

## THE NEW DEUTZ ENGINE FAMILY 2013 FOR COMMERCIAL VEHICLES

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**ABSTRACT**—DEUTZ AG, co-founded in 1864 by Nicolaus August Otto, the inventor of the four-stroke cycle engine, has developed the new 2013 engine for commercial vehicles on the basis of the tried and tested 1012 and 1013 series. With 4 and 6 cylinder models, the engine covers the power range between 100 and 190 kW. At the time of their introduction to the market, the engines will meet the exhaust emission legislation of EURO III and incorporate the potential for EURO IV. Further engineering targets were: (Compactness, Favourable power/cost relation, Low weight, Low fuel consumption and Low noise level). All targets could be accomplished in a relatively short development period via the application of modern simulation tools and test methods. In this paper, the design configuration of the engines is described with particular emphasis on measures for noise emission reduction and the combustion system including injection and turbo charging. Furthermore, we demonstrate the engine's potential to fulfill the European emission legislation EU4, which comes into force in 2005.

**KEY WORDS** : New DEUTZ truck engine for EURO III

### 1. INTRODUCTION

DEUTZ AG, co-founded in 1864 by Nicolaus August Otto, the inventor of the four-stroke cycle, is an independent manufacturer of diesel engines for automotive and versatile industrial applications. In 1992, the new liquid-cooled engines of the 1012 and 1013 series were launched on the market for these applications (Moser and Pleimling 1992).

To back up this engine family, the 2013 series has been developed with 4 and 6 cylinder in-line engines in the power range from 100 to 190 kW. Figure 1 shows the 6 cylinder engine. This series is based on the 1012 engines and meets in particular the future requirements of medium-duty commercial vehicles:

- Compactness
- Favourable power/cost relation
- Low weight
- Low fuel consumption
- Low noise level and of course
- Compliance with future exhaust emission regulations.

### 2. PRODUCT CONCEPT

The main engine parameters are shown in Figure 2.

Extensive market research work had been conducted before the technical concept was defined. The power range from 100 to 190 kW at a rated speed of 2500/min meets very well the requirement of medium-duty commercial vehicles. With a swept volume/cylinder of 0.95 l the total swept volume of the 4 cylinder is 3.8 l and that of the 6 cylinder 5.7 l.

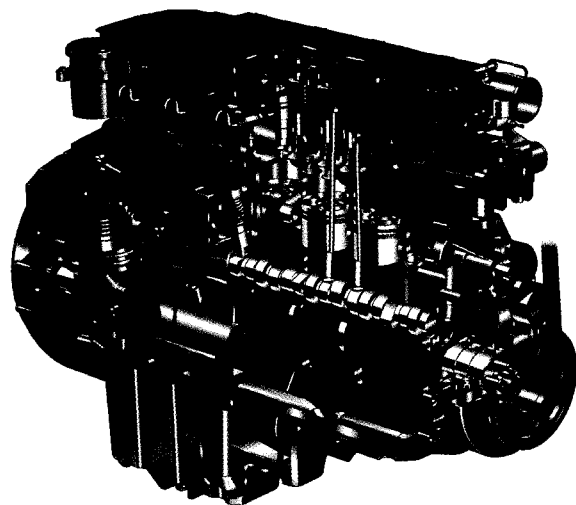


Figure 1. The New DEUTZ 2013 engines for truck application.

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| Engine type                   |                            | 4-Cylinder<br>BF4M 2013 C | 6-Cylinder<br>BF6M 2013 C |
|-------------------------------|----------------------------|---------------------------|---------------------------|
| Nominal power speed           | kW/PS<br>min <sup>-1</sup> | 125/170<br>2500           | 190/260<br>2500           |
| Swept volume<br>Bore x Stroke | Liter<br>mm x mm           | 3.8<br>98 x 126           | 5.7<br>98 x 126           |
| Specific power                | kW/Liter                   | 32.9                      | 33.3                      |
| Max torque at speed           | Nm<br>min <sup>-1</sup>    | 620<br>1400 - 1600        | 940<br>1400 - 1600        |
| torque backup                 | %                          | 30                        | 30                        |

Figure 2. Technical data of 2013 engines.

The engines are designed for the exhaust emission level EURO III. and incorporate the potential for EURO IV and EURO V. This also applies for the relevant US emission levels.

The installation dimensions in Figure 3 and the weights characterize the compactness of the engines. They conform to the demands of the commercial vehicle manufacturers for low installation space requirement and weight.

The power-to-swept volume ratio of 33 kW/liter represents a peak value for engines of this size and application. Turbochargers are used either with bypass or VGT (Variable Geometry Turbine) depending on rated power and requested torque curve. Charge air cooling is realized as air/air charge air cooling. The injection system is the fully electronic solenoid valve-controlled Unit Pump

System (UPS).

It is a matter of course that the product concept was equally focused on reaching a cost-efficient production and the technical objectives.

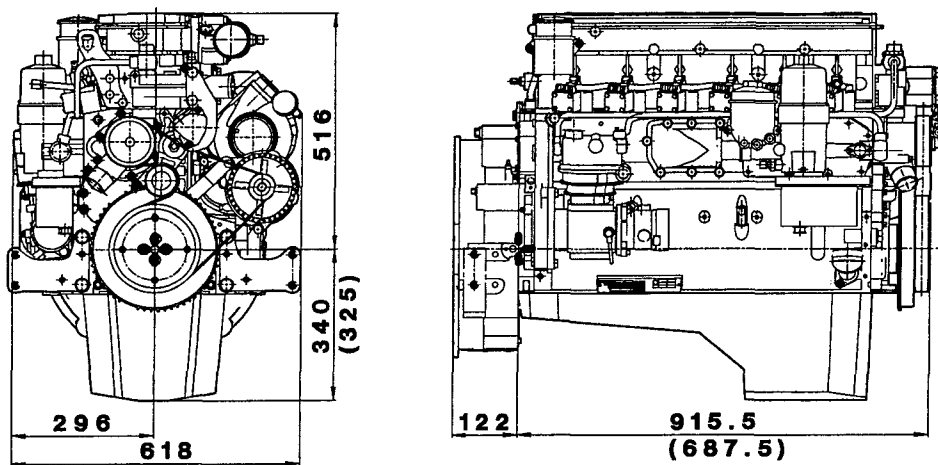
For industrial applications a relevant variant of the 2013 series is being developed with mechanical injection system and 2-valve cylinder head. A mechanical or electronic governor is available at option. With 'parent bore' cylinders a 1.0 liter swept volume per cylinder is realized.

### 3. DESIGN CONFIGURATION

#### 3.1. Crankcase

The 1012 crankcase, tried and tested in respect of structural strength and noise characteristics, has been taken over as basic concept and further optimized (Moser and Pleimling, 1992; Spessert *et al.*, 1992). Figure 4 shows the essential design features, such as straight flux of forces, stiffening ribs and decks. Wherever possible, the necessary ribs and reinforcements have been incorporated in the interior of the crankcase to improve, on the one hand, the appearance and on the other to avoid 'dirty corners' which would be irritating in practice. Reliable power transmission and minimum vibration excitation of the crankcase structure and the crankcase-related components have thus been realized. The latter essentially contributes towards reducing the noise radiation of the entire engine (Moser, 1992; Spessert *et al.*, 1992).

The favourable structure allows the use of GG25 as



|                    | 4 Cyl. | 6 Cyl. |       |
|--------------------|--------|--------|-------|
| weight DIN 70020 A | 380    | 495    | kg    |
| weight/power ratio | 3.0    | 2.6    | kg/kW |

figures in ( ) are related to the 4-cyl. engine

Figure 3. Dimensions and weight of 2013 engines.

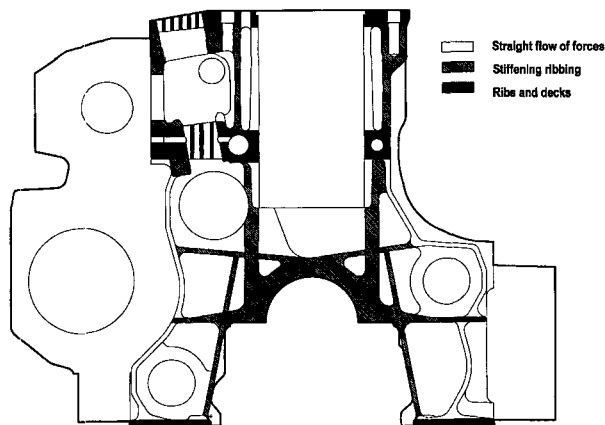


Figure 4. Optimized structure of the 2013 crankcase.

material.

Apart from the operating loads acting on critical points of the crankcase, the inherent stresses usually occurring in cast components have been taken into account in the structural assessment. These assumptions have been verified by measurements performed on genuine parts. Further functions have been added to the standard functions of a crankcase: Integration of the unit injection pumps together with the correspondingly reinforced structure with regard to the high forces acting in the injection pump drive, 3 flanging options for auxiliaries on the gear train and the integrated 2nd-order balancer on the 4 cylinder engine. Easily exchangeable dry liners, so-called 'slip fit liners', are used to meet market requirements.

The layout of design details is largely based on theoretical simulation methods. The comparably high natural frequencies for bending (550 Hz) and torsion (300 Hz) have been reached through theoretical optimization. They largely contribute to the low noise radiation. Figure 5 shows the 3D-FE model of the crankcase/cylinder head assembly. This model served to optimize the structure in respect of cylinder head gasket and cylinder distortion under assembly and operating influences. The reliability of the computation was evidenced also by the fact that even the first prototypes reached the targeted values concerning piston ring movement and lube oil consumption, a characteristic of excellent inherent stability. The computation results were verified and confirmed by hydro-pulse tests and engine endurance tests.

### 3.2. Crankshaft, Connecting Rod

Crankshaft and connecting rod are die forged. With the 4 cylinder model, all free forces and moments of 1st order are fully balanced by 8 forged-on counterweights. The inner moments are highly balanced through the arrangement of the counterweights. The inertia forces of 2nd

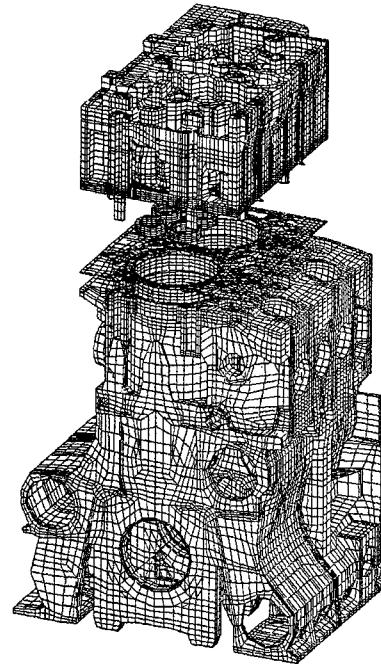


Figure 5. 3D-FE-Model of crankcase and cylinderhead structure of 2013 engines.

order are balanced by 2 crankcase-integrated balancer shafts.

The 6 cylinder engine has 8 counterweights forged onto crankshaft throws 1, 3, 4 and 6 and thus reaches a high degree of balancing of the inner moments.

The drive gear of the gear train and the flywheel flange are shrunk on.

The design of the connecting rod had to fulfill two major requirements: Optimization of the power flux from piston to connecting rod and consideration of the cracking process to separate rod and cap. The stepped connecting rod has resulted as optimum configuration of the small end with regard to the load acting on piston, piston pin and connecting rod.

### 3.3. Piston, Piston Rings, Cylinder

The pistons are monobloc pistons of eutectic aluminium alloy. Preliminary tests conducted on a similar engine with identical specific power evidenced that pure splash cooling without cooling channel is possible. This, however, required specific arrangement and configuration of the cooling oil nozzle. The desired spray distribution and cooling oil quantity was reached through the use of a "twin nozzle". The "twin nozzle" features a much more stable and less dispersed cooling oil spray than a "single nozzle" of same throughput.

Piston temperature measurements have confirmed the piston cooling efficiency. With the use of the "twin

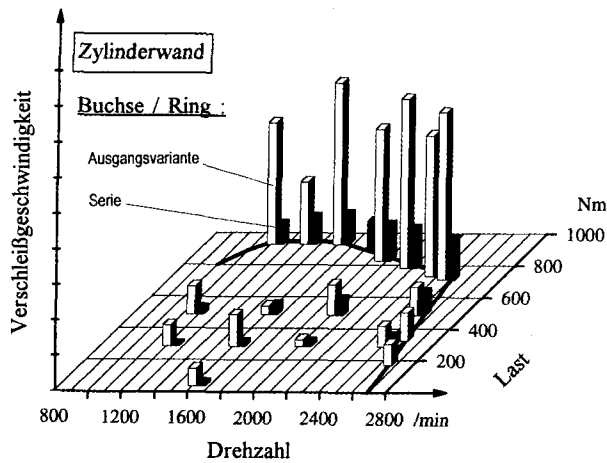


Figure 6. Liner wear test with 2013 engines.

nozzle” the temperature could be reduced by 10°C.

Low lube oil consumption (<0.15 g/kWh) and low blow-by values were reached by careful matching of the piston/ring/cylinder system.

The keystone ring in the first ring groove with ring carrier has a chromium-ceramic coating. The second ring is a tapered compression ring, the oil control ring a chromium-plated bevel-edged ring.

The “slip fit liners” feature wear-reducing alloy components and are plateau-honed. Oil consumption and wear characteristics have been optimized with the help of radionuclide technology and substantiated during endurance tests. Figure 6.

### 3.4. Gear Train

For noise emission considerations, the gear train is arranged at flywheel end, Figure 7. The teeth are straight-cut, the profile is designed as high-contact ratio gear type for noise reduction purposes. The camshaft is directly driven by the crankshaft and thus ensures high mechanical stiffness. The auxiliaries are driven by the camshaft gear. As an option, to meet utmost smooth-running requirements, the 4 cylinder engine has two crankcase-integrated 2nd-order balancer shafts which are driven via intermediate gears from the crankshaft and camshaft.

Arrangement and design of the gear train essentially contribute to the low engine noise level.

### 3.5. Cylinder Head

The cylinder head is designed a 4-valve cylinder head with vertical, centrally arranged injection nozzle. It consists of 3 functional units: the cylinder head proper of grey cast iron, the rocker casing of aluminum die casting and the cylinder head cover of plastic, Figure 8. The arrangement of 6 cylinder head bolts per cylinder, tried

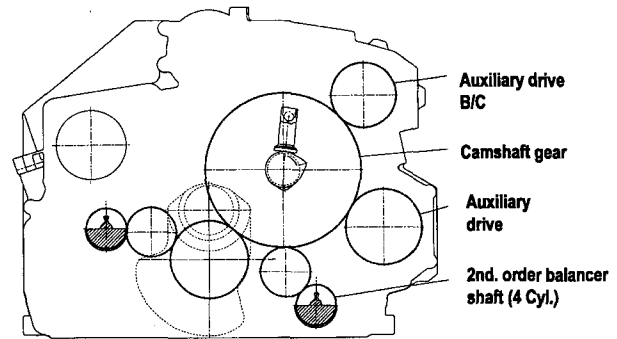


Figure 7. Gear train of the 2013 engines.

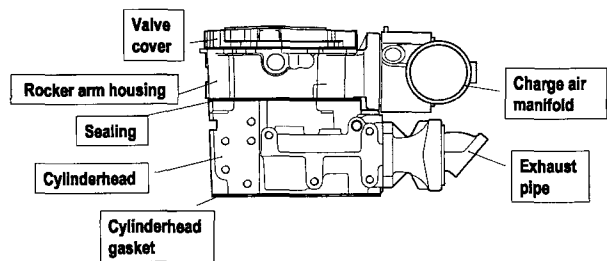


Figure 8. 2013 engine cylinderhead assembly.

and tested on the 1012 engines, has been retained, although it initially caused some restrictions with regard to the arrangement of the 4 valves and the inlet port ducting. In addition there existed the objective to directly route the injection line to the nozzle holder bypassing the oil space. Another secondary prerequisite was to locate the charge air duct and exhaust manifold on the left-hand engine side, as tried and tested on the 1012 series, to allow an easy-to-service installation of the auxiliaries on the right-hand engine side.

This task could be solved by ducting the inlet ports as shown in Figure 9. From the charge air pipe a duct is routed between two cylinders in transverse direction to the engine to supply the inlet ports of these two adjacent cylinders. In this way a cross-flow arrangement can be realized, although the charge air pipe is arranged on the left-hand engine side remote of the inlet valves. The 6 cylinder engine is provided with three of these transverse ducts, the 4 cylinder with two.

A multi-layer steel gasket is used as cylinder head gasket. The sealing between cylinder head and rocker casing is a coated steel bead seal. The U-shaped charge air pipe is bolted to the rocker casing acoustically decoupled. Its structure is also acoustically optimized.

Rubber sealing elements are used for decoupling purposes between charge air pipe and rocker casing as well as between rocker casing and cylinder head cover. The

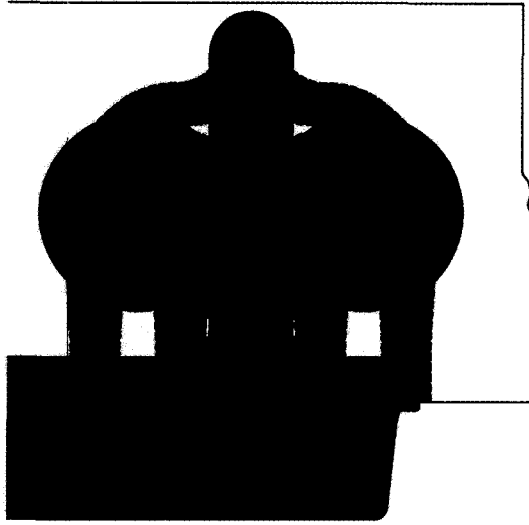


Figure 9. Air intake and exhaust ducts of 2013 engines.

fastening bolts are also designed as decoupled elements.

### 3.6. Auxiliary Drives

On the gear train are provided several options for driving auxiliaries, e.g. for hydraulic pumps, air compressor with and without power steering pump. The belt drive on the front engine end is designed as Poly-V-belt drive with permanent tensioner, Figure 10. From here are driven the alternator, water pump and fuel feed pump. An air

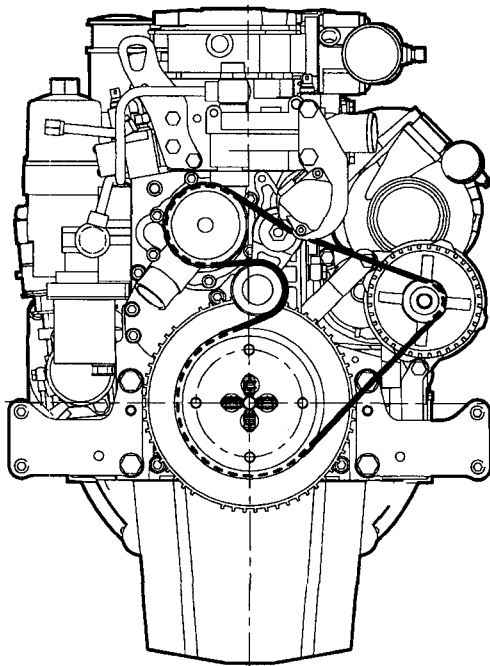


Figure 10. 2013 Engine front end and belt drive.

conditioning compressor can also be integrated as option. The standard position for fan mounting is on the crankshaft via integrated viscous clutch. Fan mounting on a high-level fan bracket is also possible as option in order to meet specific installation conditions.

## 4. INJECTION AND COMBUSTION, TURBO-CHARGING

The injection system is largely characterized by the technically advanced fully electronic solenoid valve Unit Pump System (UPS) (Moser *et al.*, 1992; Thiesen *et al.*, 1992); Figure 11 shows the arrangement. The unit pumps are integrated in the crankcase for each cylinder and are driven by the camshaft via roller tappets. The fuel is supplied via an external line which is fed by the fuel feed pump via a micro-filter. The fuel is returned via bores in the crankcase. A pressure control valve regulates the supply pressure within 5-6 bar to ensure reliable fuel charge of the injection pumps. The high-level position of the injection pumps in the crankcase allows the realization of very short injection lines and thus a hydraulic stiffness, comparable with unit injector systems, but with less engineering input (Figure 12 shows the pressure profiles at rated power). Line routing and connection to the nozzle holder are so configured that there is no contact with the oil space.

The centrally arranged vertical injection nozzle offers good preconditions for optimized combustion. Matching of combustion has resulted in a VCO nozzle with 6 spray holes in combination with the piston bowl shape and swirl parameters. Combustion matching was not solely

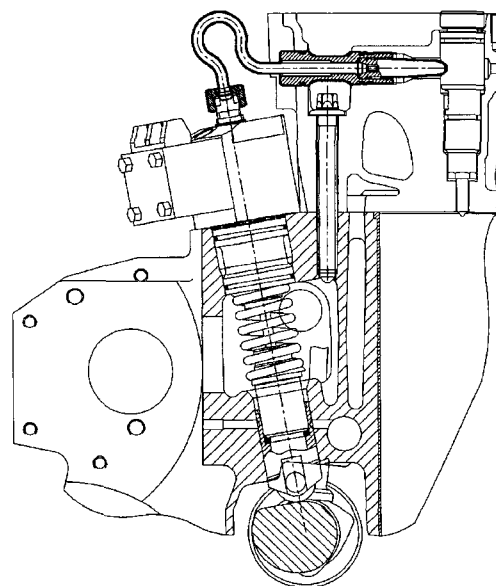


Figure 11. Pump/Line/Nozzle assembly of 2013 engines.

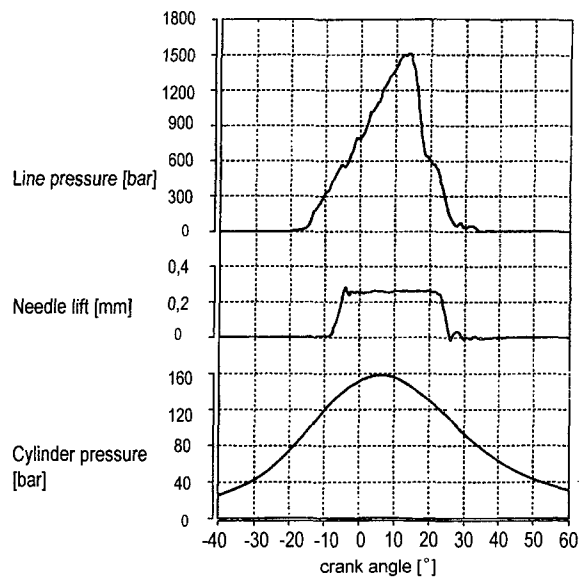


Figure 12. 2013 Engine injection data.

aimed at reaching emission level EURO III as standard, but was equally focused on fuel consumption, acoustic characteristics and contamination of the lube oil. The double-spring nozzle holder planned in the initial engineering stage was exchanged in the course of investigations against a single-spring nozzle holder without fuel return line after it had proved advantageous in every respect. The main data of the injection system is summarized in Figure 13.

Exhaust turbocharging is realized by a turbocharger and air/air charge air coolers. Turbochargers with bypass or VGT (Variable Geometry Turbine) are used depending on rated power and desired torque curve. The use of VGT also allows to achieve a very high engine braking power of up to 65% of the engine rated power.

## 5. POTENTIAL FOR REACHING EXHAUST EMISSION LIMITS EURO IV

### 5.1. Conducted Investigations

With the introduction of the envisaged emission limit level EURO IV in 2005, a transient test (European Transient Cycle ETC) will be specified for certification for the first time in Europe also for commercial vehicles in addition to the European Steady State Cycle ESC and the European Load Response Test ELR. With reference to emission level EURO III, the particulate emission limit will be lowered in the ESC under EURO IV from 0.1 g/kWh to 0.02 g/kWh, i.e. by 80%, and simultaneously the NO<sub>x</sub> emission limit from 5 g/kWh by 30% to 3.5 g/kWh. In the ETC with same NO<sub>x</sub> level as in the ESC, 50% higher particulate emissions are permissible.

|                             |     |              |
|-----------------------------|-----|--------------|
| Type of injection pump      | -   | PLD12B (UPS) |
| Plunger diameter            | mm  | 9,0          |
| Stroke                      | mm  | 12,0         |
| Peak pressure               | bar | 1600         |
| Plunger velocity $c_{1000}$ | m/s | 1,86         |
| Length of injection line    | mm  | 214          |
| Number of spray holes       | -   | 6            |

Figure 13. 2013 Engine injection system data.

These more stringent emission requirements for future commercial vehicle engines, together with higher demands on the part of customers call for an early awareness of the engineering potential of existing products in order to safeguard their future-proofness through systematic advancement.

The Common Rail system was selected for the necessary investigations in view of its distinctly more flexible injection profile as compared to the current technical standard of the solenoid valve controlled UPS. The BOSCH commercial vehicle CR system allows with a max. rail pressure of 1350 bar the possible application of 2 pilot-injections, one main injection and one post injection. In Figure 14 are summarized the components of the commercial vehicle CR system.

The conversion of the engine with solenoid valve-controlled UPS injection to the CR system is illustrated by the comparison of the engine cross sections in Figure 15.

A VGT turbocharger has been provided to be able to realize over the entire engine map the optimum charge air pressure for every operating point. When designing the turbocharger, it has been taken into account that even with 30% exhaust recirculation sufficiently high air mass flow rates are ensured to achieve an excess air factor above 1.75. Reserves for a mean effective pressure increase over the entire engine speed range have been provided. The charge air pressure is controlled by the closed loop integrated in the CR software, without using the turbocharger speed signal. The pulse-width-modulated output signal drives a pneumatic valve which in turn actuates the vane adjustment device.

In another emission reduction stage, a dual-flow, cooled exhaust recirculation system has been applied to the engine, Figure 16.

The exhaust gas is withdrawn from either duct of the exhaust pipe and fed to a reed valve via electrically actuated valves and exhaust cooler. The recirculated exhaust gas enters the charge air line about 150 mm upstream of the inlet manifold, thus ensuring sufficient

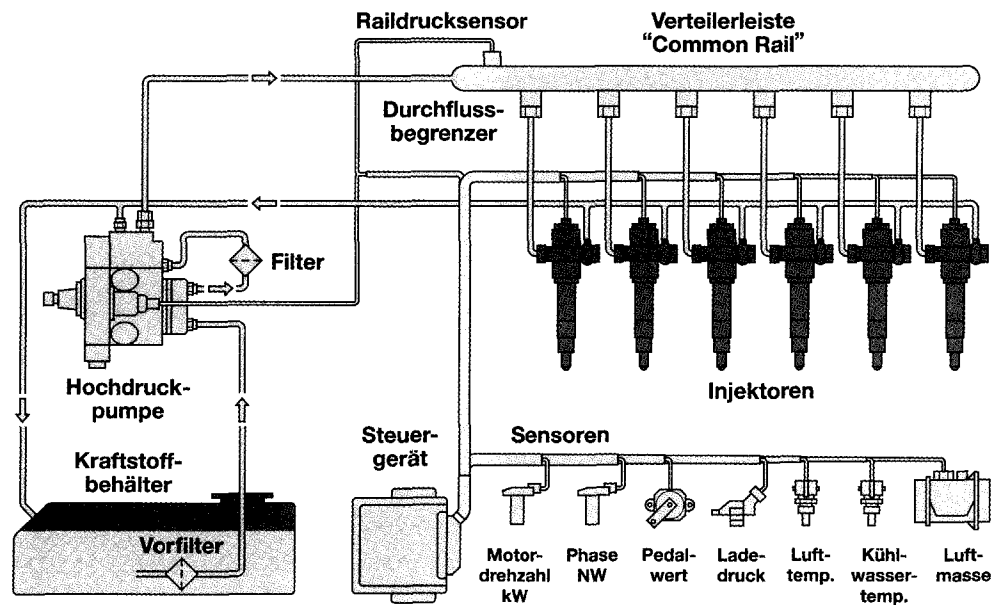


Figure 14. Common rail system for truck engines.

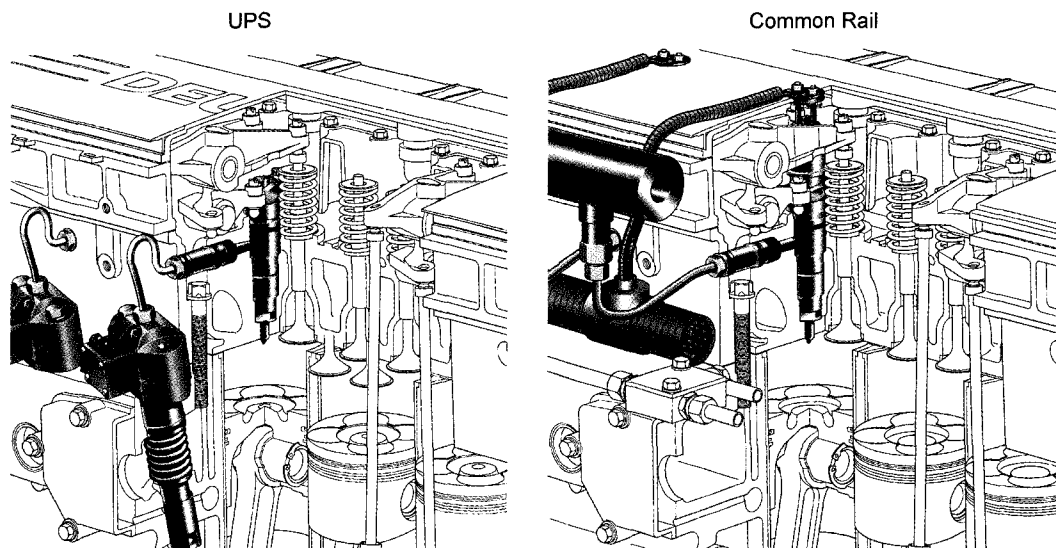


Figure 15. Engine view with UPS and common rail.

mixing with the air. The mixture quality could be confirmed by individual exhaust temperature measurements at all operating points of relevance.

### 5.2. Achieved Exhaust Emission Levels

For the initial engine matching with the CR injection system nozzles with parameters (flow, number of holes, spray angle) identical with those on the UPS engine were used. For initial testing the start of injection was also taken over from the engine with UPS. The rail pressure

nominal map was generated by adopting mean values of the line pressure curves of the UPS engine as nominal values at distinct operating points. For the sake of simplified application the waste gate turbocharger was used for basic matching. With this very simple matching it was possibly very quickly after the first engine run with CR to stay below the emission limits for EURO III under ESC test conditions. Further to systematic parameter variations of pilot injection and post injection an adaptation was made for minimized particulate emissions

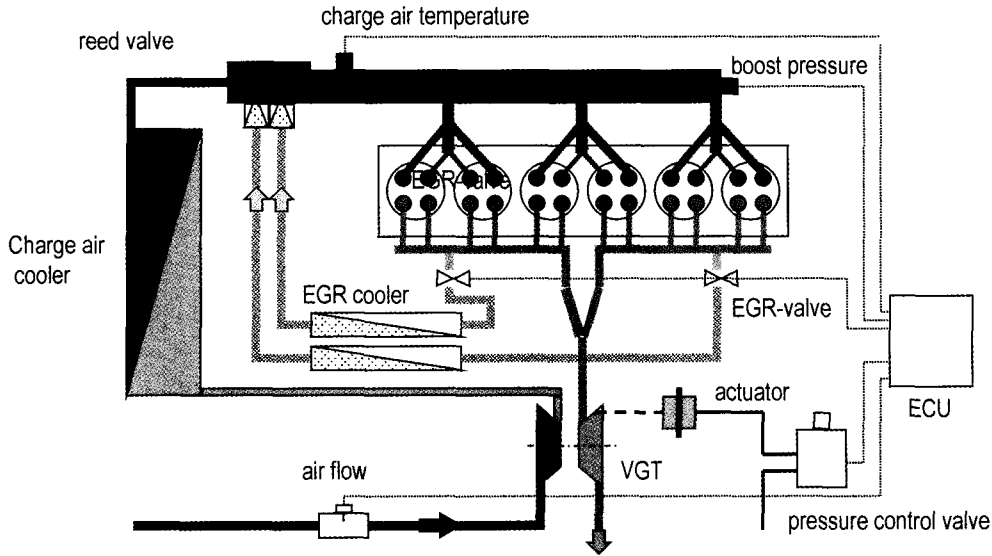


Figure 16. Schematics of turbocharging and EGR.

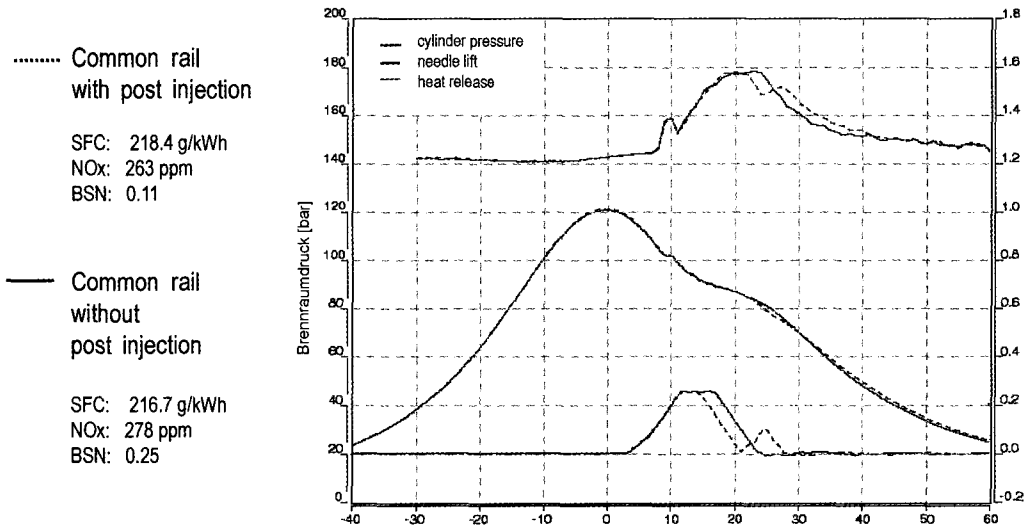


Figure 17. Influence of post injection on emissions and SFC.

at 4.8 g/kWh NOx under ESC test conditions by optimizing post injection metering and timing. Over a broad spectrum of the engine map more than 50% reductions of the smoke number can be realized, practically without influence on fuel consumption and nitrogen oxide emission; an example is shown in Figure 17 for the ESC test point 3. The effect of post injection on heat release is clearly noticeable in the combustion process.

Figure 18 shows the comparison of the measured smoke number maps between the engine with UPS and the engine with CR injection and optimized post injection.

It becomes clearly obvious that distinct smoke number reductions are possible over the entire engine map with the backup of particulate secondary oxidation through a post injection that is set relatively close to main injection. Usual values for the interval between the end of main injection and the start of secondary injection are 600 to 750  $\mu$ s; the secondary injection quantity is around 10 to 15% of the main injection quantity.

With individual charge air pressure adjustment, when using a turbocharger with variable turbine geometry instead of the bypass turbocharger, it is possible to lower the particulate emissions once again while nitrogen oxide



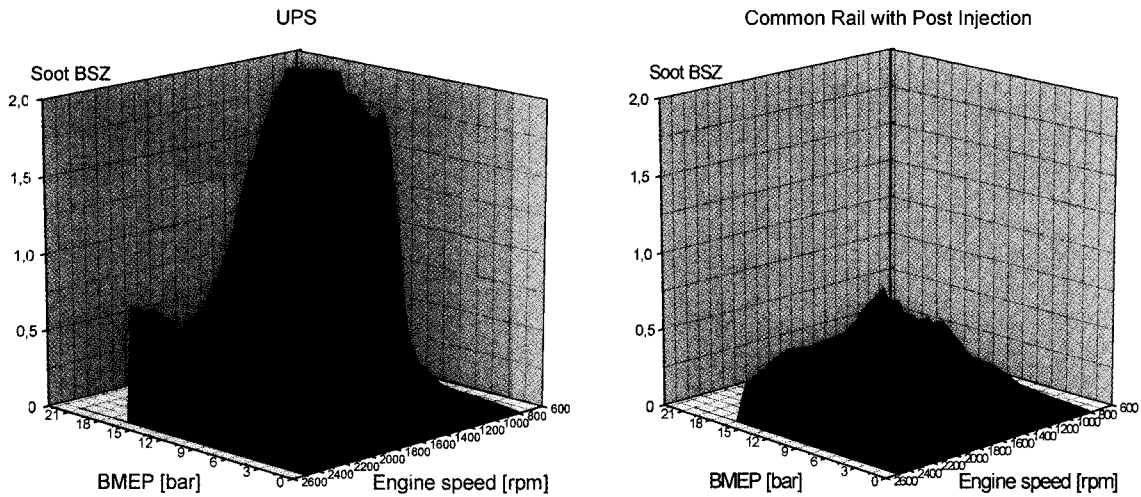


Figure 18. Bosch smoke number map for UPS-CR (with post injection).

emissions remain nearly identical or are even reduced. It is true that the integration of a VGT turbocharger in an engine concept with any injection system offers even at low engine speeds a clear potential for an increase in charge air pressure and thus mean effective pressure. With all cam driven injection systems the permissible exhaust opacity values are reached very quickly because of poor mixture quality caused by insufficient injection pressure. The flexibility of the CR injection system with regard to system pressure and secondary injection might be used for increasing the fuel pressure to allow higher mean effective pressure and lower exhaust opacity at low

engine speeds simultaneously compared to cam driven injection systems. The use of cooled exhaust gas recirculation in combination with Variable Geometry Turbine, VGT, is standard in diesel-powered cars (Spessert *et al.*, 1992). The application of these technologies in commercial vehicles is much more complicated in terms of VGT mapping. Contrary to mere low-load operation of car diesel engines under MVEG test conditions, the commercial vehicle emission tests also include large full-load portions. Under emission aspects a cutoff of exhaust recirculation at these operating points is not appropriate; it is rather necessary

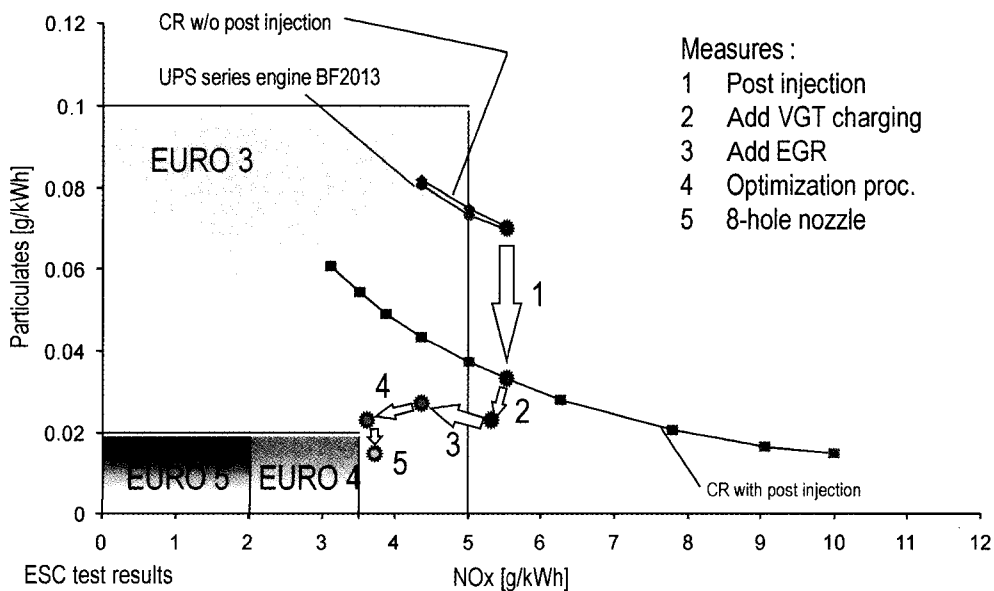


Figure 19. Test results with common rail system.

to simultaneously control the charge air pressure and exhaust recirculation rate.

Most European truck engine manufacturers consider the application of high exhaust gas recirculation rates up to full load together with a continuously regenerating particulate filter system to be the most feasible solution to fulfill the commercial vehicle emission level EURO IV. To fulfill the nitrogen oxide standards of 3.5 g/kWh under ESC and ETC test conditions, exhaust gas recirculation rates of 20% up to above 30% are required depending on the basic NOx emission of the engine. A modular EGR system has been developed which in its final stage provides a dual-flow recirculation of the exhaust gas via electrically actuated valves on the hot side of the EGR coolers. Reed valves are arranged between EGR cooler and intake manifold which permit recirculation of the exhaust gas even with a positive scavenging gradient by making use of the dynamic

exhaust pressure peaks. Owing to the recirculation line being separated for either duct up to the reed valves and the resulting high pulse rate of the recirculated exhaust gas, recirculation rates of more than 20% are possible over a broad spectrum of the map without having to apply an intake air throttling, as in passenger cars, or a Venturi feed system.

Figure 19 shows an overview of the obtained results in combination with the individually applied measures (secondary injection, VGT, EGR).

The results confirm the future-proof potential of the 2013 engine series. It is very likely that comparable emission levels can be achieved with a technically much advanced UPS.

### 6. NOISE CHARACTERISTICS

In the description of the individual components emphasis

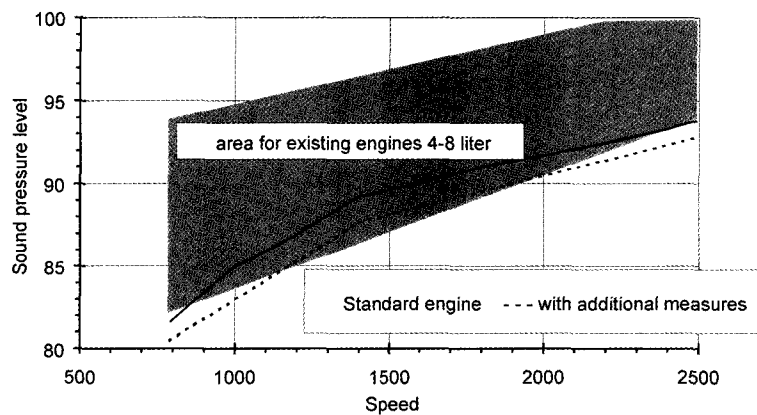


Figure 20. 2013 6-Cyl. engine full load noise at 1m distance.

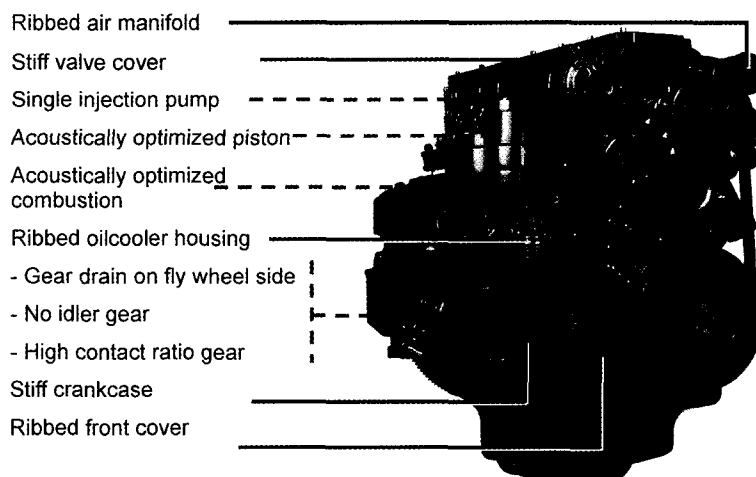


Figure 21. Noise reduction measures for 2013 engines.

was placed on the significance of acoustic optimization of all components of relevance. The series-produced 1012/1013 engines set new standards at the time of their market launch in view of their very low noise emission level. The development of the 2013 series was focused on reducing the noise level even further despite a considerably higher power density of the engines.

The development output can be assessed by means of the overall noise (standard measurement at 1 m distance), Figure 20. Shown is here the noise on the full-load curve. The measured value of the 6 cylinder engine at rated power is 93.7 dB(A) and is at the lower end of the range of established engines with 4-8 liter swept volume. On the whole, the noise spectrum of these engines is up to 6 dB(A) in the rated power range and in the medium-speed range up to 7 dB(A) higher. The investigations have revealed furthermore that with relatively simple measures (such as a sandwich oil pan instead of a simple sheet-metal oil pan and some shielding measures) a noise reduction is possible to about 92 dB(A) at rated power and accordingly over the entire speed range. This result was achieved on the basis of intensive basic research at DEUTZ and by systematic application of the achievements in the configuration of components.

The acoustic concept is summarized in Figure 21.

The noise attenuation concept is backed up in particular by the very stiff, acoustically optimized crankcase, the gear train on flywheel end and the optimization of all components concerning sound transfer and radiation.

Large components like valve cover and charge air pipe have been acoustically decoupled and optimized by shaping and ribbing. Due to UPS integration in the crankcase the injection pumps have no essential influence on noise emission.

## 7. CONCLUSIONS

With the new 2013 series, DEUTZ systematically continues along the path of the tried and tested 1012 and 1013 series with powerful engines for commercial vehicles and industrial applications. The 2013 backs up this engine family, particularly for medium-duty commercial vehicles whose power requirement is well met with 100 to 190 kW.

Despite a 50% power increase, the outer dimensions of the 1012 series have only been negligibly exceeded, a

proof of compactness and low weight, Figures 2 and 3.

At the time of its introduction to the market, the engine will fulfill the exhaust emission level EURO III and US 98. It is a matter of course, however, that an adequate potential has been built into the engine to meet future emission requirements. The engines thus feature the necessary future-proofness, as demonstrated in Figure 19.

An engine variant with mechanical injection system and mechanical governor or electronic speed control at option has been series-produced since October 1998 for a new agricultural tractor of the upper power class.

The industrial engine with 2-valve cylinder head and mechanical injection is in the development stage and will be launched in 2001.

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