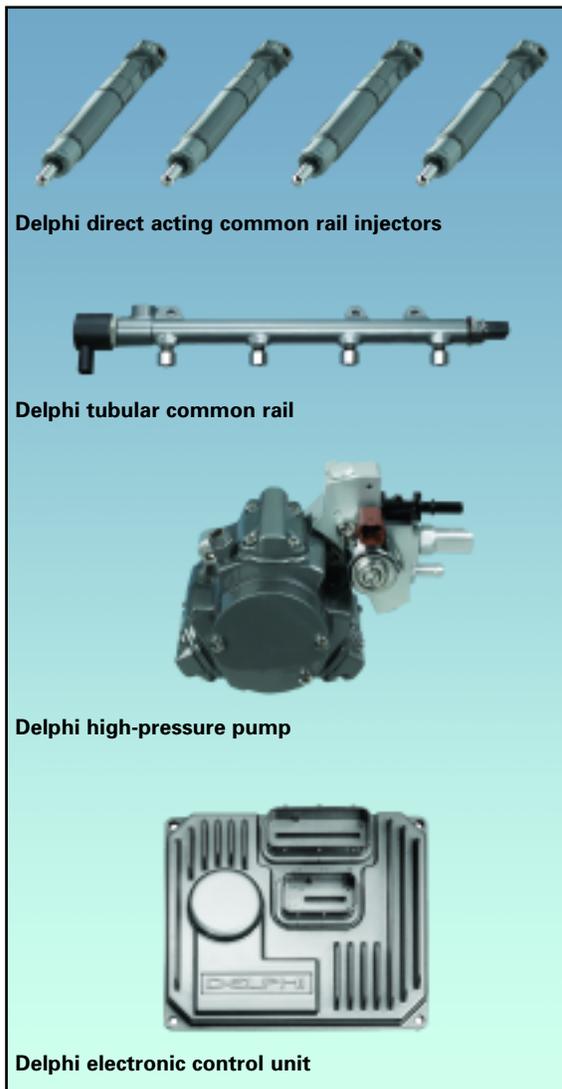


Delphi Direct Acting Diesel Common Rail System

Delphi is an industry leader in diesel common rail fuel injection technology. Being actively involved in the development of advanced diesel technology allows Delphi to create fuel injection equipment that continues to help meet stringent emission requirements while enhancing fuel economy and performance. Extensive experience in high-pressure fuel injection technology has helped Delphi develop several innovative design and control strategies to meet customer needs for cost-competitive, high-value fuel injection systems. These systems provide accurate injection over the life of the vehicle, helping minimize emissions while providing robust performance and low noise.

Description – The Delphi direct acting diesel common rail system uses a direct actuated injector, where the piezo ceramic actuator directly operates the needle valve of the injector, eliminating the servo-hydraulic circuit that other common rail injectors use. This allows the injector to spray fuel into a diesel engine combustion chamber faster, with greater accuracy, and at higher pressure (over 1800 bar) than most current injection technologies. For diesel engines, that can translate to up to 10 percent more torque and power, up to 30 percent lower emissions, and better fuel economy compared to the best servo-piezo available today.

In the Delphi direct acting diesel injector, the hydraulic circuit makes best use of the characteristics of piezo ceramic actuators: high force and speed in



Delphi direct acting common rail injectors

Delphi tubular common rail

Delphi high-pressure pump

Delphi electronic control unit

DELPHI

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efficient packaging. Piezo injectors use piezoelectric material to produce motion when excited by an electrical voltage. The motion created by the piezo device opens the injector. It takes less than 100 microseconds to open and close the needle valve of the injector and spray the high-pressure diesel fuel into the engine, allowing five (and possibly more) injections per engine cycle. In addition, the injector's radically new operating principle does not need a return flow to operate. That means all fuel is injected, and no high-pressure fuel is wasted into a return flow. The returnless system is unique and distinguishes the Delphi direct acting diesel injector from its competitors. It also allows downsizing of the high-pressure pump, helping provide an improvement in engine fuel economy.

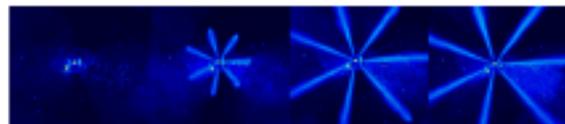
Typical Application – Thanks to the Delphi direct acting common rail system, medium- and large-size vehicles will be better able to meet future emission legislation requirements (Euro V and U.S. Tier II Bin 5) by eliminating or relaxing the need for costly nitrogen oxides (NO_x) aftertreatment devices. The Delphi direct acting common rail system is scheduled for production in 2007.

Performance Advantages – The Delphi direct acting common rail system can offer drivers up to 10 percent higher power and torque, a 30 percent reduction in particulate matter (PM) and NO_x emission level, reduced engine noise, better driveability, and increased fuel economy compared to the best servo-piezo systems available.

Features	Benefits
Piezo injectors	<ul style="list-style-type: none"> – Enhances multiple injection capability – Helps increase fuel economy and power – Helps lower emissions – Helps lower noise – Excellent stability over lifetime – No fuel backflow cooler needed (no backleak)
High-pressure pump	<ul style="list-style-type: none"> – Allows operation up to 2000 bar – Modular pump design 0.6 to 1.2 cm³/rev – Includes integrated inlet metering valve, pressure limiter, temperature sensor, and transfer pump
Rail	<ul style="list-style-type: none"> – 2000 bar capable high-pressure valve being developed
Electronic control unit (ECU)	<ul style="list-style-type: none"> – 32 bit processor – Accelerometer pilot control (APC) “listens” to engine and corrects minimum drive pulse over life of the engine for improved reliability over the vehicle life

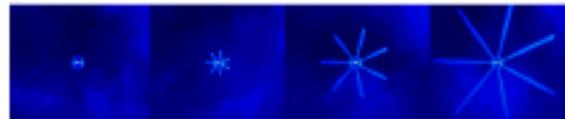
Spray: Direct Acting vs. Servo-Hydraulic

DF13 Direct Acting Injectors



0 microsec. 100 microsec. 200 microsec. 300 microsec.

Conventional Servo-Hydraulic Injectors



0 microsec. 100 microsec. 200 microsec. 300 microsec.

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For OEMs, the Delphi direct acting common rail system offers:

- Improved accuracy of injected fuel quantity, which enables better emissions and less engine noise
- Faster nozzle needle velocity (two to three times faster than servo systems), allowing for a square rate shape injection that provides more fuel flow for more power and torque at a better fuel consumption
- No return fuel flow, which improves efficiency, allows pump downsizing, and eliminates the need for return flow fuel coolers
- Multiple injection capability with high quantity stability, allowing emission improvement and giving flexibility in the use of aftertreatment devices

Advanced Diesel Technology – The popularity of diesel vehicles is growing globally. In Europe, approximately one of every three new cars sold is powered by a diesel engine. There are many reasons for this surge in popularity. Consumers are discovering that diesel engines offer:

- **Better fuel efficiency:** Light-duty diesel engines use 30-40 percent less fuel than gasoline engines of similar power under similar circumstances
- **More torque:** Diesels produce more drive force at low engine speeds than gasoline engines under similar circumstances, making diesels more fun to drive
- **Lower greenhouse gas emissions:** Less fuel consumed translates to lower emissions of carbon dioxide

To continue to offer consumers these advantages, vehicle manufacturers are required to meet stringent diesel emission standards. These standards vary throughout the world and are one factor driving development of advanced diesel technology.

Increasing injection pressure is one way to help increase the power density of diesel engines and help decrease emissions. Increased power density also allows for smaller engine sizes—and enhanced fuel economy—without sacrificing power. Two areas

of improvement to meet new demands of increased pressure include strengthening the injector to withstand increased cycling and introducing a new pump family capable of handling fuel pressures up to 2000 bar. Delphi is also optimizing the injector and hydraulic system to minimize restriction of flow.

In addition to increasing the fuel injection efficiency, Delphi is researching and developing enhanced closed-loop controls for diesel engines. When the engine management system (EMS) delivers air, recirculated exhaust gas, and fuel at the correct quantities and timing, the diesel engine can be made to perform closer to the limits of its capability, helping result in more power and torque at consistently low emissions and fuel consumption. Both the accelerometer pilot control (APC) and individual injector characterization (I2C) have been improved to help better maintain Euro IV emission standards. Delphi plans to make available linear oxygen sensors to better control the air/fuel ratio and combustion feedback so that the combustion takes place at the correct time. With these improvements in fuel injection, control, and combustion technology, an engine with power densities above 65 kw/liter can be produced that can adapt to and withstand the different fuel quality standards found around the world.

The Delphi Advantage – Delphi is the only fuel injection equipment supplier with in-house design and manufacturing capabilities in aftertreatment catalysts. Plus, Delphi offers air subsystems, exhaust gas recirculation components, and sensors, offering vehicle manufacturers the widest portfolio of engine management systems and components. Delphi can integrate air and fuel management systems, exhaust aftertreatment, and the associated electronic controls and sensors, helping provide complete end-to-end diesel engine control systems that meet emission requirements worldwide.

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Because of their higher air-to-fuel combustion ratio, diesel engines naturally run "lean," helping lead to better carbon monoxide (CO), hydrocarbon (HC), and carbon dioxide (CO₂) emission performance. However, diesel engines do tend to generate higher levels of nitrogen oxides (NO_x) and particulate matter (PM) than gasoline engines. Higher NO_x levels are a result of the higher temperatures and excess oxygen of the lean combustion process. Higher PM levels are a result of incomplete combustion caused by low oxygen levels around individual fuel droplets. (This is a result of an incomplete air/fuel mixture in the injection system due to the fact that diesel fuel vaporizes less readily than gasoline.) The higher levels of these two substances in the diesel exhaust stream has prompted extensive research on how to minimize them.

Delphi is developing Diesel NO_x Particulate Traps (DNPT) and already produces Diesel Catalyzed Particulate Traps (DCPT) that together have the potential to nearly eliminate the NO_x and PM coming out of the tailpipe. Delphi's research is focused on both perfecting design and manufacturing of these components, along with the control strategy to best utilize the devices as part of the EMS. With its extensive aftertreatment knowledge, Delphi has the know-how to help achieve Euro V and U.S. Tier II Bin 5 standards set to come in the latter half of the decade.

Delphi has two common rail development centers, five diesel applications facilities in Europe, Asia-Pacific, and the United States, and nearly 8,000 employees working to further advance diesel technologies. Delphi has 12 manufacturing facilities that produce diesel systems components in seven countries, enabling high on-time delivery performance.