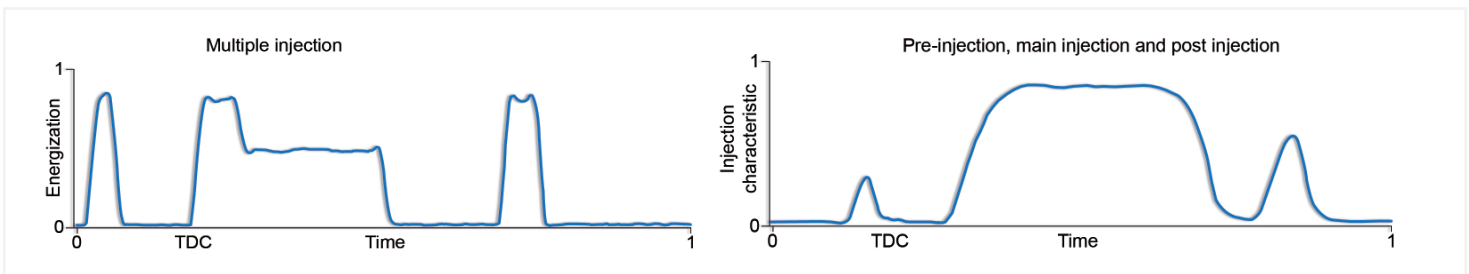
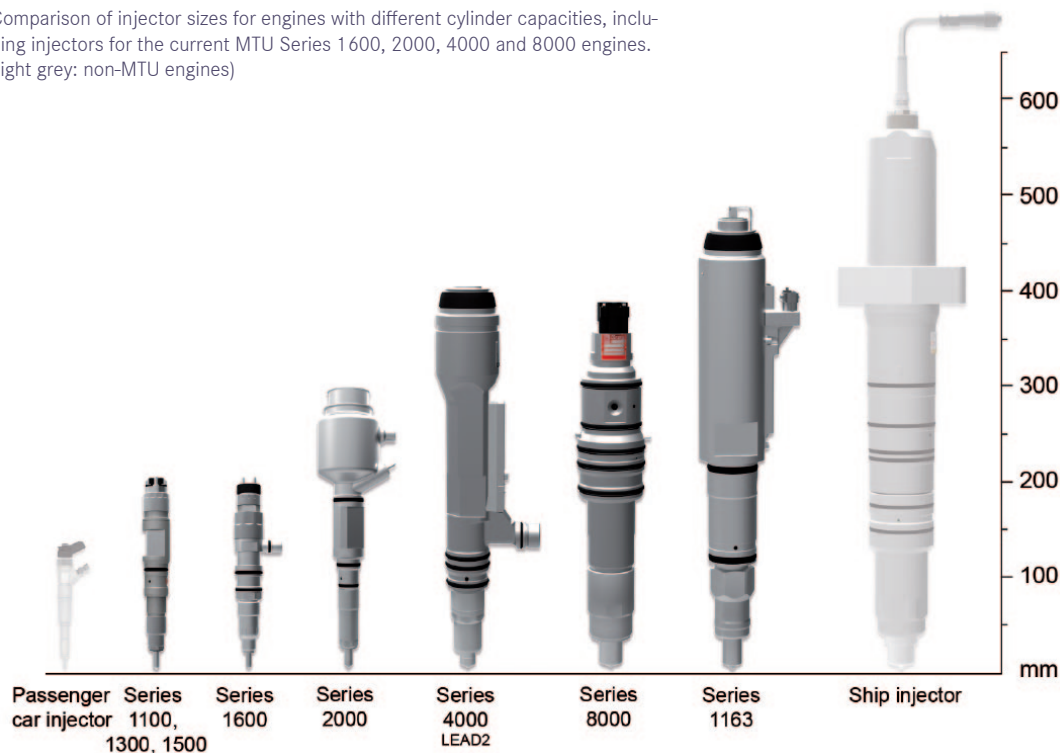


Fig. 2: Fuel flow and injection sequence for multiphase injection

MTU divides the fuel injection sequence into as many as three separate phases. The main injection phase delivers the fuel, a pre-injection phase reduces the load on the crankshaft drive gear, and a post-injection phase reduces particulate emissions. This enables both fuel consumption and emissions to be reduced.

Comparison of injector sizes

Comparison of injector sizes for engines with different cylinder capacities, including injectors for the current MTU Series 1600, 2000, 4000 and 8000 engines. (light grey: non-MTU engines)



injection phase initiates advance combustion to provide controlled combustion of the fuel in the main injection phase. This reduces nitrogen oxide emissions, because the abrupt combustion prevents high peak temperatures. A post injection phase shortly after the main injection

phase reduces particulate emissions. It improves the mixing of fuel and air during a late phase of combustion to increase temperatures in the combustion chamber, which promote soot oxidation. Depending on the engine's operating point, the main injection phase can be

supplemented as required by including pre-and/or post injection phases.

Injection pressure: peak pressures of up to 2,200 bar

Injection pressure has a significant influence on particulate emission levels. The higher the injection pressure, the better the fuel atomizes during injection and mixes with the oxygen in the cylinder. This results in a virtually complete combustion of the fuel with high energy conversion, during which only minimal amounts of particulates are formed. For this reason, MTU has continually raised the maximum injection pressure of its common rail systems from 1,400 bar in the case of the Series 4000 engine in 1996 to the present 2,200 bar for the Series 1600, 2000 and 4000 engines (see Figure 3). In the case of the Series 8000 engine, it is 1,800 bar. For future engine generations, MTU is even planning injection pressures of up to 2,500 bar.

Over the same period, MTU has further improved the system's durability and ease of maintenance. A filter concept designed to meet the requirements has further improved the injection system's ability to cope with particle contamination in the fuel. In future, injector servicing intervals will be extended with the aid of electronic diagnostics.

Solo system: injectors with their own fuel reservoir

Because of its performance capabilities, the common rail injection system has established itself as standard equipment on car diesel engines in the course of the last few years. The

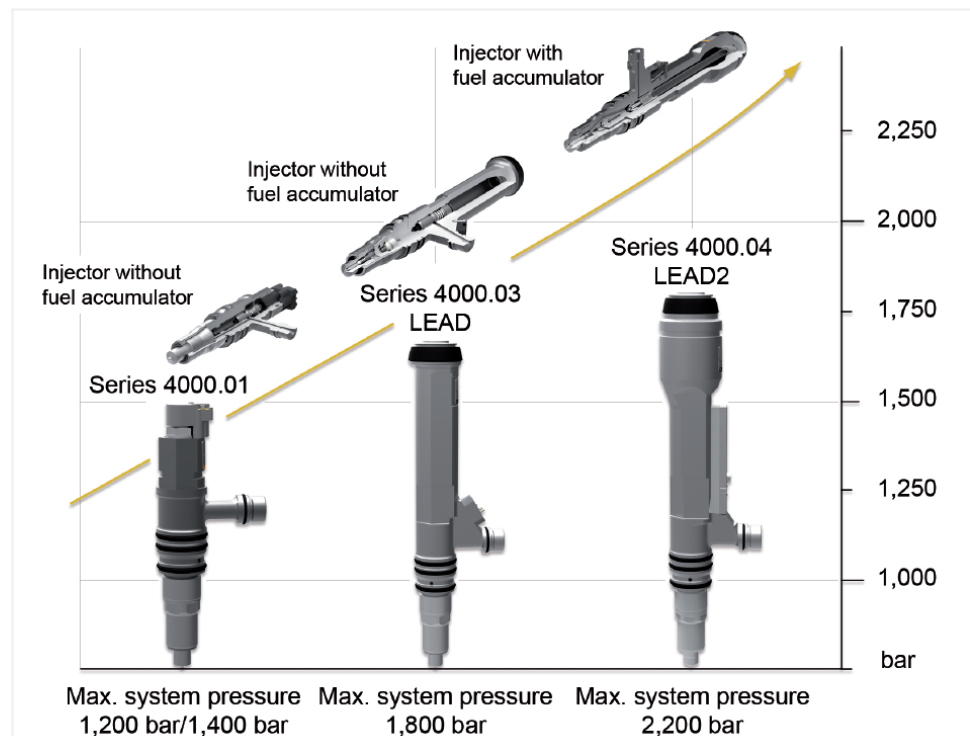
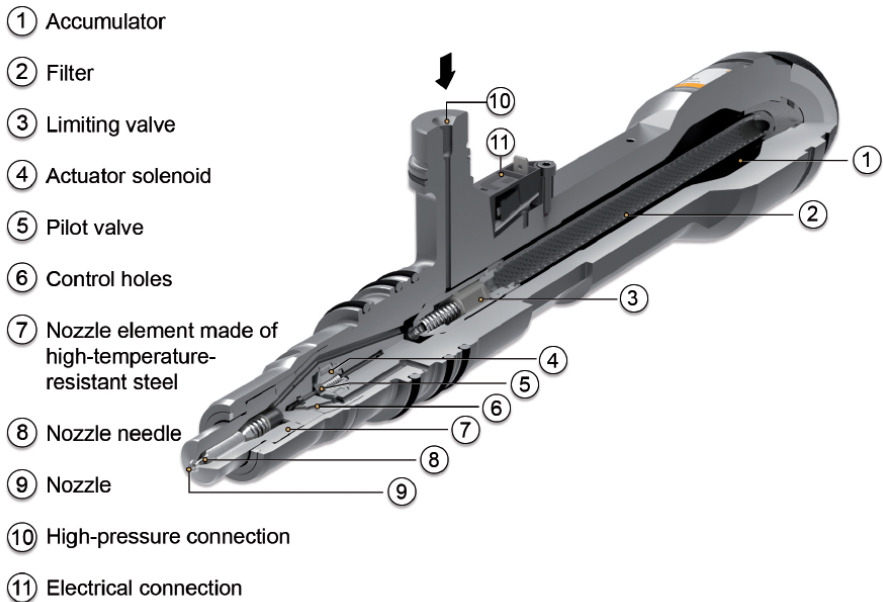


Fig. 3: Change in injection pressures since 1996 for Series 4000 engines

Since 1996, MTU has steadily increased the injection pressures to further reduce consumption and particulate emissions. Since 2000, MTU has used advanced versions of the common rail system on the Series 4000, amongst others, in which each fuel injector has its own fuel reservoir. The advantage is that even with large injection quantities, the fuel rail remains free of pressure fluctuations and the injection sequences of the individual cylinders do not interfere with each other.

Fig. 4: **Injector with integrated fuel reservoir**

The use of injectors with an integrated fuel reservoir prevents pressure fluctuations in the common rail system and, therefore, a momentary undersupply or oversupply of fuel to the injectors.



version of the system as described is also well suited for use in small capacity industrial engines. In the case of engines with larger cylinder capacities, however, the conventional common rail system is now revealing its limitations, since these require a relatively large quantity of fuel to be injected into the cylinder for each ignition stroke. This produces pressure pulsations in the common rail system's fuel reservoir that can interfere with the subsequent injection sequences. Since 2000, MTU has used an advanced version of the common rail system for the Series 4000 and 8000 engine, and since 2004 for the Series 2000 as well, in which the fuel injectors have an integrated fuel reservoir (see Figure 4). This permits the fuel lines between the injectors and the common rail to have a relatively small cross section. During an injection sequence, all that happens is that the pressure in the injector's own fuel reservoir drops slightly. This prevents pressure fluctuations in the common rail system and, therefore, a momentary undersupply or oversupply of fuel to the injectors.

Tailored solutions for flexible use of fuel

With the higher technical performance levels of the injection systems, the demands placed on the fuel in terms of purity and quality also rise. Thus the fuel must comply with pre-defined values for viscosity and lubricity, as components of the high-pressure pumps and injectors are lubricated by the fuel. It must also be free of any contamination that would lead to abrasive damage at the high pressures employed. To ensure that the engine operates correctly, therefore, only diesel fuel that is approved for the application in question and meets the applicable standard may be used. At the customer's request, MTU carries out analyses for specific application-related approval of other fuels in close cooperation with Rolls-Royce Power Systems brand L'Orange or alternative suppliers. With some applications, for example, a lack of lubricating properties on the part of the fuel can be compensated for by special coatings on the injection system. In addition, MTU assists customers when designing the onsite tank and fuel system. This is of great interest for mining vehicles, for instance, that are subjected to high levels of dust exposure.

Summary

MTU continually develops its engines to ensure they will meet the tough future emissions standards, while at the same time consuming as little fuel as possible. To this end, MTU optimizes fuel combustion in the cylinder by means of its electronically controlled common rail fuel injection system in combination with other technologies such as exhaust gas recirculation. By achieving clean and efficient combustion, the expense of exhaust aftertreatment systems can be minimized and, in some cases, eliminated altogether. MTU has used common rail systems successfully since as long ago as 1996 and has continually advanced the technology in collaboration with Rolls-Royce Power Systems brand L'Orange and other suppliers. Due to its extensive expertise in common rail injection systems, MTU is able to optimally exploit the potential of the technology in order to make engines extremely economical and clean.

MTU Friedrichshafen GmbH

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MTU is a brand of Rolls-Royce Power Systems AG. MTU high-speed engines and propulsion systems provide power for marine, rail, power generation, oil and gas, agriculture, mining, construction and industrial, and defense applications. The portfolio is comprised of diesel engines with up to 10,000 kilowatts (kW) power output, gas engines up to 2,150 kW and gas turbines up to 35,320 kW. MTU also offers customized electronic monitoring and control systems for its engines and propulsion systems.



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