AUTHORS

Dipl.-Ing. Ömer Özdemir is Research Assistant at the Institute for Powertrain and Automotive Engineering, Chair for Machine Elements and Tribology (iaf-mt) of the University of Kassel (Germany).

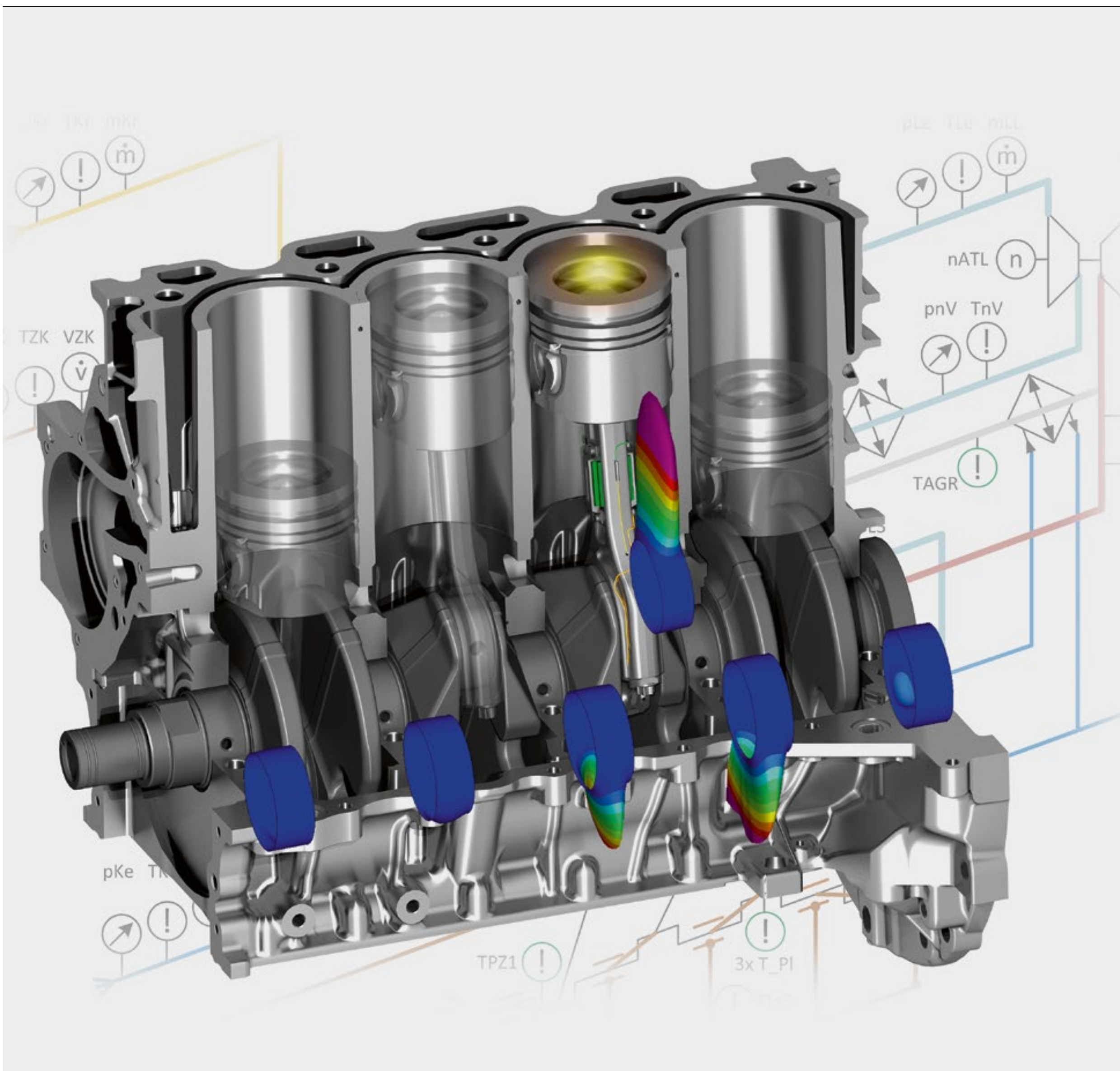
Kevin Huttinger, M. Sc. is Research Assistant at the Institute of Internal Combustion Engines and Automotive Engineering, Chair in Automotive Powertrains (IVK) at the University of Stuttgart (Germany).

Prof. Dr.-Ing. Adrian Rienäcker is Director of the Institute for Powertrain and Automotive Engineering, Chair for Machine Elements and Tribology (iaf-mt) of the University of Kassel (Germany).

Prof. Dr.-Ing. Michael Bargende is Director of the Institute of Internal Combustion Engines and Automotive Engineering, Chair in Automotive Powertrains (IVK) at the University of Stuttgart (Germany).

Reduction of Friction Losses by Local Management of the Oil Temperatures

In the development stage, the lubrication system of a combustion engine has to be designed for operating points of highest load and speed. But the customer-relevant operation is dominated by moderate loads and speeds. It can therefore be concluded to reduce the friction losses in hydrodynamically dominated journal bearings such as the crankshaft by a lower oil viscosity due to local oil temperature increase in operating points of partial load. However, it must be ensured that mixed friction after speed or load increase does not rise critically.



© IVK | iaf-mt

1 MOTIVATION

Within the aspiration to reduce the fuel consumption and emissions of vehicles driven by combustion engines, the reduction of engine-out emissions and the increase of the total efficiency are fundamental approaches. Conventional passenger cars are operated mainly in lower partial loads most of their lifetime. Under these conditions, oil temperatures which are far below the maximum allowed, dominate inside the journal bearings. Therefore, the objective of the FVV research project "Reduction of friction losses by local management of the oil temperatures" was to investigate potentials of friction reduction by optimizing the lubricating oil circuit of a combustion engine. In that case, it means the supply of the different journal bearings and the lubricated functional surfaces of the engine with accordingly conditioned oil. The viscosity class and the oil temperatures in the different bearing groups of the engine are changeable boundary conditions. With increasing oil temperature, the oil viscosity decreases and therefore also the hydrodynamic friction. But at the same time, the bearing capacity of the lubricating film decreases which can lead to a high increase of mixed friction. Therefore, the operational safety after sudden load and speed increase has to be ensured in any case.

2 METHODS

A current in-line four-cylinder diesel engine with 1.5 l displacement and 80 kW output was the basis for testing and simulation. For the determination of the friction changes due to oil temperature variations and for the component specific validation of the simulation models, measurements at the fired engine as well as strip measurement in motored operation were performed. Furthermore, the influence of the thermal boundary conditions on the friction in fired operation of the engine was investigated with a modified oil circuit for the external oil supply and oil conditioning.

For the simulative investigation of the friction losses in the crank drive and in the lubricated contacts of the camshaft, component specific (T)EHL-MBS models were built up which make a space- and time-resolved calculation of friction results possible [3]. For this purpose, newly developed TEHL approaches based on the energy equation for fluid and solid were used, which consider the influence of the temperature in the lubricating film and in the solid structures [1]. Also, new approaches to couple the main bearing with the connecting rod bearing in the simulation, calculate the oil supply of the connecting rod bearing with influence of centrifugal force [2]. Besides the simulative investigations of the engine, tests at the journal bearing test rig ensure the operational safety of the highly stressed connecting rod bearing at high critical oil temperatures. For this purpose, contact voltage measurements were made in the bearing to measure the mixed friction part qualitatively and quantitatively [4]. Additionally, detailed comparisons with simulation results allow a better understanding of critical conditions of the journal bearing. Based on the simulation results, component specific friction maps were made for the implementation in a driving profile simulation to estimate the influence of the different frictional contacts on the total friction losses at different local oil temperatures and the possible total potentials for the reduction of the fuel consumption of the engine.

3 COMPARISON OF FRICTION RESULTS IN MOTORED OPERATION

Within the engine investigations, strip measurement under motored conditions were performed. So, seven strip levels at eight oil temperatures and eight speeds were measured. Here, the commonly known dependency of the friction on the oil temperature and speed in journal bearings dominated by fluid friction is shown. According to **FIGURE 1**, especially the friction of the main bearings can be reduced with an increase of the oil supply temperature. The

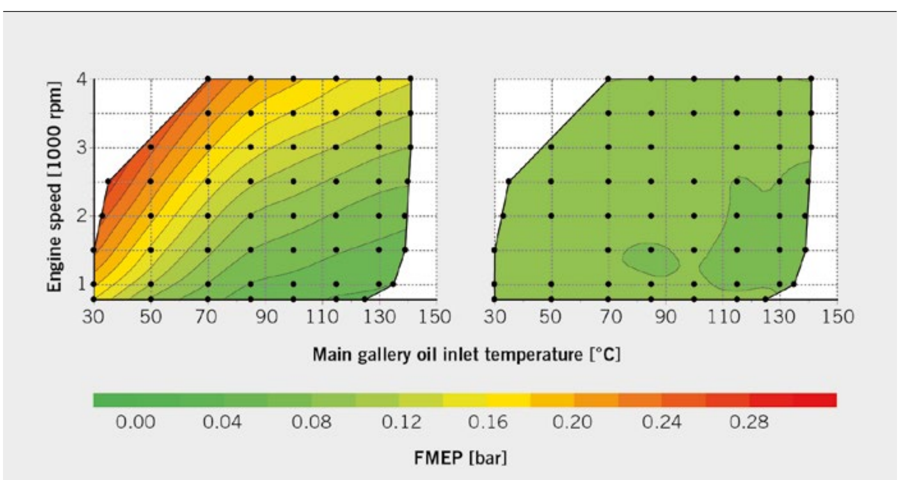


FIGURE 1 Friction Mean Effective Pressure (FMEP) of the crankshaft (left) and of the valve train (right) in motored operation (© IVK)

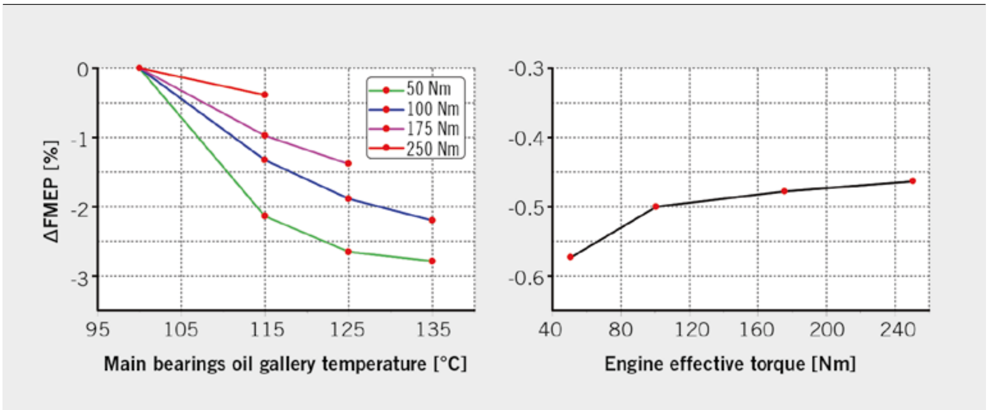


FIGURE 2 Relative FMEP changes of the full engine at different loads (left) and due to oil temperature increase in the cylinder head from 90 to 110 °C (n = 2500 rpm) (© IVK)

saving potentials in the valve train of the test engine are not in the same range, neither relatively nor absolutely.

Furthermore, it is shown that an increase of the oil temperature in the cylinder head under real conditions is limited. The reason for this is the strong cooling of the oil due to the low oil flow and comparatively high water flow through the cylinder head.

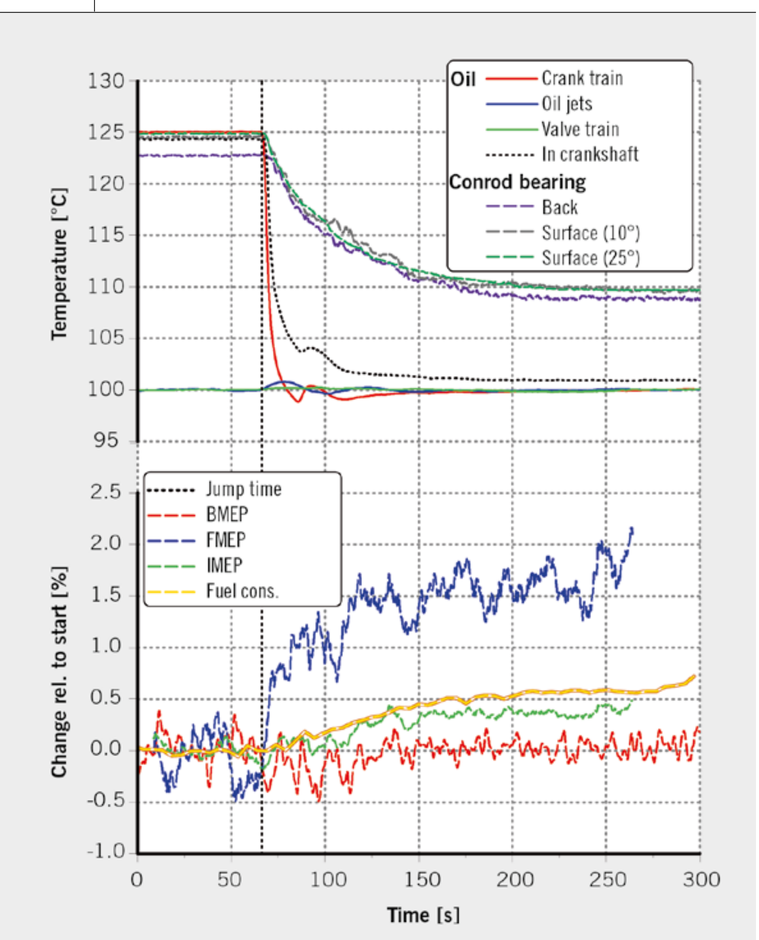


FIGURE 3 Temperature behavior within the oil circuit of the main bearing at temperature jump (ΔT = -10 °C) and behavior of friction and combustion during the jump (Md = 54 Nm, n = 2500 rpm) (© IVK)

Afterwards, the oil circuit of the test engine was modified to realize three separate oil supplies of main and connecting rod bearing, cylinder head, the piston jets and turbocharger. Additionally, a corresponding external oil supply unit supplies each circuit individually with oil at different pressures and temperatures and makes fast changes of these parameters possible for each circuit. To determine runtimes of the oil stream and the effects of oil temperature changes, temperature measurement points were applied in the oil pipe between main bearing, connecting rod bearing of the crankshaft and under the surface of a connecting rod bearing shell. Following stationary measurements confirm the qualitative conclusion of the strip measurements.

The absolute Friction Mean Effective Pressure (FMEP) changes of the results in **FIGURE 2** are in the range from 0.01 to 0.03 bar (left) as well as maximally 0.01 bar (right). In the cylinder head as well as in the main and connecting rod bearings, it is shown that the relative changes on the FMEP decreases with increasing load, but the comparison of the absolute results shows increasing FMEP.

The operation of the journal bearings of a combustion engine with oil temperatures which can lead to a reduction of friction losses in partial load but also can lead to a damage of the bearing during full load phases, make it necessary to be able to feed the corresponding lower oil temperatures. Runtimes of the oil stream in the engine as well as the thermal inertia of the engine block limit the reaction time. Therefore, the reactions of the whole system of main and connecting rod bearing on defined temperature jumps at the oil inlet into the engine at different speeds and loads were investigated.

According to the measurement in **FIGURE 3**, a significant reduction of the connecting rod temperature (ΔT = -10 °C) occurs after about 49 s. Parallel to the decreasing oil and bearing temperature, it is visible that the FMEP increases by 1.6 % and the fuel consumption by 0.6 %. The achievable cooling gradients in the full engine were reproduced in wear and failure investigations at the journal bearing test rig and rated as sufficient to avoid damage and excessive wear in the bearing at repeated load step changes.

4 SIMULATION RESULTS

FIGURE 4 displays the comparison of the FMEP in the main bearings at different speeds in dependency of the temperature between measurement and simulation. It shows that the simulation results

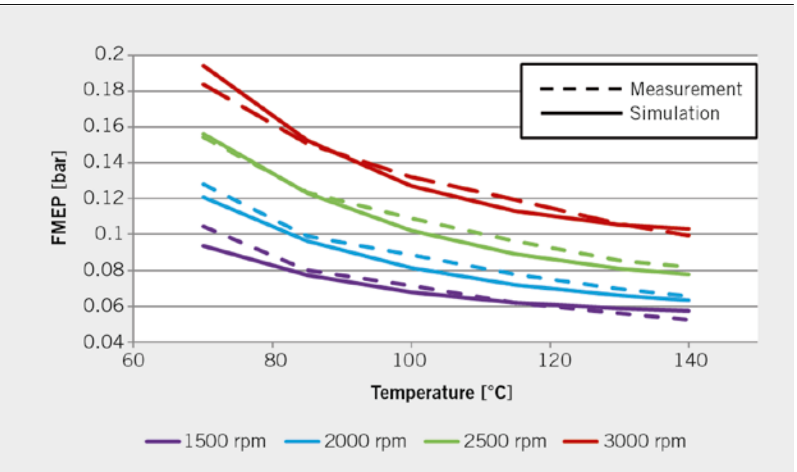


FIGURE 4 Motored friction of the main bearings in the crankshaft (© iaf-mt)

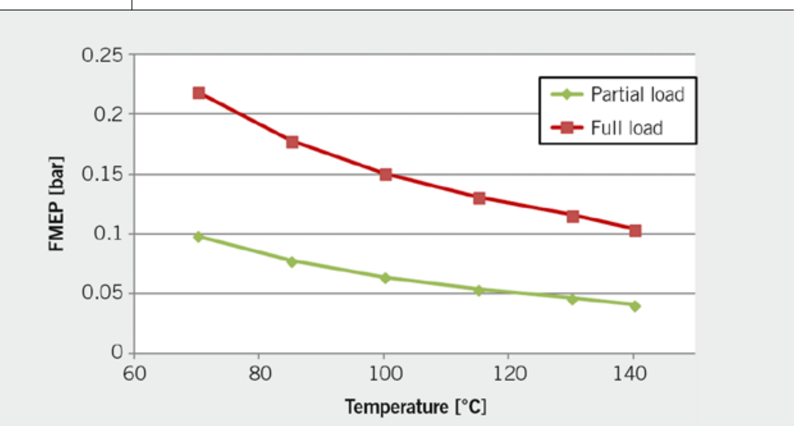


FIGURE 5 FMEP of the connecting rod bearings at n = 1500 rpm (© iaf-mt)

match very well with the measured results. These illustrate the potential that doubling of the oil temperature in the main bearings can reduce friction by a factor of 2.

In addition to the motored investigations, fired measurement and simulations show similar potentials. Besides the main bearings, also the connecting rod bearings and camshaft bearings were investigated. These show friction advantages at higher oil temperatures, too. **FIGURE 5** outlines the FMEP of the connecting rod bearings at a speed of 1500 rpm.

Based on the motored friction and consumption maps, the measured oil consumption curves of the cylinder head, of main and connecting rod bearing as well as the simulated friction maps of the iaf-mt, a driving profile simulation for a current middle class passenger car was built up in the end at the IVK. Besides an NEDC and a WLTC ride, an RDE ride was also simulated and the achievable reduction of fuel consumption respectively CO_2 emissions due to local thermal oil management in the different bearing groups were determined. Because of the sphere of the investigated measures, the driving profiles were investigated at constant temperatures and at operating temperature of the engine.

FIGURE 6 shows the results of the simulation depending on the oil temperature at the oil filter of the engine. An increase of the oil supply temperature of the main bearing by 30 °C gives a reduction of the CO_2 emissions by 0.94 g/km for a driving profile according to the WLTC.

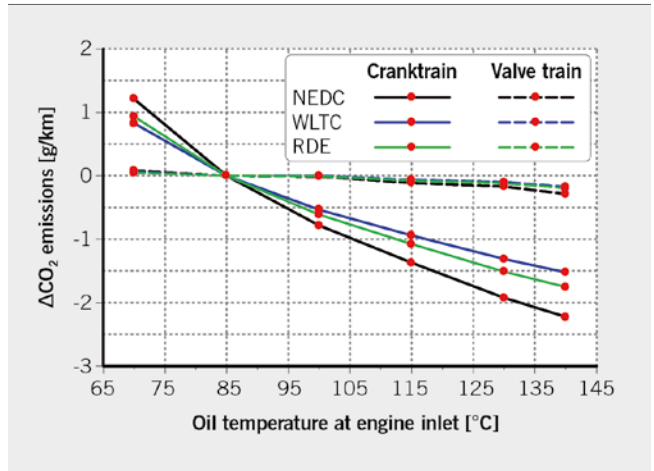


FIGURE 6 Changes of the CO_2 emission for different driving profiles with variation of the oil temperature (reference temperature 85 °C) (© IVK)

5 CONCLUSION

Within the FVV research project "Reduction of friction losses by local management of the oil temperatures," it could be shown that a local increase of the oil temperature in the main and connecting rod bearings lead to significant friction advantages in the range of partial load but in the cylinder head, the achievable advantages are very small. Additionally, detailed simulation models were built up which can show an assessment of these saving potentials. Furthermore, it was shown that no damage of the bearings is to be expected in case of load increase and simultaneous supply of cooler oil.

REFERENCES

[1] Jaitner, D.: Effiziente Finite-Elemente-Lösung der Energiegleichung zur thermischen Berechnung tribologischer Kontakte. University of Kassel, dissertation, 2017

[2] Backhaus, K.: Low Friction Powertrain: Energetisch optimierte Ölversorgung von Tribosystemen im Verbrennungsmotor. FVV research project nr. 983, final report, 2013

[3] Schönen, R.: Strukturdynamische Mehrkörper-Simulation des Verbrennungsmotors mit elastohydrodynamischer Grundlagerkopplung. Universität Kassel, dissertation, 2001

[4] Umbach, S.: Schmierstoffeinfluss auf Gleitlagermischreibung. University of Kassel, dissertation, 2009

THANKS

The research project "Reduction of friction losses by local management of the oil temperatures" (project number 18419 N/1) was financially supported by the Federal Ministry of Economics and Energy (BMWi) via the Federation of Industrial Research Associations AiF (IGF number 18419). The authors thank for the financial support and also for the support by the working group during the project within the FVV which was leaded by the Chairman Dr. U. Lehmann (Federal-Mogul Wiesbaden GmbH).