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On the influence of surface roughness on the wear behavior in the running-in phase in mixed-lubricated contacts with the finite element method

A. Albers, S. Reichert *

Karlsruhe Institute of Technology (KIT), IPEK – Institute of Product Engineering, Germany

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ABSTRACT

To determine the influence of the surface roughness on the friction and wear behavior, there are only limited experimental possibilities available. Due to the manufacturing process, the variation of the roughness also causes a change of the waviness and of the boundary layer of a surface. Thus, the roughness cannot be taken in isolation. It is therefore the objective of the present work to investigate the influence of the surface roughness on the running-in behavior with a numerical model, using the finite element method.

All calculations have been carried out with the finite element software ABAQUS in combination with the programming language PYTHON. They are based on a mixed-lubrication model, which was extended by a wear routine. This routine enables the calculation of local wear depths on both tribological partners in non-lubricated and lubricated regimes. For modelling the local wear depths, the surface nodes of the finite element mesh were adjusted by a modified wear law based on Archard. In first investigations, the influence of different manufacturing processes on the wear behavior was determined.

1. Introduction

To reduce the fuel consumption and the CO_2 emissions of vehicles, new innovative operating strategies like the start-stop system have been implemented in the automobile industry. Thereby, a problem is the stationarity of the oil in powertrain components in the stop phase. Due to the frequent and distinct static phases, the lubrication cannot always be kept in the tribological contacts. At every change from stop to start, the oil has to be transported into the lubrication gap again and mixed-lubrication occurrence increases. Due to the raised solid contact ratio, the machine elements wear faster. This is leading to an earlier operational failure. Therefore, journal bearings, piston rings, timing chains and other powertrain components have to be adapted and evolved [1]. In previous works, the surface roughness could be identified as decisive factor influencing the friction behavior [2–4]. Therefore the surface roughness has to be designed specifically in the development of tribological systems.

In the context of PGE - Product Generation Engineering by Albers et al. [5], this process is defined as a new development, based on the activity of embodiment variation. Thereby, the principle solution of the reference product remains and only the shape of the surface roughness is adapted. The newly developed share of a new product, in this case resulting from the embodiment variation, has to be verified and validated [5]. The validation can be implemented by virtual and physical approaches [6]. However, the isolated evaluation of the influence of surface roughness has not been possible yet in experimental tests. Due to different finishing and post-machining processes of the workpieces, the boundary layer and the waviness will be changed as well. As the validation is a central activity in product development [7] and there is no physical approach available, this work presents a virtual approach for the investigation of the influence of surface roughness of tribological systems. For this reason, the existing finite element model [2] is linked with a wear routine to enable a virtual verification.

The results obtained in this work contribute to extend the understanding of the influence of surface roughness on the wear and friction behavior. With this approach, the product engineer is also assisted in the preconditioning of tribological partners for designing resource-conserving machine elements. That means that the high wear rates in the running-in phase can be decreased and the durability increased. Therefore the wear behavior in the running-in phase is investigated in the present work in a detailed way.

2. State of the art

The empiric wear law by Archard is often used in numerical investigations for modelling different forms of wear with the finite

* Corresponding author.
E-mail address: stefan.reichert@kit.edu (S. Reichert).

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element method. A macroscopic wear coefficient defines the volume loss per load of a tribological system, at a constant load and sliding distance. In this section a survey about modelling different forms of wear, like fretting, rolling and sliding wear is given.

2.1. Fretting wear

Fretting wear is resulting from a small relative movement between two surfaces in contact. There are two different types of fretting: partial slip and gross sliding. If the normal load is very high or the oscillating amplitude is small, there are some areas in contact in stick regime and some others are sliding. In this case there is partial slip. If the normal load is decreased or the oscillating amplitude increased, the asperities are in a sliding regime and it is called gross sliding. McColl et al. [8] investigated the fretting wear in a cylinder-on-flat fretting configuration. The calculated and the measured wear profiles showed a good agreement. Yue et al. [9] modelled fretting wear with the wear law by Archard and implemented a varying coefficient of friction. With this method, he could improve the accordance of experiment and simulation.

2.2. Wear under sliding conditions

Bhattacharya [10] modelled wear on an artificial cervical disc in a non-lubricated regime. Ali [11] did the same investigation by the example of hip implant devices. Both of them neglected fluids in contact. Podra et al. [12] modelled a spherical pin-on-disc unlubricated steel contact with the linear wear law by Archard and the Euler integration scheme. It could be shown, that the FE-software ANSYS is well suited for wear simulations. Argatov et al. [13] indicated that the contact pressure is very important in determining the end of the running-in phase. This approach is a combination of the theory of elasticity in conjunction with Archard's law. Chmiel [14] investigated dry sliding wear of a slipper on a rail. Also the wear law by Archard was used. Furthermore, Chmiel created a PYTHON script to rectify mesh distortions. With this code, wear could also be applied in an explicit calculation method in ABAQUS.

2.3. Wear under rolling-sliding conditions

Khader et al. [15] used this approach for modelling wear in silicon nitride rolls in a rolling-sliding contact under dry conditions. The surfaces were ideally smooth and the experiments were conducted on a twin-disc tribometer. The results have shown that there was an acceptable accuracy. The simulations were carried out with ABAQUS and the subroutine UMESHMOTION. With this routine, the surface nodes could be moved by using the adaptive mesh method in ABAQUS for applying local wear depths. With this subroutine, applicable with implicit analysis methods only, wear could be modelled on one surface.

Hegadekatte et al. [16] developed a further method, predicting wear in rolling-sliding contacts. With the Global Incremental Wear Model he determined the pin wear on a pin-on-disc tribometer. For this approach he used the wear law by Sarkar [17]. Sarkar extended Archard's wear law by relating the friction coefficient to the volume of material loss. Model.

Ismail [18] investigated the running-in phase of a rolling contact of a rigid hemisphere on a rough surface. Above a certain load, a significant change in surface topology is observed. The observation was made that the running-in of rolling contacts takes place within the first few cycles.

Telliskivi [19] used the wear law by Archard for modelling wear of a disc-on-disc devise. Next to the good agreement between experiments and numerical investigations, a good agreement in regard to the form change of the rollers was achieved.

3. Model

The mixed-lubricated model by Reichert et al. [2] is extended by a wear routine, which enables the calculation of local wear depths for real technical surfaces. All calculations are carried out with the finite element software ABAQUS on the microscale. The wear routine is implemented with the programming language PYTHON and is therefore also available for explicit calculation methods.

3.1. Mixed lubrication model

The real technical surfaces are measured non-destructively with a white-light-interferometer and implemented into the finite element model. The waviness of the measured profile is eliminated, which ensures that only the surface roughness is taken into account.

The setting of the mixed-lubricated model is displayed in Fig. 1. The two rough bodies are arranged vertically. The fluid is between the contacting surfaces. The dimensions of the upper body are $225 \times 225 \times 80$ μm. The lower body is spatially fixed. In a first calculation step, the upper body is pressed against the lower body with a constant force (force-controlled) and in a second step displaced with a constant velocity (velocity-controlled). To guaranty a constant average contact pressure while displacing the upper body, the lower body is extended by 10 μm to a length of 235 μm. The solid bodies are meshed with linear hexahedron elements with an edge length of 2.5 μm in the contact area. The fluid part is also meshed with linear hexahedron elements with an edge length of 2.0 μm. The influence of the mesh density on the wear behavior is shown in the first result Section 4.1. The sliding of the asperities is influenced by a critical shear stress, which is implemented at the contact area for the solid-solid contact. This contact formulation corresponds to the tangential adhesion effects established by Bowden and Tabor [20] and is defined as a function of the yield stress σ of the softer material:

$$\tau_{krit}=\frac{\sigma}{\sqrt{3}} \tag{1}$$

The implementation of the critical shear stress is also temperature dependent. After calculating the nodal temperatures, the local shear stress is adapted by a user routine.

The upper body is connected via dashpot elements with a damping plate, to avoid vibrations in case of asperity contact of the two bodies. The fluid pressure can be varied. By the ratio between the adjusted normal load and the fluid pressure, the average lubrication gap can be defined.

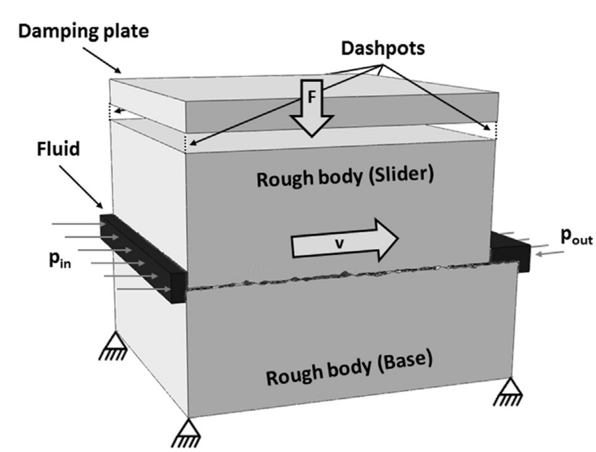

Fig. 1. Mixed-lubrication model.