

Development Trends for Commercial and Industrial Engines

Michael Franke, Shirish Bhide, and Jack Liang
FEV North America, Inc.

Michael Neitz and Thomas Hamm
FEV GmbH

ABSTRACT

Exhaust emission reduction and improvements in energy consumption will continuously determine future developments of on-road and off-road engines. Fuel flexibility by substituting Diesel with Natural Gas is becoming increasingly important. To meet these future requirements engines will get more complex. Additional and more advanced accessory systems for waste heat recovery (WHR), gaseous fuel supply, exhaust after-treatment and controls will be added to the base engine. This additional complexity will increase package size, weight and cost of the complete powertrain. Another critical element in future engine development is the optimization of the base engine. Fundamental questions are how much the base engine can contribute to meet the future exhaust emission standards, including CO₂ and how much of the incremental size, weight and cost of the additional accessories can be compensated by optimizing the base engine.

This paper describes options and potentials to improve the base engine for future commercial and industrial engines. Downsizing engine displacement, new materials, friction reduction and advanced boosting and fuel injection technologies have demonstrated potentials in light-duty vehicles and implementation is underway. The paper will provide an outlook of how these technologies can improve the base engine for commercial and industrial applications with regards to future exhaust emission and fuel efficiency requirements.

CITATION: Franke, M., Bhide, S., Liang, J., Neitz, M. et al., "Development Trends for Commercial and Industrial Engines," *SAE Int. J. Engines* 7(4):2014, doi:10.4271/2014-01-2325.

INTRODUCTION

The legislative limit values for pollutant emissions of commercial vehicle diesel engines have drastically been reduced during the last two decades. This has been an essential driving force for the development of engine technologies. The main components of diesel emissions are NO_x and particulate matter with often conflicting requirements for their control. The compliance to today's emission legislations for heavy-duty diesel engines in commercial vehicles demands a reduction of NO_x and particulate matter emissions in the entire engine operating range including high load points. A very effective way to reduce the raw NO_x emissions at high loads is to operate the engine with high exhaust gas recirculation (EGR) rates. At the same time the Air Fuel Ratio (AFR) must be kept constant to a level needed to hold the particulate emissions under the allowed limit. Increase of fuel injection pressure also aids in lowering of particulate emissions. Meeting these and future emissions legislation requirements while maintaining or even increasing the specific torque and power output of the engine presents challenging requirements to the base engine design. Increased EGR and boost result in an increased peak cylinder pressure (PCP) to

as high as 250bar, increasing the forces experienced by the cylinder head, crankcase and the cranktrain components requiring the designs and materials to be upgraded. Higher fuel injection pressure requires the fuel pump and its drive mechanism to withstand the increased torque and forces.

In future, regulations will increase focus on limiting pollutants with contributions to global warming such as CO₂, N₂O and CH₄. Because CO₂ is a natural product of petroleum fuel combustion, development focus will need to be applied to increase fuel efficiency of the combustion engines by reducing friction in engine components and other parasitic losses. Even though some of the development burden will be shared by vehicle technologies, the internal combustion engine will continue to be developed and optimized further to provide the best balance of performance, emissions and fuel economy.

A brief overview of the technologies utilized in on-highway heavy duty engines over the past few decades and potential future trend is shown in [Figure 1](#). Starting with model year 2014, CO₂ / fuel consumption of on-highway trucks have to be reduced up to 20% in a phased approach until 2017/2018.

Further reductions may come into effect in 2020 or later. To meet these CO₂ emissions limits, new base engine technologies will be required in addition to the technologies currently in production. Some or all of the technologies outlined in Fig. 1 are projected to be utilized in combination for friction reduction and increase of thermal efficiency. This paper introduces base engine design trends and examines how they may support meeting the emissions and fuel-economy limits.

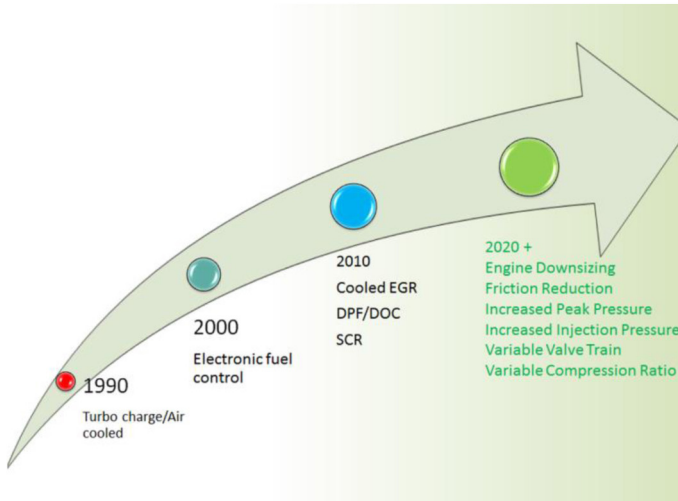


Figure 1. Diesel engine technology evolution for reduction of emissions and CO₂

ENGINE DOWNSIZING

Engine downsizing is a trend where the specific power output of the engine is increased, thereby requiring a lower displacement to generate the same power. Downsizing by merely decreasing the displaced volume without reducing the number of cylinders does not necessarily lead to a significant friction reduction. Fig. 2 shows a comparison of two design variants of a medium-duty truck engine.

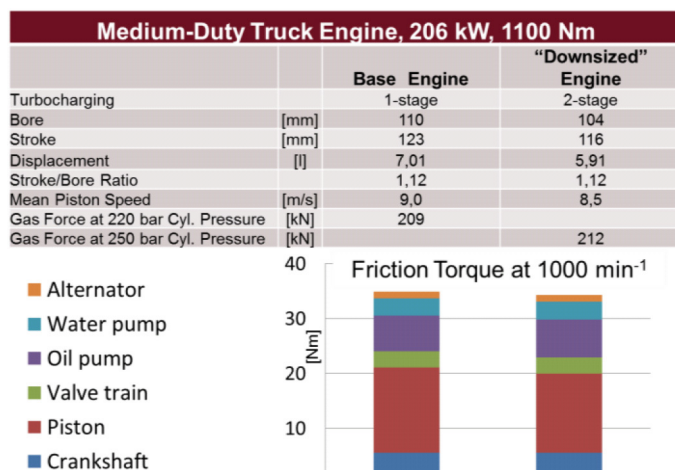


Figure 2. Effect of downsizing on engine friction

For this "downsized" variant, the displacement is reduced proportionally to the bore and stroke keeping the stroke/bore ratio constant. This downsizing requires dual stage

turbocharging leading to a peak pressure increase of approximately 30 bar. In spite of a smaller bore diameter, the gas force remains approximately the same. Therefore a reduction of the bearing diameters, the resultant bearing friction and the oil flow through the bearings is not possible. The lower piston speed caused by the slightly smaller stroke at the same engine speed is the only friction-decreasing effect. This positive effect is partly consumed by the additional oil flow through the second turbocharger, which causes a higher oil pump driving power. The friction contributions of crank shaft, valve train, water pump and alternator remain the same. Therefore the friction estimate shows only a small difference in the frictional torque; merely the thermodynamic fuel consumption advantage via a shift in the operating point can be realized.

On the other hand, downsizing via a reduction in the number of cylinders would offer a significant potential for decreasing the engine friction. Due to dual-stage turbocharging and the measures necessary to cope with high peak pressure and power, the engine cost will increase significantly. This is compensated by the reduction in the number of cylinders due to a lower quantity of components. The cost comparison in Fig. 3 clearly shows that downsizing is financially only attractive, if the displacement reduction is realized via a reduction in the number of cylinders.

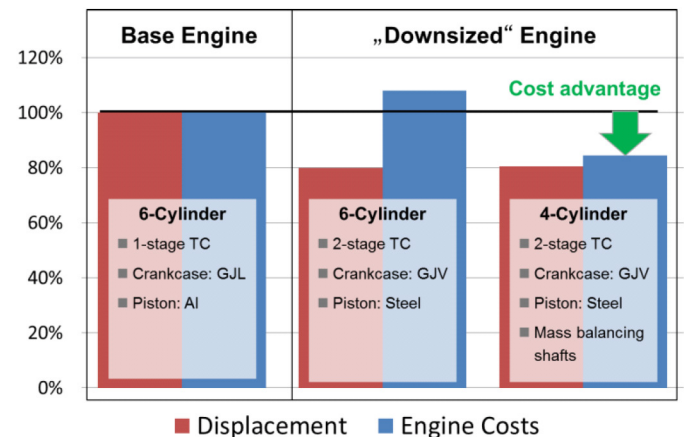


Figure 3. Effect of downsizing and reduction of the number of cylinders on engine costs

Even the use of mass balancing shafts for the elimination of the second order free inertia forces in order to optimize the NVH behavior of the four-cylinder, is more than compensated by the cost advantage compared to a six-cylinder engine. Considering these friction and cost reduction potentials the introduction of large four-cylinder engines instead of the usual six-cylinder engines would be beneficial. A four-cylinder engine with a cylinder displacement of approximately 2 l, which is common for heavy duty engines, could successfully enter the performance class of 300 kW, which represents the leading class in drive systems for 40-t long-haul trucks and consequently provide a considerable cost saving potential. The significantly shorter length of the four-cylinder would provide free space in the engine compartment, which could be used for

the increased space required by the exhaust gas after-treatment and cooling. In addition, a weight advantage of approximately 150 kg is to be expected even in case mass balancing shafts are used, which can be directly utilized to increase the payload of the vehicle. The higher torque fluctuation due to the smaller number of cylinders would probably be the focus of development, in order to meet customers' NVH requirements. The main question that remains is of customer acceptance of such engines in a rather conservative commercial vehicles market. In passenger cars the trend for a lower number of cylinders is in full swing. Here a large number of six-cylinder engines have been replaced by four-cylinder engines with higher power density. The substitution of four by three-cylinder engines in small passenger vehicle is imminent.

CYLINDER LINER AND CRANKCASE TECHNOLOGY

The methods for application of thermal spray coatings to the cylinder running surface [1], which are also available for series production application, offer potential for reducing the friction as shown in Fig 4. The FMEP with the plasma coated liner is about 12% lower than the baseline cast iron liner at rated speed. Up to 20% friction reduction has been reported at rated load in other studies [2]. This technology, originating from passenger car engines, has also been tested for commercial vehicles and large bore engines [3]. Furthermore, it allows a free choice of the running surface material independent of the basic material of the cylinder liner.

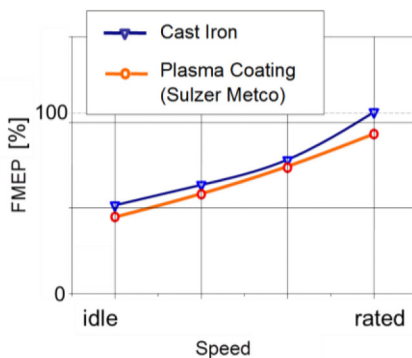


Figure 4. Potential of liner coating for friction reduction

It is common practice in light/medium duty engines today to use crankcases with integrated cylinder liners (so-called parent bore). If this practice is adopted in heavy duty engines instead of using wet cylinder liners, significant potentials regarding production costs of the crankcase and cylinder spacing could be realized, as shown in Fig 5 [4]. In case of an engine overhaul, the worn cylinders would have to be bored out and a new spray coating be applied, instead of exchanging the separate cylinder liners. Special overhaul pistons with slightly increased diameter would not be required for this. However, corresponding production facilities would be needed for

carrying out such overhaul work. It would be possible to implement this technology in technically developed markets with good manufacturing infrastructure.

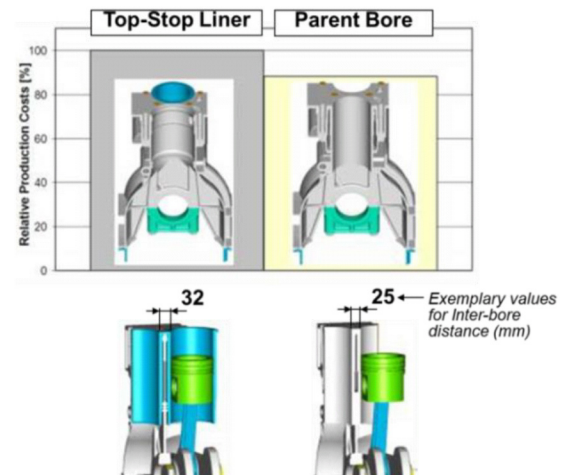


Figure 5. Advantages of parent bore compared to wet cylinder liners

CRANKSHAFT AND CRANK-TRAIN DESIGN

Crankshaft main and connecting rod big end bearings are a significant source of friction in engines. Fig. 2 indicates the relative frictional torque for different sub-assemblies of the engine and the crankshaft contributes ~14% of the total engine friction. At rated speeds and loads this contribution can increase to upwards of 25%. There is potential of reducing the crankshaft friction by reducing the main and connecting rod journal diameters. Fig. 6 shows benchmarking data for diesel engines comparing the size ratio of the main bearing and connecting rod bearing to the main bearing diameter.

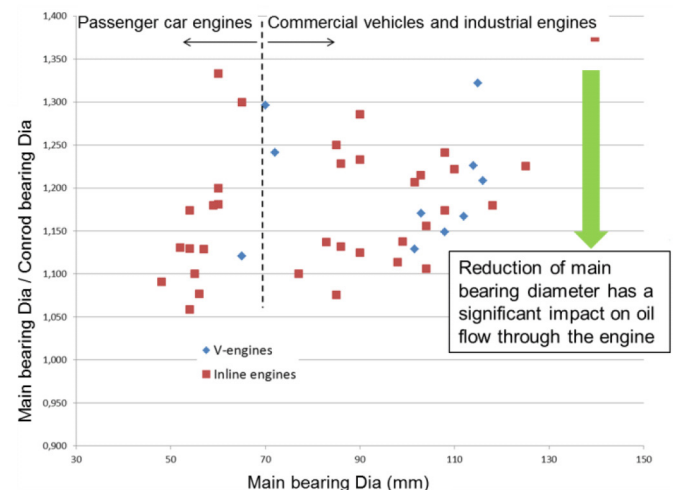


Figure 6. Relationship between main and conrod bearing diameters

A reduction in the main bearing diameter decreases the quantity of oil flowing through the bearing. This reduces the oil demand from the oil pump lowering the parasitic losses. This reduction in main bearing diameter goes opposite to the trend of increasing specific power and peak cylinder pressure. A counter-effect is not provided by manipulating the connecting