Combining an innovative measurement technique with accurate simulation to analyze engine friction

H. Allmaier, C. Knauder, D.E. Sander, Franz M. Reich

Virtual Vehicle Research Center, Graz, Austria

The entanglement of an innovative measurement technique with an accurate simulation yields in total a powerful tool to investigate the friction power losses in engines under realistic operating conditions, as will be discussed in the following. While the total engine friction power losses and the friction of the valve train are measured experimentally, the friction power losses of the crank train journal bearings are calculated using simulation. The result is in an efficient and powerful determination of the individual engine subassemblies under realistic operating conditions ranging from idle to full load operation. The presented method can be used to assess the efficiency of various friction reduction measures like cylinder deactivation, (ultra)low viscosity lubricants or coatings and won in 2014 the Innovation award of Magna Logistics Europe.

The increasingly strict emissions legislation and the customer's wish for increased mileage per gallon pose a demanding challenge for today's automotive industry. In addition to trends like downsizing and downspeeding, lightweight design, the optimization of combustion and the embodiment of increasingly complex after treatment systems, friction reduction offers still a significant potential to increase efficiency. As engines have already been optimized mechanically for a long time, it is often not possible to obtain significant improvements by optimizing only a single part. Therefore, it is commonly necessary to perform a number of small optimization that yield in total a significant improvement [1]. The experimental assessment of such small optimizations in the 100-200W range, however, is a challenge in itself due to the considerable measurement uncertainties of common measurement techniques. The method to be presented in the following can be a valuable tool to investigate such small optimizations.

The method was recently developed at the Virtual Vehicle Research Center and comprises a measurement method with superior accuracy as well the employment of an accurate and reliable simulation method to determine the friction power losses of the journal bearings of the crank train. The combination allows investigating the friction power losses separately for the subassemblies valve train, piston assembly and journal bearings of the crank train for arbitrary operating conditions. In the following the two parts – measurement and simulation – are discussed.

Meet FRIDA

FRIDA – the short hand for Friction Dynamometer – is the test-rig utilized to measure the total engine friction under realistic operating conditions with improved accuracy. In the following the term friction relates to the power losses in dry or lubricated contacts and does not consider the power required to operate auxiliary devices (e.g. coolant/lubricant pumps etc.). To this task a motoring test-rig was realized that includes an external charging system that allows to realize realistic peak cylinder pressures in the engine under test (see Figure 1).

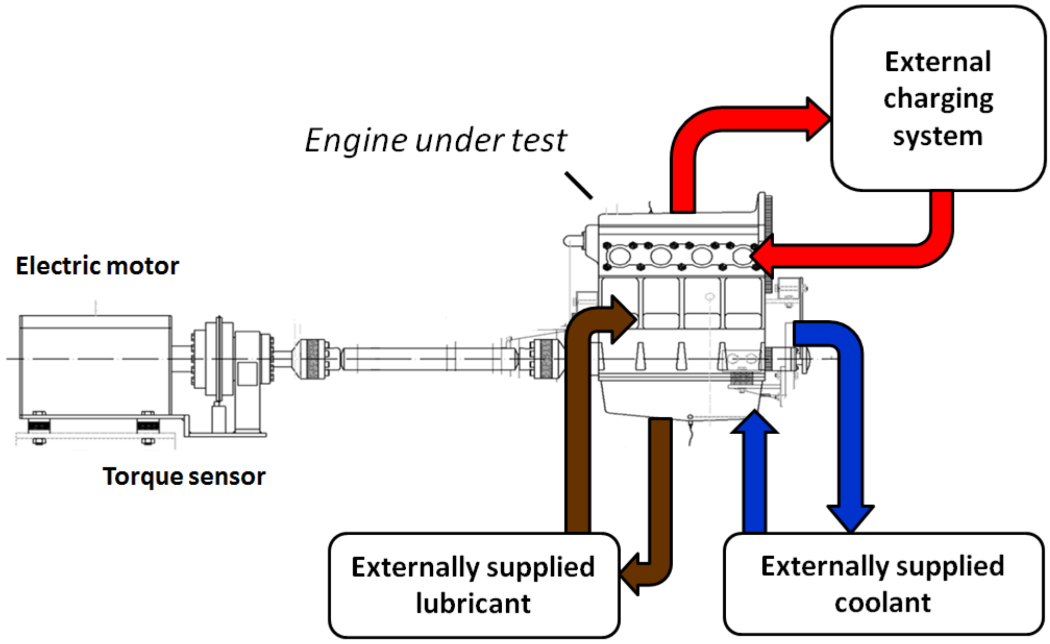

Figure 1: Overview of the charged motoring test-rig FRIDA

This measurement technique, sometimes called charged (or pressurized) motoring, exists for a long time and several different realizations are in use at different companies today (see e.g. [3]). Compared to the common strip-down measurements the advantage of the charged motoring test is the realistic mechanical load on the engine. The mechanical load has a considerable impact on engine friction (see Fig. 2), although it is often covered by other effects in practice.

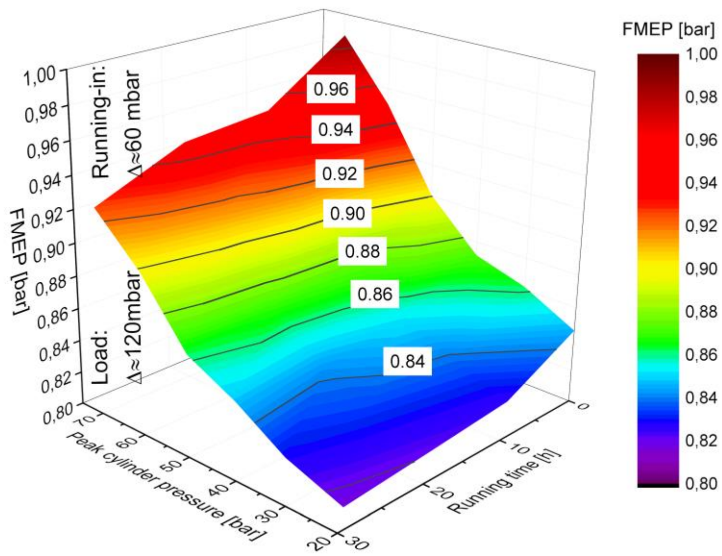

Figure 2: Influence of the engine load and of the running-in process on total engine friction.

With the external charging system peak cylinder pressures of more than 200 bar can be realized. In comparison to fired engine operation another advantage of the charged motoring test is the insignificant thermo-shock effect of the used sensors, as the thermal conditions in the combustion chamber are very stable. FRIDA utilizes an external charging system that supplies up to 200°C hot air to the engine inlet, which yields peak temperatures in the combustion chamber of about 800-1000°C, independent of the peak cylinder pressure.

The major advantage of the charged motoring method is the significantly improved measurement accuracy that allows to investigate also quite small optimizations. The general challenge in friction measurements is that friction (Friction mean effective pressure FMEP) is the small difference of two rather same sized large quantities, indicated and brake mean effective pressure (IMEP and BMEP, respectively)

$$FMEP=IMEP-BMEP$$

While the measurement of the BMEP can be conducted with great precision, the measurement accuracy of the IMEP is limited by several factors in practice. Amongst others, the precise determination of the top dead center position of the piston is critical. In addition, unavoidable variations in the combustion between different engine cycles influence this measurement as well as the thermo-shock effect that directly affects the measurement uncertainty of the sensors. While the latter two effects are naturally irrelevant in charged motoring, the main advantage in the charged motoring technique is the strong reduction of the IMEP itself, which reduces proportionally the measurement uncertainty at the same time. In numbers this means that for a Diesel engine with a nominal torque of 2200 Nm in fired operation the IMEP in charged motoring is reduced to about 460 Nm. The friction power losses are unaffected and stay around 100 Nm, which gives a roughly 5-fold advantage in measurement uncertainty.

The lack of combustion and the, consequently, different thermal situation in the combustion chamber represent therefore the most significant compromise of the charged motoring method. In a direct comparison of the results for the same engine from fired operation and from charged motoring it was found that the largest differences between the two methods are confined to part load conditions. For full load operation the results agreed within 0.5% accuracy (in relation to the nominal power of the engine) as well as trends were found to agree closely.

In addition to the determination of the total engine friction losses for all operating points of interest, the knowledge of the valve train friction is also required. To achieve this task several different methods are available at Virtual Vehicle, which, however, are not in the focus of this article.

The simulation

For the calculation of the friction power losses of the main and big-end bearings of the crank train a predictive simulation method was developed at Virtual Vehicle. The method was validated with a large number of measurements and has been presented in detail in a previous article (see [2]). Therefore, only a short overview is given in the following.

The simulation of the crank train journal bearings considers both the elastic properties of the involved bodies (crank shaft, con rod etc.) as well as the microscopic geometry of the surfaces (e.g. roughnesses) and the complex rheological properties of the lubricant. As it was not the aim to develop a new software package, the simulation builds on AVL Excite PowerUnit[1]. The simulation does not only allow to predict the friction of the journal bearings, but also to determine if mixed lubrication is present and if so, how severe it is. Due to the continuously increasing mechanical loads, this is a valuable property of the method [4].

To investigate the accuracy of the simulation method, a large number of experimental measurements on several different journal bearing test-rigs have been conducted using different lubricants, rotational speeds and loads (both static and dynamic). In [2] this validation was presented in detail for dynamic loads and in addition Figure 3 shall aid to illustrate the accuracy of the simulation method.

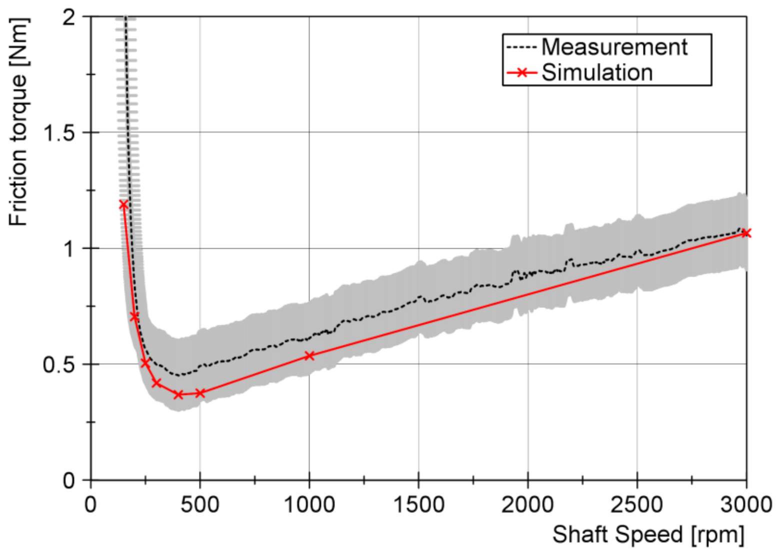

Figure 3: Comparison of the measured journal bearing friction to the result calculated with simulation for a 0W20 lubricant; the measurement uncertainty is shown as grey band for comparison

Figure 3 shows the direct comparison between simulation results and experiment for a stop-start test, where the shaft is accelerated from rest to 3000rpm and then stopped again. Consequently a large part of the Stribeck-curve is investigated. As can be seen, the simulation agrees closely with the experimental data from full film lubrication to severe mixed lubrication.

<u>Measurement and Simulation</u>

The combination of measurement and simulation is the actual innovation of the FRIDA test-rig, for which also a patent application has been submitted.

By combining the measurement of the total engine friction and valve-train friction with the simulation of the crank train journal bearings, a virtual strip-down becomes possible. In other words, it is possible to investigate the friction power losses separately for the subassemblies valve train,

[1] AVL List GmbH, Advanced Simulation Technology, Hans-List-Platz 1, Graz, Austria 8020, www.avl.com

piston assembly and crank train journal bearings for all operating conditions (from idle to full load) of interest. With this tool friction maps of these subassemblies can be generated as well as it is possible to investigate the consequences of optimizations of one part for the other parts of the engine.

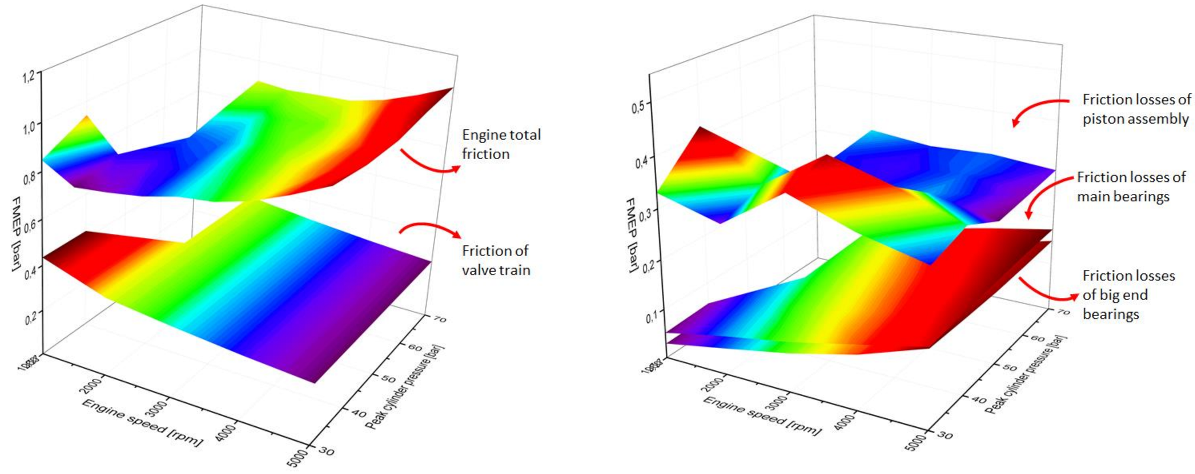

Figure 4: Exemplary illustration of the measured total engine and valve train friction (left) and the virtual strip-down using simulation for the main and big end bearing (right).

<u>Further possibilities</u>

With the presented combination of measurement and simulation it is not only possible to investigate the friction power losses in detail for the current generation of the engine. In a next step it is possible to use the simulation to investigate different optimizations and their efficiency to reduce engine friction. E.g. it is possible to investigate the potential for friction reduction by using (ultra)low viscosity lubricants for the crank train journal bearings, as is depicted in Figure 5. If mixed lubrication is predicted to occur, it is then straightforward to determine optimum bearing diameters and widths.

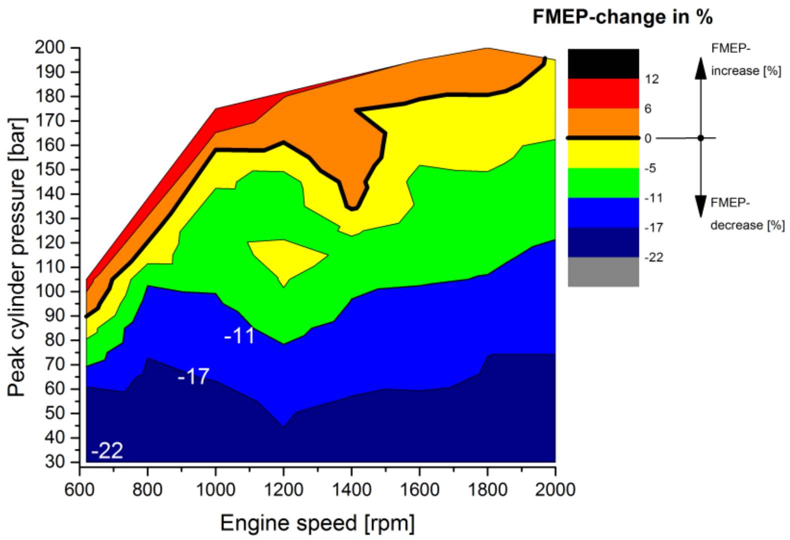

Figure 5: simulation can also be used to investigate the potential of different optimization strategies; the figure shows the reduction of the friction power losses for the journal bearings of the crank train by utilizing

a low viscosity lubricant: while significant gains can be obtained for low and part load conditions, at full load mixed lubrication sets in and counteracts the obtained benefits.

Summary

The presented combination of measurement and simulation provides a powerful tool for the friction analysis of the entire engine and all its subassemblies for all operating conditions of interest. The test-rig utilized for the friction measurements offers improved measurement accuracy in comparison to common fired engine tests. The simulations can be used in a next step to investigate friction reduction strategies and provide a valuable aid in the engine development process.

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