

The Contribution of Engine Mechanics to Improved Fuel Economy

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ABSTRACT

Measures for reducing engine friction within the powertrain are assessed in this paper. The included measures work in combination with several new technologies such as new combustion technologies, downsizing and alternative fuels. The friction reduction measures are discussed for a typical gasoline vehicle. If powertrain friction could be eliminated completely, a reduction of 15% in CO₂ emissions could be achieved.

In order to comply with more demanding CO₂ legislations, new technologies have to be considered to meet these targets. The additional cost for friction reduction measures are often lower than those of other new technologies. Therefore, these measures are worth following up in detail.

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1. INTRODUCTION

The reduction of CO₂ emissions is one major driver for new powertrain technologies. Driven by stricter legislations and increased customer awareness, more cost-intensive measures find their way into new powertrain configurations. Friction reduction measures often have a better cost-benefit ratio compared to other new technologies, such as electrification of the powertrain, and therefore must be a standard measure for CO₂ reduction for all engines.

The CO₂ emissions of newly registered vehicles in Europe during 2012 plotted as a function of vehicle weight are shown in [Figure 1](#). Marked in greyscale are the total numbers of newly registered vehicles in Europe in 2012. Additionally, the CO₂ emission target lines for 2015, 2020 and 2025 (under discussion) are shown. The targets are increasing with vehicle weight while the majority of newly registered vehicles in Europe in 2012 lie around or just below the weight dependent target line for 2015. Only a few vehicles with very low registration volume fall below the 2020 target line.

Considering only gasoline and hybrid electric vehicles ([Figure 2](#)), even fewer vehicles are below the 2015 target line. Only a few vehicles with hybrid electric powertrains reach the 2020 targets. Additionally, a line of the mean CO₂ emission values of the gasoline vehicle fleet in 2012 is shown. If it was possible to eliminate all friction within the powertrain, this line could be reduced by about 15%. The mean values would shift to the lower line as shown in the graph.

In order to discuss the potential friction reductions available within the powertrain, an example vehicle has been chosen. It is a C-class vehicle with a vehicle weight of 1500 kg producing 150 g/km CO₂ over the NEDC ([Figure 2](#)). It is a downsized turbocharged, direct injection I4 engine with manual transmission. Its CO₂ emission target for 2020 is approximately 100 g/km. For reaching this target, friction reductions targeting engine and transmission are promising steps which are not only suitable for conventional gasoline and diesel powertrains but also useful for more advanced new technologies, such as hybridization.

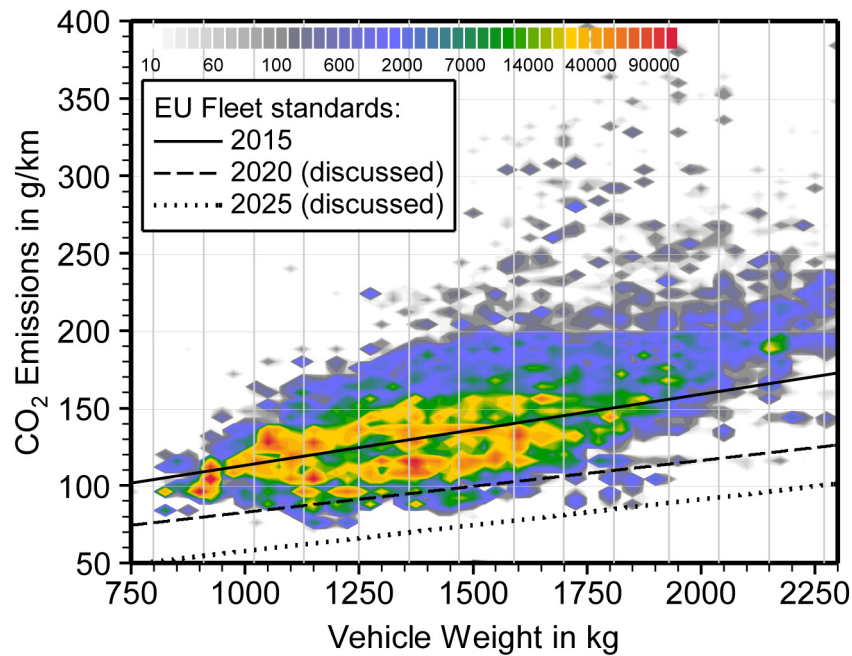


Figure 1. CO₂ emissions and registration volume of newly registered gasoline, diesel and hybrid electric vehicles in Europe with targets for 2015-2025

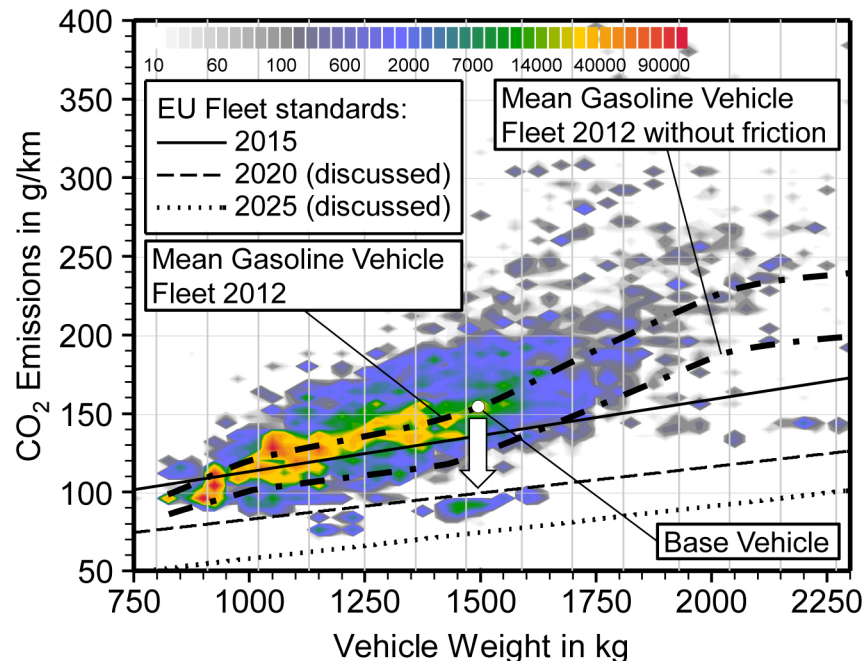


Figure 2. CO₂ emissions and registration volume of newly registered gasoline and hybrid electric vehicles in Europe with targets for 2015-2025

2. FRICTION REDUCTION IN FUTURE INTERNAL COMBUSTION ENGINES

For many years, efforts have been undertaken to reduce friction in engine mechanics. As shown in Figure 3, the scatter band of motored friction measurements of production engines shows a decreasing trend over time. Focusing on the regression line, it can be stated, that within the last two decades, engine friction has been reduced by approximately 30%, contributing to a reduction in CO₂ emissions by 7% disregarding any other changes, such as thermodynamics.

But this trend seems to converge to a limit within the last 10 years. The reason for that is an increase in specific power output of today's downsized engines (Figure 4).

Equipped with direct injection and turbocharging (including two-stage turbocharging), modern downsized engines have a much higher specific power output. Because of the higher cylinder pressures and hence higher mechanical loads on power distributing parts, such as the cranktrain, these parts require a more robust design. This offsets the decrease in friction reduction to some extent.

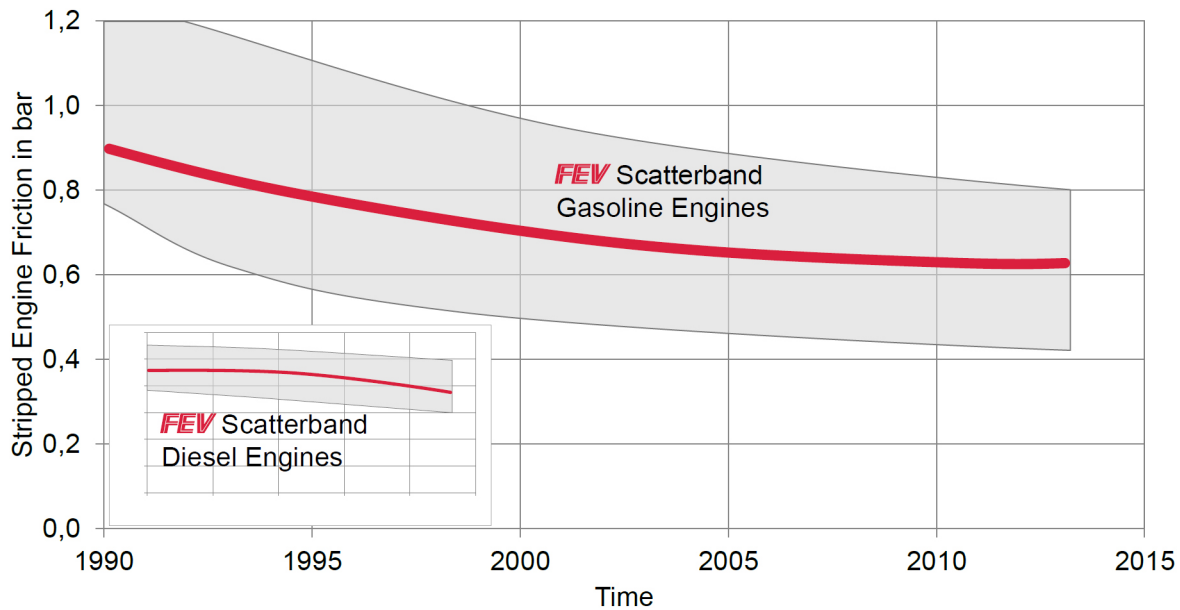


Figure 3. FEV Scatterband and trend line of gasoline engine friction measurements

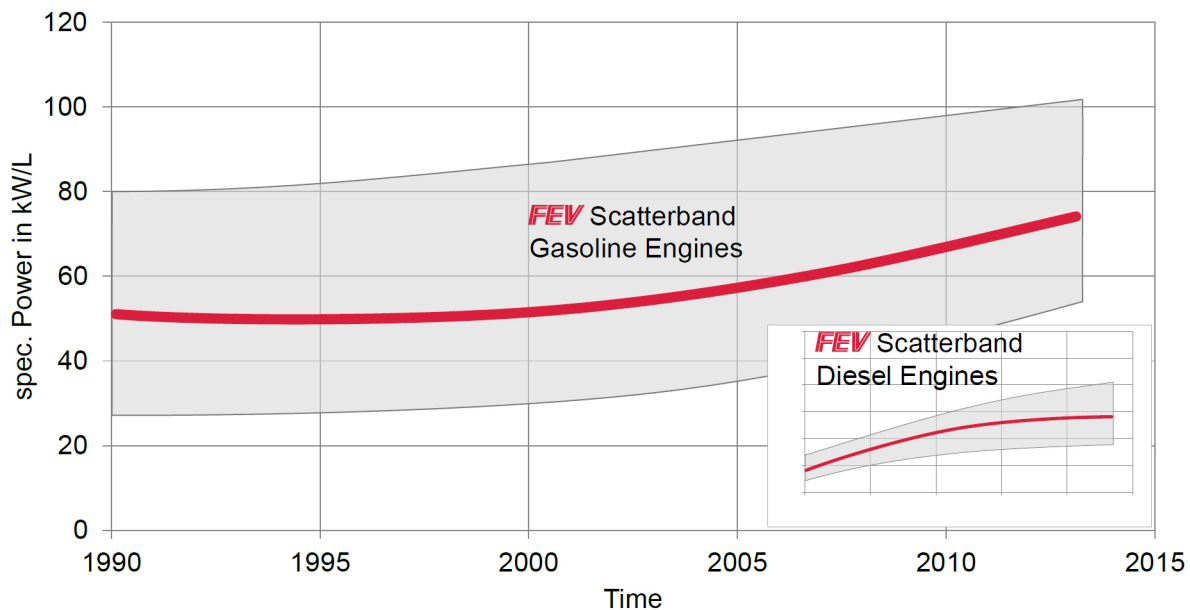


Figure 4. FEV Scatterband and trend line of specific power for gasoline engines

In modern Diesel engines, the trend of friction reduction is not as clear as gasoline engines because specific power of diesel engines has increased at a much higher rate within the last years. Nevertheless, the potential for fuel reduction in modern diesel engines is expected to be even higher; by using engine families, engines with different specific power are offered using the same base engine. The lower power variants then offer a high potential for friction reduction when optimizing their base engine for a lower specific power. It can be stated, that friction reduction measures in diesel engines show a higher potential for CO₂ emission reductions. With a more efficient combustion, friction contributes to a higher share of all engine losses. Additionally, the friction loss share is higher at part-load conditions (relevant for the NEDC) than at full load.

The opposite applies to hybrid electric vehicles. Most of the part-load operation points are covered electrically, so that the combustion engine is operated at higher average load regimes. In these load cases, friction contributes at a smaller share. Nevertheless, friction reduction measures also increase overall efficiency of hybrid electric vehicles.

Friction losses of a C-class vehicle with a downsized 1.8 L I4 turbocharged direct-injection engine in a transversal configuration (with manual transmission) can be divided into friction losses of the engine (83%) and the transmission (17%). Friction in the engine is dominated by friction of the cranktrain, comprising of the piston group and the crankshaft (Figure 5). Frictional losses are produced in the main and connecting rod bearings and at the cylinder liner to piston interface. Additional

friction sources include the valvetrain and, if applicable, the mass balancing shaft bearings and drive system, and all accessories.

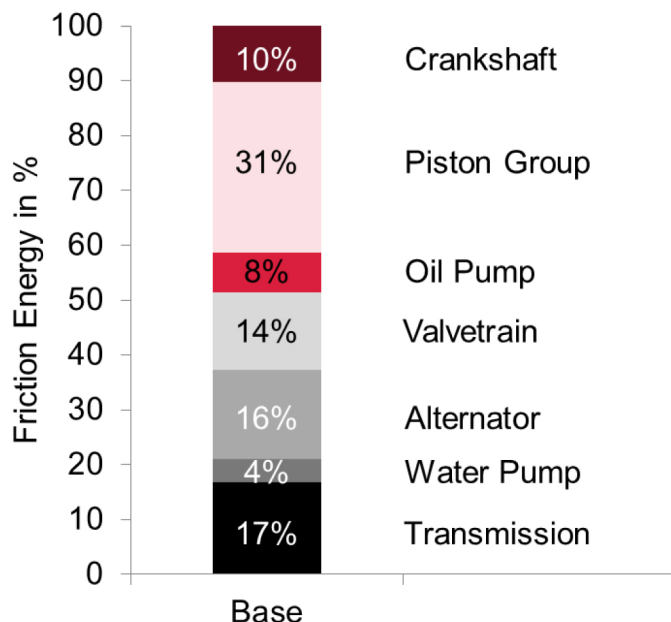


Figure 5. Friction losses of a Gasoline I4 (TC DI) powertrain in a C-class vehicle

2.1. Potential of Plain and Roller Bearings

Regarding plain bearings (journals) a bearing diameter reduction offers a high potential for friction reduction due to the fact that the friction of a plain bearing is depending on the bearing diameter to the power of three ($FMEP_{\text{Plain Bearing}} \sim \text{Diameter}^3$). A diameter reduction can be achieved by using a

combination of advanced simulation and measurement tools for the bearings and the crankshaft stiffness, which allows for a further optimized “close to borderline” dimensioning of the bearing/crankshaft design. New material specifications and new manufacturing technologies, e.g. fillet rolling, can allow bearing dimensions to be reduced even more. Figure 6 shows main bearing diameters of series production engines and a regression line for in-line SI engines.

Using the above mentioned “better” material combined with advanced manufacturing tools it would be possible for the defined base engine (450 cm³ cylinder displacement) to reduce the main bearing diameter from 55 mm to 43 mm. This results in friction reductions up to 50% for the main bearings. In addition, a similar potential is existing for the con rod bearings. For the mechanical validation of the crankshaft, a strain gage measurement in the highly stressed areas is very important in order to analyze the stresses under real fired conditions (Figure 6). These investigations allow for a precise determination of the bending and torsional loads of the crankshaft and provide a detailed picture of the crankshaft dynamics over the entire load- and speed range. For the data transfer, a telemetric system is used [1].

Reducing the moving masses of crankshaft, connecting rod, piston pin and piston (by reducing wall thicknesses and optimized piston design, [2]) as well as the stroke, can further reduce main bearing loads. This again allows reducing the diameters and thereby friction. This is generally applicable to all engines with additional benefit for engine families with lower power variants [3]. The friction reduction achieved through reductions of bearing diameters can lower the crankshaft friction by up to 40% (Figure 5), leading to CO₂ emission reductions of up to 1.2%.

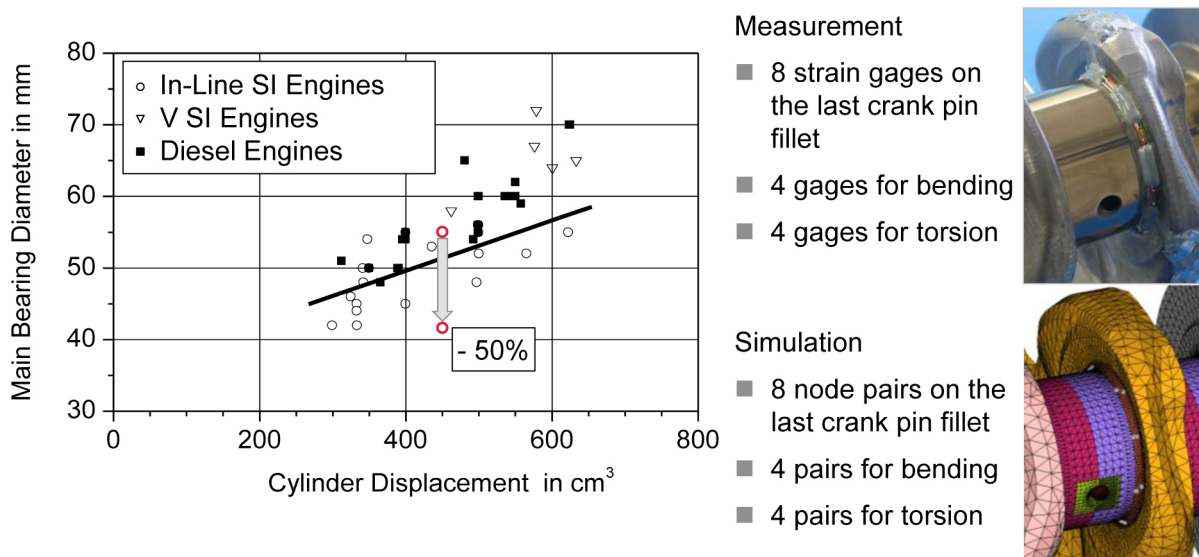


Figure 6. Main bearing diameters of different engine types and their friction reduction potential by reducing diameters