THU-T1-S13-R4

7th World Tribology Congress, WTC 2022
July 10-15, 2022, Lyon, France

Thermal modelling strategies for TEHL of line contacts using CFD-FSI

Peyman Havaej [1], Joris Degroote [2, 3], Dieter Fauconnier [1, 3*]

[1)] Soete Laboratory, Department of Electromechanical, Systems & Metal Engineering, Faculty of Engineering and Architecture, Ghent University, Technologiepark 903, 9052 Zwijnaarde, Belgium
[2)] STFES, Department of Electromechanical, Systems & Metal Engineering, Faculty of Engineering and Architecture, Ghent University, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium
[3)] Flanders Make @ UGent – Core Lab EEDT-MP
*Corresponding author: dieter.fauconnier@ugent.be

This study focuses on thermal modelling in Thermo-Elastohydrodynamic lubrication (TEHL) for bearing and gear contacts using a 2D CFD-FSI method in OpenFOAM. Two different approaches and thermal boundary conditions for the solid bodies are investigated and evaluated. First, the equivalent linear elastic half-space conjunction for TEHL is considered, imposing Carslaw-Jaeger boundary condition, as classically done in TEHL modelling using e.g. Reynolds-Boussinesq method. Second, two linear elastic bodies are considered, using a conjugate heat transfer model. Results show that Carslaw-Jaeger boundary condition using the equivalent geometry overestimates the temperature profile at the contact; hence, film thickness and shear stress are underestimated.

Keywords (from 3 to 5 max): Thermo-Elastohydrodynamic Lubrication (TEHL), Computational Fluid Dynamics (CFD), Fluid-Structure Interaction (FSI), Carslaw-Jaeger, Conjugate heat transfer.

1. Introduction

Elastohydrodynamic lubrication (EHL) is a typical lubrication regime for non-conformal rolling-sliding bearing and gear contacts. Under optimal lubrication conditions, both surfaces are separated by a very thin lubricant film, in which the hydrodynamic lubricant pressure raises so high that it induces elastic deformation of the surfaces. In the case of high-loaded contacts and higher shear rates (e.g. slippage), proper prediction of the contact temperature becomes key to assess the film thicknesses and pressure distributions correctly, as the temperature and shear rates largely influence all thermomechanical properties of the lubricant. In addition, also the heat transfer through the lubricant film and the contacting bodies greatly influences the contact temperature. In this work, proper modelling of the contact and the heat transfer through the solids is under investigation.

2. Methods

2.1. Basic model description

Classically TEHL is modelled using Reynolds-Boussinesq equations, supplemented with a temperature equation for solid and/or fluid heat transfer. Following, e.g. [1], a 2D CFD model is developed in OpenFOAM to simulate TEHL with increased accuracy for the thermal modelling, though at a higher computational cost. The linear elastic solid and compressible fluid models are solved in a two-way partitioned fluid-structure interaction (FSI) coupling algorithm. The solid is modelled as a linear, homogeneous isotropic material using the Navier-Cauchy equation. For the fluid side, the full set of Navier-Stokes equations is solved. Cavitation in the diverging region is taken into account by a Homogenous Equilibrium model (HEM). Appropriate constitutive models are adopted to describe the thermomechanical behavior of the lubricant and the solids. The Tait equation of state, the Doolittle viscosity model for temperature-pressure dependency, and shifted Carreau shear-thinning models are employed in this study as constitutive models for the lubricant. Squalane is selected as the lubricant of interest; the properties are given in [2].

2.2. Thermal Modelling

First, the classical TEHL approach is followed, in which an equivalent TEHL contact geometry is considered, which consists of an equivalent roller on a half-space, on which Carslaw-Jaeger boundary condition are imposed.

$$T_{Cars} = \sqrt{\frac{1}{\pi \rho_s C_s K_s U_s}} \int_{-\infty}^{x} q_f(\hat{x}) \frac{d\hat{x}}{\sqrt{x-\hat{x}}} \quad (1)$$

In the second approach, two linear elastic bodies are modelled separately, and the conjugate heat transfer (CHT) model is applied at the fluid/solid thermal interface.

$$\rho_s C_s \frac{\partial T}{\partial t} + \dot{v_s}.\nabla T = \nabla \cdot (k_s \nabla T) \quad (2)$$

Both strategies will be assessed against each other.

3. Results

Two surfaces with radii of curvature of 5.35mm and 22.05mm exposed to an external load of 124kN/m rotating with entrainment velocity of 2.26m/s and slide-to-roll ratio SRR=1.26 have been considered here. Film thickness, pressure, shear stress, and heat flux profiles are shown in Figure 1.

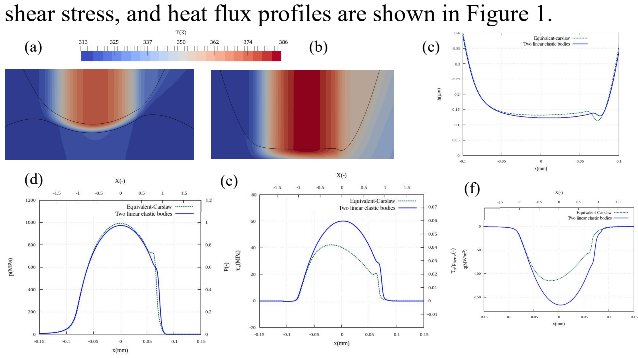

Figure 1: temperature profile for a) two linear elastic bodies, b) equivalent geometry, c) film thickness, b) pressure profile, e) shear stress at the interface, f) heat flux at the lower body.

The film thickness profiles show a slight deviation of 7.1% and 6.3% for central and minimum film thickness. However, the pressure field is almost identical. The shear stress at the upper and lower bodies is significantly different. The maximum shear stress and coefficient of friction for the equivalent geometry are 33% and 31.5% lower in contrast to the two-body approach, respectively. The difference in heat flux at the lower body is the main source of the observed difference in the results predicted by these two approaches. The Carslaw-Jaeger thermal boundary condition imposes a lower rate of heat over the subjected surface, and then the heat is not evacuated as it is in the CHT model. Hence, the temperature increases for the equivalent cases using the Carslaw-Jaeger boundary condition, influencing all thermomechanical properties and the contact conditions.

4. Conclusion

It was observed that using equivalent geometry in half-space with the well-known Carslaw-Jaeger boundary conditions leads to overestimating the lubricant temperature at the contact and underestimating friction compared to the case that the real geometry with conjugate heat transfer model was used. Hence, viscosity, film thickness and shear stress were underestimated.

5. References

[1] M. Hartinger, M.-L. Dumont, S. Ioannides, D. Gosman, and H. Spikes, “CFD modeling of a thermal and shear-thinning elastohydrodynamic line contact,” *J. Tribol.*, vol. 130, no. 4, p. 41503, 2008.

[2] S. Bair, “Reference liquids for quantitative elastohydrodynamics: selection and rheological characterization,” *Tribol. Lett.*, vol. 22, no. 2, pp. 197–206, 2006.