MAN D3876

Innovative truck engine modified for off-road use

Framework conditions
The MAN D3876 was presented as a completely new and standalone engine series from MAN in 2014. This 15.26 l in-line 6-cylinder engine has replaced the previous MAN D2868 16.2 l V8 engine in the commercial vehicles sector and will also gradually replace the V8 engine in off-road applications with the introduction of the new emissions categories. Key features of the D3876 are its excellent power-to-weight ratio, the high ignition pressure strength and the Common Rail injection system with injection pressures of up to 2,500 bar. The basic engine is therefore predestined for a variety of different applications, whereby a distinction can be made between on-road and off-road applications. On-road applications include heavy trucks with a wide range of uses, from operation on construction sites and off-road traction transport to long-haul transport and heavy-duty transport. Off-highway use focuses on applications requiring high power levels in agricultural engineering (self-propelled harvesters) and construction machinery (wheel loaders, earth movers, etc.).

While the basic power train and the injection equipment are identical for both application areas, the on-road and off-road versions differ in their concepts for turbocharging, combustion and electronics as well as the attachments and the exhaust gas aftertreatment.

The 6-cylinder D3876 was revised in time for the IAA Commercial Vehicles 2016 and is thus available in commercial vehicles with power ratings from 397 kW to 471 kW (540 hp to 640 hp) for powerful trucks and heavy-duty semitrailer tractors. With power ranging from 415 kW to 485 kW (564 hp to 660 hp) and torque of up to 3,100 Nm, the D3876 is available for heavy,
medium and light off-road applications in the EU Stage IV and US Tier 4 final emissions categories.

Fundamental differences between the on-road and off-road applications can be found particularly in emissions legislation, the requirements regarding power characteristics and dynamics, the packaging and system integration of the engine and exhaust gas after-treatment, as well as the environmental conditions and the on- and off-road load profiles. The requirements set by customers from both application areas overlap for the most part in regards to the total cost of ownership (TCO), power density and engine weight, as well as reliability. Figure 1.

Development objectives
Typical requirements for commercial vehicles are high torque values at low engine speed ranges, low fuel and AdBlue® fluid consumption with relatively uniform driving cycles, dynamic power development, high brake output and low engine and system weight [1]. The production volumes are high and distributed across comparatively few variants. In contrast, off-road applications have a large variety of different driveline configurations, installation spaces and load profiles. These profiles range from light-duty, often semi-static operations, for example combine harvesters, up to heavy-duty dynamic operations, such as wheel loaders. It is therefore necessary for a wide range of torque values and dynamics to be available at up to 3,000 m above sea level and in a range of different climate conditions. A simple interface design and flexible configurations are intended to simplify the engine and system integration for the different machines in complex installation conditions. In addition to the already demanding environmental conditions for commercial vehicles, off-road engines are often exposed to extreme vibrations and very dusty and hot conditions. Many applications also require inclinations of up to 45° in all directions. Thanks to modular components and standard interfaces, the lower production volumes which are typical in this sector can be handled using a manageable variety of options.

Robust, lightweight and compact build
A robust basic engine is the foundation for all applications. The D3876 engine reaches this high strength and rigidity at a comparatively low weight. At MAN the basic engine consists of the crankcase, crankshaft, connecting rods, pistons, cylinder head including valve gear, camshaft and gear train, Figure 2. Just as for the smaller D20 and D26 engines, the crankcase of the D3876 is made exclusively from high-strength GJV-450 (vermicular graphite cast iron). The D3876 is designed for ignition pressures of 250 bar to meet the requirements of modern combustion processes and provide adequate potential for the future. [2] Moreover, the cylinder-liner concept selected for the D3876 enables a particularly fill-gree bulkhead design, as can be seen in the large ventilation openings above the main bearing, which enabled the weight of the component to be further optimised. As such, the D3876 is one of the lightest engines in its performance class.

Despite having only four forged counterveight, the crankshaft has an adequately high degree of compensation. This means that even at engine overspeeds, the loads exerted on the bearings do not exceed permissible levels.

The cylinder unit (PCU – Piston Cylinder Unit) also originates from the on-road application. The robust PCU has been reliably undergone in exten-

Figure 1: The off-road engine (left) is even more robustly built than the on-road model (right).
sive function and endurance tests to ensure the requirements for load spec-
trum and running time operations are met in both on and off-road applica-
tions. The D3876 engine is fitted with steel pistons because of its high peak
pressure. Their high strength and rigidity allow a low piston height with a
low compression height. The favourable push-rod ratio made it possible to
reduce the piston side force. This enables a reduction of the friction
torque in the engine compared with types that are fitted with conventional
aluminium pistons and contributes to economical fuel consumption. The
connecting rod with its FEM-optimised design and weight is made out of
heat-treated 70MnVS4 steel. This permits easy cracking at room tem-
perature.

The D3876 has a single-piece cylinder head. This design has established itself
as the standard for modern commercial-vehicle engines. The valve ar-
angement has been rotated through 45° to realise optimal charge cycles in
conjunction with better protection against cracks developing in the valve
links. [3]

The engineering design of the D3876 cylinder head was also consistently
optimised for the use of casting mate-
rival GJV-450. In order to optimise the
flow to the intake ports and thus the
gas exchange and the tolerance of
swirl, a slight amount of added weight
resulting from the integration of the air
distributor pipe into the cylinder head
was accepted. One of the positive
effects of this engineering design is the
omission of the sealing between the
cylinder head and the air manifold.
Being able to omit this sealing, which is
highly stressed by thermal cycling,
contributes to increased reliability.

The D3876 valve gear is implemented
with an overhead camshaft. Actuation
of the valves is controlled by roller
rocker arms and flying valve cross-
heads, resulting in a highly compact
form. The high rocker-arm ratios for
intake (1.3) and exhaust (1.5) are able
to achieve high valve lifts with compar-
atively small cam lifts. This enables
rapid opening of the valve to its
maximum. A second overhead

camshaft has been omitted for the
sake of compact installation dimen-
sions and for reasons of cost.

What are known as 'domed valves' are
used in the D3876 series. Thanks to
the dome-shaped reinforcement to the
combustion-chamber side of the valve
plate, optimised by means of FEM,
there is as good as no deformation and
relative movement of the valve in the
area of the valve seat ring. This mini-
mises seat wear, making it possible to
extend the intervals between valve-
clearance checks. [4]

The D3876 has a dual timing gear train
with high, straight-toothed gears. Due
to the type of toothing, axial bearings
for the intermediate gears can be
dispensed with, so that the minimum
engine length is achieved. For opti-
mising the weight and the manufac-
turing costs, nitried or case-hardened
gears are employed, depending on the
application.
The basic engine is also fitted with the latest-generation Common-Rail system from Bosch, which achieves a maximum rail pressure of 2,500 bar and is used for all applications.

For commercial vehicle applications, low weight is prioritised to attain the highest possible payload. The basic engine is a good starting point for achieving this. Components made from aluminium, such as the flywheel housing, and plastic, such as the oil sump and cylinder head cover, contribute to the low weight of the complete engine.

The priority for off-road applications is compactness, robustness and ease of servicing, which is attained by lowering the complexity, amongst other things. It must also be easy to make adjustments for different installation conditions.

The more stringent requirements for robustness and rigidity are met by using a flywheel housing made of the material GJS-500. Different oil sump types for differing installation spaces and for operational inclinations up to 45° are available.

Reliability and service life
So-called ‘top-down cooling’ is used for the cylinder head, with the upper cooling jacket functioning as coolant distributor. The coolant is distributed longitudinally to the engine by the upper cooling jacket of the cylinder head. This saves an additional coolant-distribution manifold with consequent sealing points, increasing the robustness and reducing costs. Coolant for each cylinder flows from the upper cooling jacket along the injector sleeve to the points subjected to high thermal loads, such as the injector nozzles, valve seat rings and valve links on the floor of the combustion chamber. Using cross-sections which have been specially harmonised using CFD simulation, the coolant is then used for cooling the cylinder liners of each cylinder in the crankcase. With this flow configuration, the full amount of coolant is available to the cylinder head, considerably reducing the total volumetric flow rate required by the engine.

Top-down cooling ensures a robust and uniformly high cooling performance for all cylinders. [5] As a result, by preventing local overheating with its consequent peak stresses it was possible to design a cylinder head that is thermomechanically very robust.

Service costs and common parts
The D3876 uses proven components from the modern D20/D26 engine series such as the fan drive unit, PTOs, fuel filters and air filters. [6] This increases ease of servicing and repairs and optimises parts logistics across all MAN series.

Long service intervals further reduce the total cost of ownership. For example, it is possible for trucks to have an oil-change interval of 100,000 km and the valve clearance must only be checked at every second oil change. For off-road applications, the service intervals are every 500 operating hours.

Performance and emissions
The requirements placed on a modern turbocharging system in a commercial vehicle engine in the top power segment are multi-faceted. A high torque output which is already available at just above idling speed, a high specific power output at nominal (engine) speed, as well as low fuel consumption in the main operating range with only a minimal increase in fuel consumption when moving to full-load operation all require efficient turbocharging. As the two-stage exhaust-gas turbocharging with intercooling fulfils these requirements very well, all D3876 on-road engines are equipped with this type of turbocharging.

The air system is made up of a low-pressure compressor with a downstream low-temperature water-cooled intercooler as well as a high-pressure compressor and a downstream low-temperature water-cooled intercooler. [7]

The two differently sized turbochargers are connected in series on the exhaust side and charge air side. The smaller, high-pressure charger responds well at low engine speeds. As the engine power increases it receives an increasing amount of assistance from the larger, low-pressure charger. In the upper characteristic map area, the charging pressure governing system of the engine control system opens the pneumatically operated wastegate of the smaller high-pressure charger. The larger low-pressure charger, which is better suited to these engine operating points, takes over the majority of the compression work. With this system, the engine air requirements (which depend on the operating point) are fulfilled by whichever charger size offers optimal efficiency. The advantages of a two-stage turbocharging
<table>
<thead>
<tr>
<th>Engine model</th>
<th>D3876 LFxx</th>
<th>D3876 LExx</th>
</tr>
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<tbody>
<tr>
<td>Configuration</td>
<td>Inline Six-Cylinder Engine</td>
<td></td>
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<tr>
<td>Displacement [l]</td>
<td>15.26 l</td>
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<tr>
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<tr>
<td>Stroke</td>
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<td>Application</td>
<td>Onroad</td>
<td>Offroad</td>
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<tr>
<td>Emission level</td>
<td>Euro 6 c</td>
<td>EU Stufe IV, US EPA/CARB Tier 4 final, LRC</td>
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<tr>
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<td>one-stage with VTG</td>
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<td>Power [kW/PS] / Maximum torque Md max [Nm]</td>
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<tr>
<td>D3876 LF09 - P= 471 kW / 640 hp - Md= 3000 Nm</td>
<td>D3876 LE1xx - P= 485 kW / 660 hp - Md= 3100 Nm</td>
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<tr>
<td>D3876 LF07 - P= 427 kW / 580 hp - Md= 2900 Nm</td>
<td>D3876 LE1xx - P= 450 kW / 612 hp - Md= 2900 Nm</td>
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<tr>
<td>D3876 LF08 - P= 397 kW / 540 hp - Md= 2700N m</td>
<td>D3876 LE1xx - P= 415 kW / 564 hp - Md= 2700 Nm</td>
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<tr>
<td>Emission concept</td>
<td>EGR, DOC, DPF, SCR</td>
<td>EGR, SCR</td>
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</table>

Table 1: Technical Data

concept are a particularly high total compression efficiency which is attained by using intercooling to reduce energy losses, as well as by a very wide working range.

The exhaust gas recirculation (EGR) is a key technology in the D3876 thermodynamics concept which helps reach both emissions and fuel consumption targets. The cooled exhaust gas recirculation is known to have a large influence on the engine’s NOx emissions. The most important parameters here are the EGR rate and the EGR temperature downstream of the exhaust gas cooler.

A two-stage cooling concept with a high-temperature (HT) and a low-temperature (LT) EGR cooler was implemented for on-road applications to reduce the exhaust gas outlet temperature as much as possible.

The D3876 on-road engine has a high-pressure exhaust gas recirculation system which extracts exhaust gases upstream of the turbine, cools them in the two exhaust gas coolers and returns them to the engine mixed with charge air. An electric EGR shut-off flap on the hot side upstream of the EGR cooler controls the amount of the returned exhaust gases and allows fast actuating and exact positioning of the shut-off flap. [8]

One of the most important development objectives for the D3876 off-road engine was compliance with the legal limit values for US EPA/CARB Tier 4 final and EU Stage IV, while also providing the best possible fuel efficiency at nominal (engine) speed as well as high torque values at low engine speeds. These development objectives are crucial for off-road applications for serving a broad driveline and application spectrum in contrast to trucks. A comparison of torque and power characteristics of the engines, as well as other characteristics, is shown in Table 1 as well as Figure 3.

Built on the solid foundations of the D3876 on-road engine, the off-road engine employs one-stage variable turbine geometry (VTG) charging and a one-stage high-temperature (HT) EGR cooling system. The omission of the intercooler as well as the simpler piping of the charge-air system and EGR
system, combined with the compact VTG turbo charger, cover all requirements for a robust, smaller unit for off-road applications.

Due to the required EGR rate being lower for the D3876 off-road, a more powerful one-stage, high-temperature EGR cooler is used and the second cooling stage is omitted. The omission of the second cooling stage also considerably simplifies the system integration.

All D3876 engines are equipped with a Common Rail injection system that works at an injection pressure of 2,500 bar for optimal fuel atomisation quality, which in turn helps to achieve a considerable reduction in particle emissions. Due to low particle masses in the exhaust gas, the D3876 off-road does not require a diesel particulate filter (DPF), while the D3876 on-road benefits from improved fuel consumption, for example. At 2,500 bar, the Common Rail injection system offers one of the highest pressures on the market.

The dynamic response in off-road-specific engine speed ranges was optimised using the VTG technology. Especially for off-road use, a fast and dynamic response is vital to ideally cover the wide range of requirements placed on the application-specific engine characteristics.

The fuel consumption map of the D3876 off-road has been adjusted so that the best fuel consumption as well as another area of low fuel consumption occur at medium engine speeds during partial load operation. Field trials further confirm the leading position of the unit regarding fuel consumption in its branch.

The fuel consumption map of the D3876 on-road shows two features which improve efficiency: In a wide map area, the specific fuel consumption is below 200 g/kWh. At the same time, the best fuel consumption, as well as a second area of low fuel consumption, occur at the typical load spectrum for long-haul applications. [9] The EDC control unit of the D3876 off-road is an EDC17 by Bosch. It brings together the CAN customer interface which is based on the protocol SAE-J1939. This includes the connection of sensors and actuators on the vehicle, as well as all control unit functions necessary for engine operation and diagnostics. This also includes the completely integrated recording, triggering and monitoring of exhaust gas aftertreatment components. Additional control units are therefore not required. [10] Figure 4 provides an overview of the entire system.
As is usually the case for Euro 6, the truck’s permanent exhaust gas aftertreatment system is made up of an oxidation catalytic converter (DOC), a closed diesel particulate filter (DPF), a urea hydrolysis section and an SCR catalytic converter with an ammonia slip catalytic converter (AMOX) (SCR-T) [11], all connected in series. All components are contained in a silencer box to be installed in the truck frame.

Despite the higher exhaust gas volumetric flow, the silencer of the D3876 on-road requires the same installation space and is the same design as the one in the D20/D26 engines [12], making it one of the most compact systems in its performance class. The well-known and proven MAN modular exhaust gas aftertreatment system from the D2676 Tier 4 final and D2862 Tier 4 final off-road applications, which consists of an SCR catalytic converter and slip catalytic converter, has been adjusted to fulfill the requirements of the D3876 off-road. The modular exhaust gas aftertreatment system provides maximum flexibility to adjust to different installation spaces as the components can be installed flexibly. Customers can thus make better use of the limited installation space and complex installation situations than with a bulky integrated individual solution. Figure 5.

The emissions regulations EU Stage IV and EPA Tier 4 final are met without using a DOC and a DPF. The modular exhaust gas aftertreatment system can easily be expanded to include additional components, such as a DPF, enabling the system to already fulfill the upcoming EU Stage V emissions requirements.

Summary and outlook
With the D3876, MAN has released an engine that can be specifically equipped for a wide range of applications thanks to its basic concept. The use of the same basic engine concept for on and off-road applications...
reduces costs in development, production and after sales. Application-typical special features and requirements are optimally fulfilled by specifically chosen technology concepts which build on the basic engine. This enables maximum flexibility. The state-of-the-art design of the D3876 provides the best foundation for additional stages of emissions regulations regarding on and off-road use, as well as more stringent future requirements regarding power and dynamics. Particularly the upcoming emissions category EU V Offroad, which is currently being developed, is set to benefit significantly from the current experience gained with commercial vehicle engines at similar emissions levels in Euro 6. The engine has the long-term potential to be fully included in the product portfolio for all application areas covered by MAN.

Literature references:


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