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Development of a novel aerosol-lubricated ring-on-liner test methodology

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1. Introduction

This work explores the development of a novel aerosol-based and simulation supported piston ring test methodology, aimed at enhancing the accuracy and reliability of engine component evaluations. The test methodology is used to investigate the wear mechanism scuffing. Despite the extensive focus of numerous publications and research projects on this wear phenomenon, a comprehensive understanding of scuffing remains elusive. In order to test and compare piston rings from real engines, the profile of the rings must be considered, as this geometry tends to vary greatly. Therefore, the experimental test rig is combined with an EHD simulation model to determine geometry reduced scuffing limits. This approach allows the coatings of different rings to be compared in a one-parameter test.

2. Methodology

This chapter elucidates the details of the used test methodology, based on the work of Pusterhofer et al. [1] and Schiffer et al. [2] and the corresponding simulation model to determine geometry reduced scuffing limits.

2.1 Experimental test setup

A linear tribometer of the type TE77 from Phoenix Tribology© was used in this work. The basic setup and the test strategy used to trigger load induced scuffing events are described in a previous work of the authors [3]. In this test strategy, the contact load F between the ring and the liner specimen is incrementally increased until a scuffing event occurs. This is detected by an erratic increase in the coefficient of friction (COF). The output of the test run is the final load step reached until the COF increase, which is referred to as the termination load. The two main differences to the setup described in [3] are the lubrication system and the firmly clamped and aligned ring specimen. Figure 1 illustrates a schematic representation of the used test setup.

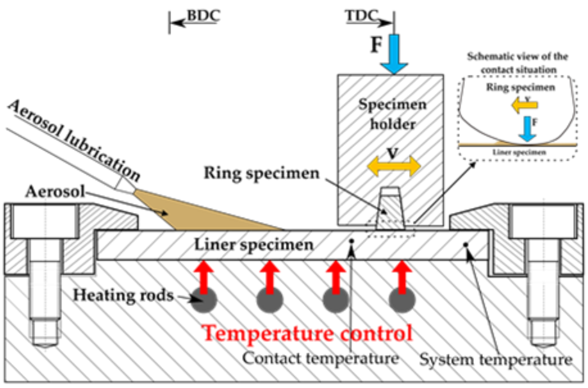

Figure 1: Schematic representation of the test setup

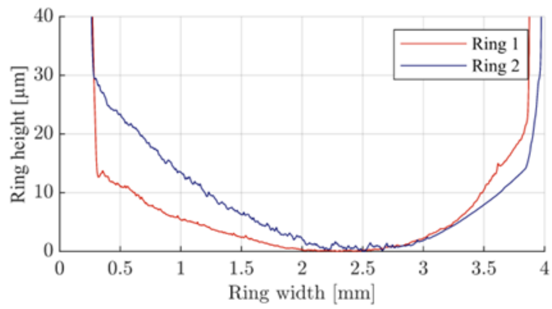

Figure 2: Rough ring profiles of two piston rings

By the use of an aerosol-based lubrication system steady lubrication rates can be applied in a wide range of 0.5 µl/min up to 100 µl/min. In particular, the low lubrication rates of a few µl/min typical of HDD engines make droplet lubrication systems, as realized by the use of pumps, unsuitable. The low flow rate can result in droplet formation, which in turn can lead to partial dry running of the contact and irregular lubrication conditions. This droplet formation can be avoided by the aerosol lubrication system.

The necessity for precise and fixed alignment of the ring specimen within the test setup is a consequence of the connection between the experiment and the simulation. Prior to each test run, each ring is precisely aligned within a measuring adapter, and the profile is measured with a tactile contour measuring device, Mahr© VD140. Figure 2 illustrates the profiles of two different rings with distinct coatings. These profiles are used in the corresponding simulation subsequent to each experimental test.

2.2 Simulation model

The simulation model developed in previous work of the authors [4] was used in this paper. In this simulation, a number of factors are considered, including hydrodynamic

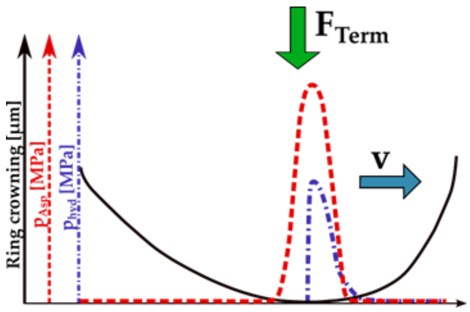

Figure 3: Schematic view of the contact situation

pressure according to the Reynolds equation, asperity contact force, and the total COF in the mixed friction regime. A mass-conserving cavitation model and a contact model based on Greenwood and Tripp are integrated. The simulation model is implemented in the open source Multiphysics software Netgen/NGSolve. As mentioned above, the profile of each ring used in a test was measured with the tactile contour meter. Consequently, the ring profile and the termination load from each test run were utilised as input parameters for the simulation.

The output parameter of the simulation is the asperity contact pressure p_{asp} occurring in the final load stage of the test. Accordingly, this parameter is primarily dependent on the termination load F_{Term} and the profile of the ring. Subsequently, the influence of the profile on the hydrodynamic properties is considered. This is implemented by the reduction of at p_{asp} higher hydrodynamic pressure in order to fulfill the force equilibrium $F_{Term} = F_{asp} + F_{hyd}$ In order to simulate the different hydrodynamic states occurring in the test setup due to the sinusoidal velocity course, 15 simulations were carried out with velocities between 0 m/s and 1.5 m/s. The respective asperity contact pressures were then averaged and displayed as a geometry-corrected test result. Figure 3 shows a schematic view of the contact situation in the simulation.

3. Results and Discussion

The substantial impact of the lubrication system on the COF is illustrated in Figure 4. The figure depicts sections of the COF of two tests with identical parameters, the sole distinction being the type of lubrication employed. The lubrication rate was 3 µl/min for both tests. It is evident that there is an alternating increase in COF with droplet lubrication. This phenomenon can be attributed to the formation of droplets of oil on the needle used for lubrication in this system.

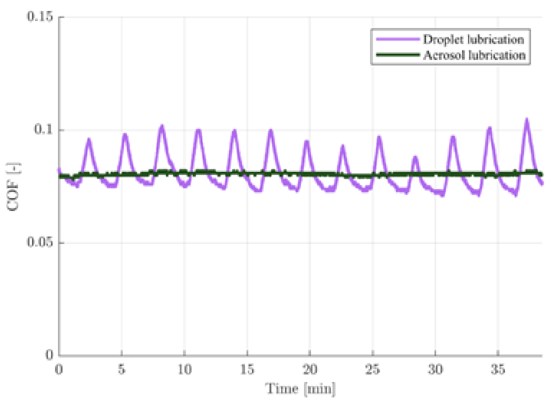

Figure 4: Comparison of the COF from Droplet and Aerosol lubrication systems

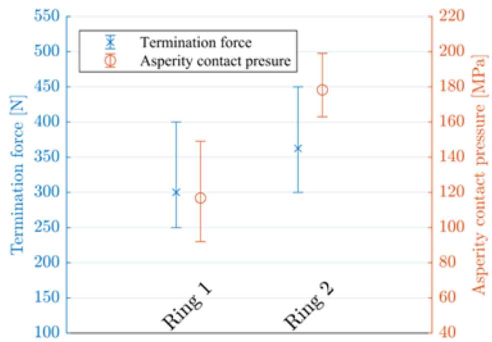

Figure 5: Comparison of the test results and the geometry corrected simulation **results**

The formation of these droplets is also discernible at significantly higher flow rates, but their significance only increases at lower flow rates. With the test parameters used, it takes approximately three minutes for a drop to detach from the needle and flow into the contact. This period is also evident in the course of the COF. The COF rises, a drop detaches, and consequently the COF falls again. Following a brief period, the oil supplied by the drop is no longer sufficient for adequate lubrication, resulting in a rise in the COF. This leads to a cyclical change in the lubrication condition in the contact, indicating that the scuffing stability with constant lubrication is not being tested. Instead, the dry running performance of the contact is being evaluated.

Figure 5 depicts the mean values and the error bars of the termination load and the asperity contact pressure of four tests for two different rings in each case. This indicates that the two rings had a very similar termination load. Furthermore, the maximum occurring test results overlap, which means that a clear ranking of the two rings is not possible. As previously stated, however, macro geometry is not considered in the experimental test procedure. The corrected asperity contact pressures from the simulations enable a clear differentiation between the two rings. Ring 2 has higher values, from which a higher scuffing limit can be derived.

Without the combined test and simulation methodology, the clear separation of test results and the resulting unambiguous ranking would not have been possible in this form. The experimental test methodology enables scuffing limits to be determined close to the application. By extending this with the help of the simulation methodology, insights of this contact can be made visible and analysed.

4. References

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