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Fluid-structure-interaction coupling for elastohydrodynamic lubricated micro structured contacts

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Abstract

The reduction of friction coefficient plays a great positive role in many technical fields. In the past decades of research, a fine surface-structuring is often used to reduce friction. Research [1,2] has shown that the application of textures on the surface of the lubricated contacts will produce a higher film thickness and reduce the possibility of mixed lubrication. Micron size textures on the contact surface helps to reduce the friction coefficient. In the 21st century, with the improvement of computer capabilities, numerical simulation is entering the field of research of EHL (Elastohydrodynamic lubrication) problems in tribological contacts. In this work, the FSI (Fluid-structure-interaction) coupling method was used to numerically simulate EHL in ANSYS software. Through simulation analysis, it can be determined that due to the microstructure on the contact surface, the pressure at the entrance of the microstructure groove drops sharply, which will cause a suction effect at the entrance. Finally, the current knowledge and assumptions about the potential driving mechanism of surface micro-texture in tribology are summarized, and the future possibility of this work is proposed.

Keywords: sliding contact, tribology, fluid-structure-interaction coupling, microstructured surface, elastohydrodynamic lubrication, UDF File.

1 Introduction

The reduction of the coefficient of friction is of great importance for machine elements under relative motion. In addition to energy loss, wear due to friction can also shorten the life of mechanical devices. The general method for improving friction is lubrication. However, if the contact area lacks lubricating oil or if the oil pressure is insufficient, it is difficult to completely separate the contacting surfaces and achieve an ideal full-film lubrication process. The improvement of lubrication methods can be achieved through a variety of methods, such as the further development of lubricants and their additives, and surface micro-textures.

Since Hamilton et al. [1] discovered the effect of micro-surface unevenness in 1966, other scientists have conducted in-depth experiments in this area. Experiments by ETSION et al. [3] proved that a suitable microstructure can increase the lubrication gap by three times and reduce friction by more than half. Yu and Wang et al. [4,5] used different micro-textured surfaces to reduce friction and improve dynamic fluid pressure accumulation. Some microstructures have been proven to be suitable for reducing friction and have practical applications in the industrial field. For example, the microstructure on the inner wall of the cylinder of a combustion engine [6]. Also in case of rolling contacts micro textured surfaces (as shown in Fig. 1) can feature improved running behaviour [7]. This paper will analyse and discuss the lubrication effect of the surface texture and the pressure distribution during the EHL by numerical simulation. After entering the 21st century, there are more and more discussions not only on analysing through experiments, but also on numerical simulation with the help of powerful computer capabilities. Dariush [8], Sutthinan [9], Stefan [10], Hajishafiee [11], etc. use different software and methods to numerically simulate the frictional lubrication state of various surface roughness and microstructure in EHL problems, and obtain results such as pressure distribution and oil film thickness.

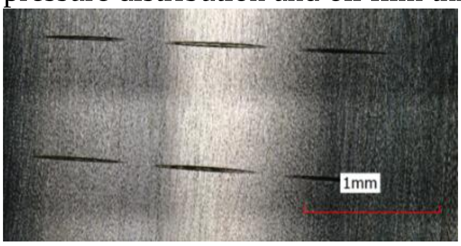

Figure 1: The exemplary shape of micro-textured surface an angular contact ball bearing inner ring [7]

2 Methods

In this paper, the FEA method (finite element analysis method) is used to establish the connection between the lubricating oil and the friction structure through the FSI coupling method with ANSYS. Under the action of the lubricant, the displacement or deformation of the structure and the flow of the lubricant in the microstructure on the surface must be taken into account. This is no longer a solution for a single physical field. In a multi-field phenomena, the interaction of physical fields plays a decisive role. The coupling method to analyse the interaction of fluid and structural deformation is called multiphysics coupling. FSI (Fluid-structure interaction) is a coupling method for multi-physics phenomena, which describes the laws of fluid dynamics and structural mechanics. When a flow comes into contact with a solid structure, stress distribution and strain occur in the solid structure. These forces can thereby deform the structure. The deformation of the structure also changes the state of the fluid domain (see Figure 2). The extent of deformation depends on the flow pressure, flow velocity and material properties of the structure. Out of consideration of simulation accuracy, the implicit method of two-way coupling is used in this study to take into account the influence from the deformation between a ball to a plate under relative motion [12].

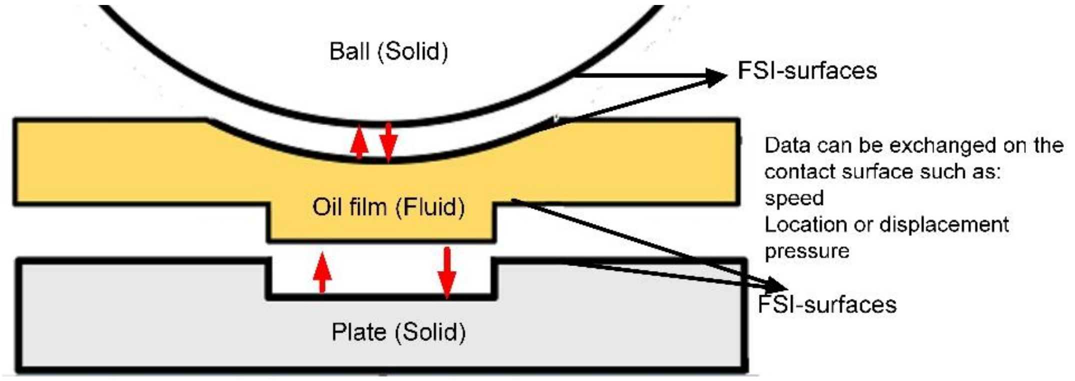

Figure 2: Schematic diagram of FSI coupling model.

For two-way coupling, the flow field must be converged in one step of the transient simulation to provide the force acting on the structure. After the force was transferred from the fluid mesh to the surface mesh of the structure by FSI, the structural dynamics under the force was also converged. The convergence result of structure is the displacement of the mesh nodes. The mesh displacement at the boundary between the structure and the flow is transferred to the fluid mesh to affect the flow field. This completes one iteration of the two-way coupling. These steps are repeated until both the fluid dynamics and the structural displacement satisfy the convergence conditions (e.g. convergence of residuals). Then the simulation continues with the next time step [13].

3 Results

Based on the Hertzian contact pressure theory [14] in EHL, the relationship between lubricant viscosity and pressure [15], the relationship between density and pressure [16], and the complete cavitation model [17], the state of lubricating oil is solved by the Navier-Stokes equations in Fluent. The contact and elastic deformation of the ball bearing is solved in transient structure. The model and mesh are shown in Fig. 3. The data exchange of each simulation step is completed by the FSI method for coupling.
Fig. 4 shows the pressure with a peak of up to 0.5 GPa at the contact zone between the ball and a structured surface. The dimple has a width of 20 µm and a depth of 5 µm. In comparison the pressure distribution of the lubricating oil in the model for a smooth contact surface reaches 0.77 GPa. The pressure peaks at the velocity outlet because the elastic deformation produces a spike at this location, which narrows the lubricating oil outlet. On the surface of the micro-texture, there is a pressure drop at the entrance of the groove, which can cause the suction effect of the entrance. This will help the groove store more lubricant. The pressure distribution of the groove as a

whole is constant, and pressure protrusions appear at the edge of the outlet. Smaller dimples with a depth of 2 µm feature increased pressure of 0.86 GPa.

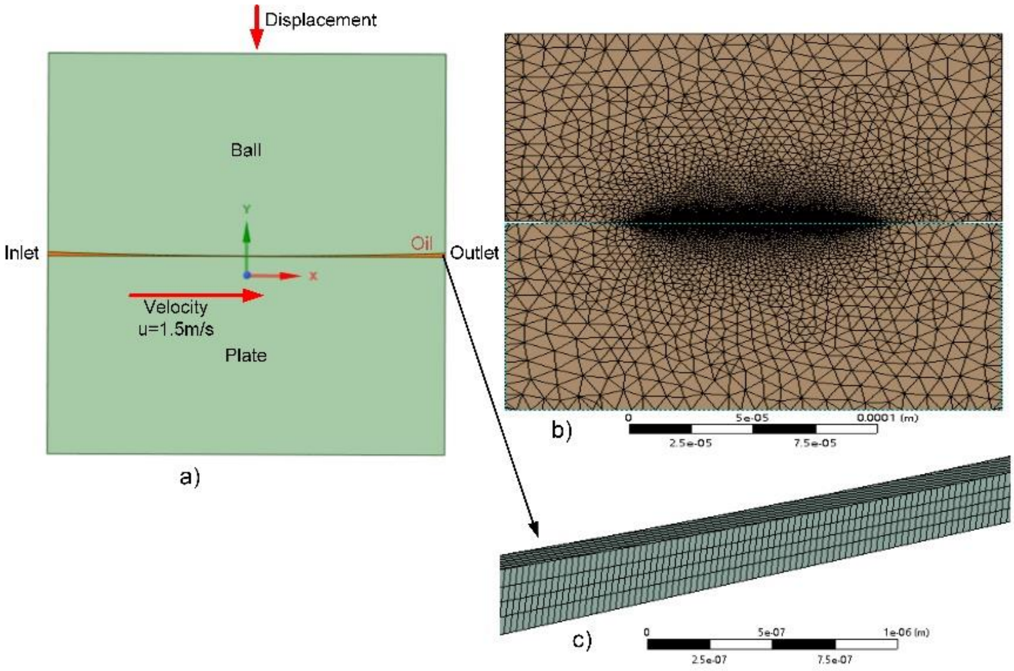

Figure 3: Used model in simulations; a) 2.5D model; b) The fixed structure with tetrahedral mesh; c) The lubricating oil film with a hexahedron network.

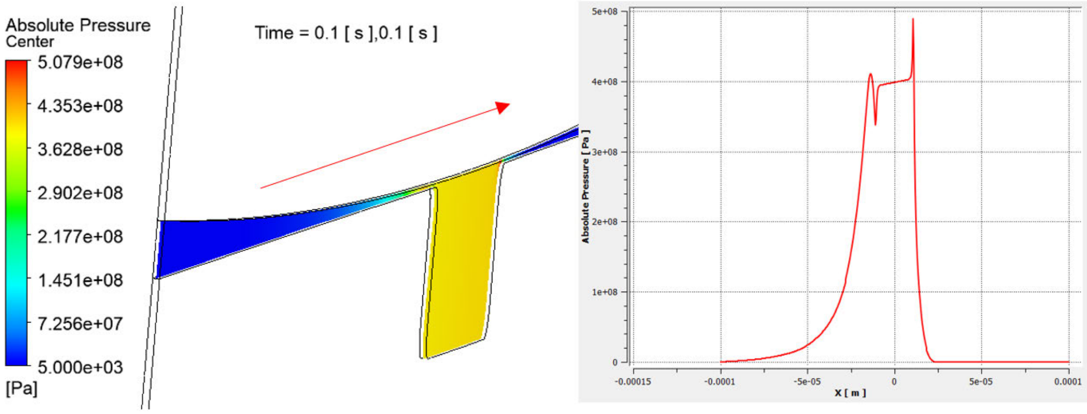

Figure 4: Numerical results of the simulations with u = 1.5 m / s: pressure distribution in sliding contact with microstructure (5 µm depth).

4 Conclusions and Contributions

This work uses an FSI coupling method for numerical simulation. This model is implemented through system coupling in the ANSYS software. The implementation of the two-way coupling finite volume method and an efficient numerical algorithm ensures that the models of different structures remain stable under different conditions. The deformation of the contact body and a contact pressure of more than 0.7 GPa are obtained by simulation. Cavitation in the lubrication is solved by using a homogeneous equilibrium cavitation model. The simulation results of the CFD (Computational fluid dynamics) method are compared with the model of the existing EHL model based on the Reynolds method, which verifies the elastic properties and the relationship between viscosity and pressure. This illustrates the overall stability and functionality of the model and is suitable for actual EHL contacting. At high sliding speeds (except the mixed friction) it could be shown that a positive pressure build-up can be determined for small pockets. A comparison with analytical calculations is carried out and the calculation using the FSI coupling method is reliable.

One problem is that the load of the EHL problem in this simulation will not be balanced, but a fixed downward displacement is used to squeeze the lubricating oil. This challenge can be solved by UDF (User defined function) files in future work. The pressure and contact area of each step are integrated, and then balanced with the target load in that step, and finally the target load is reached at the end of the simulation.

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