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Tribological study of crankshaft bearing systems: Comparison of forged steel and cast iron counterparts under start–stop operation

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The current work investigates the tribological functionality of crankshafts bearing systems focusing on the variation of shaft materials and their surface conditions. Tribological tests were carried out with a ring-on-disc test configuration representing the bearing-shaft contact under start–stop motion. Forged steel and cast iron shaft materials were sliding against an Al based bearing alloy. The surfaces in contact were analyzed by light and electron microscopy subsequently. The performance of forged steel depends on the overall roughness of the surface, whereas the tribological functionality of cast iron is mainly determined through its microstructure and the occurrence of metal flaps with burrs. The results prove the significance of proper surface finishing of forged steel and cast iron shaft materials in order to minimize wear in journal bearing systems. For both shaft materials good sliding performances with respect to optimized surface finishing can be noted.

1. Introduction

As we currently face increased requirements in automotive engineering concerning functionality, reliability, light weight design, fuel efficiency and economic feasibility technical engineers need to serve with novel and optimized engine components. High end journal bearing solutions in internal combustions engines need to be designed for ever growing load collectives comprising of higher pressure, temperature, start–stop movements and cost efficiency [1–3]. In order to meet the rising demands, tribological journal bearing systems comprising of sliding material combinations and lubricants need to be investigated and optimized accordingly. The use of start–stop techniques especially increases the operation time of journal bearings under boundary and mixed friction regimes. Hence, the journal bearing systems have to stand this shift in operation. Conventionally, the journal bearing system comprises a soft material such as aluminium or copper based alloy with overlays sliding against a shaft material. Crankshaft materials being part of crankshaft journal bearing systems have to cope with three basic requirements [1,4]:

- Mechanical properties,
- Sufficient tribological applicability,
- Cost effective manufacturing.

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The two most common types of crankshafts materials are cast iron and forged steel [1,3,5]. In general, cast iron shafts offer superior manufacturing properties compared to forged shafts. Besides, casted shafts are able to provide weight benefits up to 10% compared to forged shaft with same dimensions because of lower density [1,6]. However, technical engineers mostly associate high performance crank shaft bearing systems only with forged steel shafts sliding against the bearing material. This is in regard to their superior fatigue properties being a main driver in high loaded engine applications. However, mechanical properties of cast iron crankshafts can be loaded to that of forged steel [6]. The tribological functionality of forged steel and cast iron differs as well. According to [5] the seizure resistance of systems sliding against forged steel materials is about 2 times higher than that of systems sliding against cast iron. Especially in this regard not only the material selection itself but rather the surface conditions of the shaft materials play a key role as different surface finishing methods and roughness conditions affect the tribological processes. In this regard cast iron surfaces require highly tailored surface treatments [7]. The current study compares tribological systems using different shaft counterpart materials (34CrNiMo6 forged steel – GJS 700 casted iron) and variable surface roughness conditions of the shaft materials. The main investigation subjects of this study are emphasized below:

a. Firstly, the influence of the surface roughness has been investigated using same tribological systems consisting of bearing

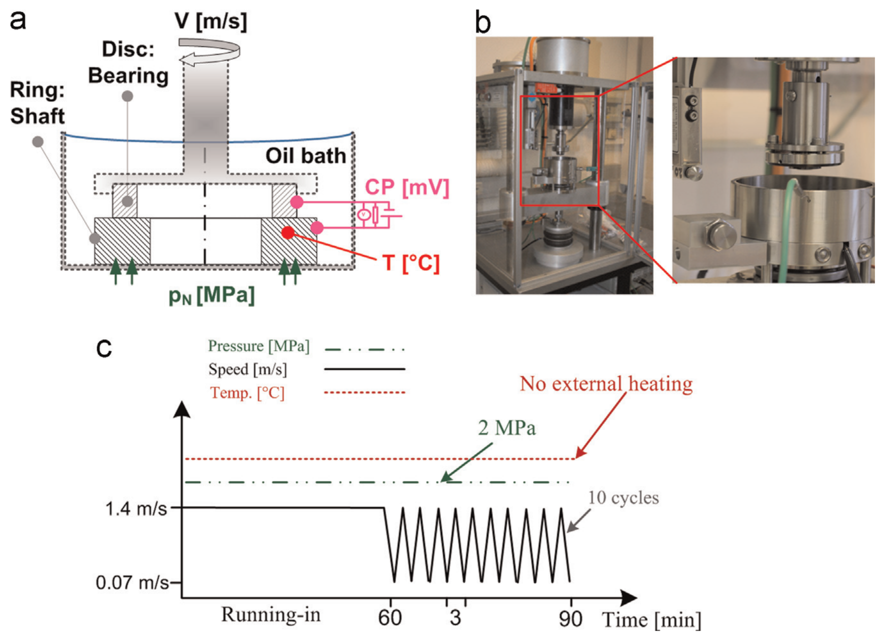

Fig. 1. (a) Test set-up "ring-on-disc", (b) implementation at TE92 test rig, (c) test strategy.

material, counterpart material and lubricant.

b. Secondly, the difference of the system performance using forged steel (34CrNiMo6) and casted iron (GJS) counterparts has been inquired.
c. Thirdly, the effect using special surface treatments on GJS counterparts has been studied.

2. Experimental procedure

2.1. Test methodology

This study based on damage equivalent tribological investigations by performing tribometric tests on a model scale and subsequent surface analysis. Lubricated tests were conducted by using a ring-on-disc (RoD) test configuration. In this experimental set-up, see Fig. 1a, the disc specimen, sliding against the fixed ring counterpart, represents the bearing material. The ring specimen is consisting of the shaft material. With this test configuration wear processes of journal bearing materials under mixed friction regime can be visualized [8,9]. The tribometric tests presented in this study have been carried out on a rotary tribometer test rig TE92 from Phoenix Tribology. Fig. 1b depicts the RoD test set up implemented at the TE92 test rig. The contact was oil-immersed during the whole testing procedure. The load was applied with air bellows. The response of the coefficient of friction (COF or μ), the temperature (T), the contact potential (CP) and the wear were recorded. The coefficient of friction is derived from torque measurement which can be seen in Fig. 1b. The temperature of the system was monitored with a thermocouple. The contact potential (CP) describing the electrical resistance in-between the contact offers information regarding the contact situation between the mating surfaces. High CP implicates isolating conditions between the surfaces thus more hydrodynamic friction parts or isolating boundary layer formation such as AW/EP tribofilms. Low CP indicates metallic contact. The wear of the softer bearing material was measured gravimetrically. Further details of the used test methodology are given in previous works of the authors [8–11].

2.2. Test strategy

In this study a Martens–Stribeck test program was performed simulating start–stop cycles. The test program is depicted in Fig. 1c schematically. After a running-in period of one hour at constant sliding speed of 1.4 m/s the speed was ramped up and down between 0.07 m/s and 1.4 m/s within 3 min for 10 times. The total numbers of start–stop ramps and the ramp duration were defined in order to visualize tribological processes going on under mixed friction regime. The applied normal load was kept constant at 2 MPa and the system was not externally heated. Thus, heat development is produced only due to friction energy dissipation. The tests were automatically stopped if a high COF above $\mu = 0.15$ was measured. The test data was acquired using a one second interval. The resulting output data of the speed ramps are plotted against the sliding speed resulting in Martens–Stribeck diagrams.

2.3. Analysis methodology

Pre- and post-test surface analysis was conducted with an Olympus BM51X light microscopy (LIMI), an Olympus LEXT OLS3000 laser confocal microscopy (LEXT) and a Zeiss MA15 scanning electron microscopy (SEM), aided by energy dispersive x-ray spectroscopy (EDX). SEM analysis was carried out at an acceleration voltage of 6 kV in order to image the top most surface. The acceleration voltage of 6 kV was also used for EDX measurements to minimize the depth of electron interaction within the specimen. The quantified EDX data in this study is given in atomic percentage (at%).

3. Materials tested

A conventional tri-metal bearing for high loaded engine applications according to [12] was used as constant bearing material in this study. The bearing specimens used in this study were provided by Miba Gleitlager GmbH. The manufacturing process of the bearing material was similar to journal bearing components. The bearing material is consisting of a Cu-based lining, a barrier interlayer and an AlSn20-sputtered overlay. Thus, functionality of the bearing is based on the sliding properties of