ROUGHNESS AMPLITUDE REDUCTION UNDER NON-NEWTONIAN EHL CONDITIONS

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ABSTRACT

The influence of surface roughness on the performance of bearings and gears operating under ElastoHydrodynamic Lubrication (EHL) conditions has become increasingly important over the last decade, as the average film thickness decreased due to various influences. Surface features can reduce the minimum film thickness and thus increase the wear. They can also increase the temperature and the pressure fluctuations, which directly affect the component life. In order to describe the roughness geometry inside an EHL contact, the amplitude reduction of harmonic waviness has been studied over the last ten years. This theory currently allows a quantitative prediction of the waviness amplitude and includes the influence of wavelength and contact operating conditions. However, the model assumes a Newtonian behaviour of the lubricant. The current paper makes a first contribution to the extension of the roughness amplitude reduction for EHL point contacts including non-Newtonian effects.

INTRODUCTION

In classical Newtonian ElastoHydrodynamic Lubrication (EHL), it is common to consider that the film thickness is determined by the conditions at the entrance of the contact. Inside the conjunction, the pressure is so high that the flow reduces to a Couette flow. Over the last decade, the Newtonian behaviour has been successfully used to predict the deformed roughness geometry. Nevertheless, the use of a Newtonian model leads to a large overestimation of the friction coefficient. Many papers have described the non-linear lubricant response. For instance see Johnson and Tevaarwerk and their classical paper published in 1977 [1].

In the present paper, the non-Newtonian lubricant model of Johnson and Tevaarwerk is used. The general Contact Mechanics equations and the numerical techniques are outlined. Numerical results for pressure and film thickness for isotropic harmonic roughness passing through a circular EHL contact are shown. Finally, the amplitude reduction of an isotropic harmonic pattern using the Ree-Eyring model is studied and compared with the one obtained using the traditional Newtonian model with the Roelands pressure-viscosity relation.

1 THEORETICAL BACKGROUND

A significant amount of friction is generated in EHL contacts, hence the shear stress is usually large and the non-linear viscous flow dominates the strain rate in the lubricant film. For this reason, the elastic part of the lubricant behaviour can be neglected. Thus, the behaviour can be modelled by the following equation:

\[ \dot{\gamma} = \frac{\tau_0}{\eta} \sinh \left( \frac{\tau_e}{\tau_0} \right) \]  

(1)

The Reynolds equation becomes:

\[ \frac{\partial}{\partial X} \left( \frac{3}{\lambda \eta} \frac{\partial P}{\partial X} \right) + \frac{\partial}{\partial Y} \left( \frac{3}{\lambda \eta} \frac{\partial P}{\partial Y} \right) - \frac{\partial (\rho H)}{\partial X} - \frac{\partial (\rho H)}{\partial T} = 0 \]  

(2)
where \( \bar{\eta}_x \) and \( \bar{\eta}_y \) denote the effective viscosities along the X- and Y-axis.

2 NUMERICAL RESULTS

2.1 Numerical solution

The equations were discretised on a uniform grid with second order accuracy in space and time. Classical solution of the system of equations is very time consuming. To accelerate the numerical process MultiLevel techniques were used for the Reynolds equation. For the computation of the elastic integral, a MultiLevel MultiIntegration (MLMI) algorithm was used. For more details the reader is referred to Venner and Lubrecht [2].

2.2 Amplitude Reduction Curve

The amplitude reduction of a harmonic pattern is studied as a function of the initial roughness parameters and the operating conditions \( M, L, S \) and \( \tau_0 \). The results are shown as \( A_d/A_i \), where \( A_d \) denotes the deformed roughness and \( A_i \) the initial roughness amplitude. For a Newtonian case, the amplitude reduction depends only on the conditions in the inlet region. However, this definition has to be changed for the non-Newtonian case. Figure 1 shows an example of the amplitude reduction of an isotropic harmonic waviness as a function of the operating conditions and the location in the central zone of the contact. One can observe that the amplitude reduction for Newtonian behaviour indeed is almost constant along the X-axis except near the inlet and the outlet of the high-pressure zone. Concerning the non-Newtonian behaviour the amplitude reduction increases (the deformed amplitude increases) compared to the Newtonian case.

2.3 Generalized Amplitude Reduction Curve

The amplitude reduction theory can be extended to include the non-Newtonian lubricant behaviour. Thus, one can generalize the amplitude reduction for all operating conditions and isotropic roughness characteristics using a dimensionless parameter \( \bar{\bar{V}} \) (Figure 2). The expression of \( \bar{\bar{V}} \) is:

\[
\bar{\bar{V}} = \bar{V}(1 - e^{-\kappa})
\]

where \( \bar{V} \) is the dimensionless parameter used in the Newtonian theory [3] and \( \kappa \) is a decay function of \( M, L, \lambda/b, \tau_0 \) and \( S \). For large values of \( \alpha, \tau_0 \) or \( \lambda/b, \bar{\bar{V}} \to \bar{V} \) and one finds the Newtonian parameter.

2.4 Amplitude Reduction in X direction

The amplitude reduction in the rolling direction can be approximated using the Newtonian \( A_d/A_i \) ratio. The obtained amplitude reduction is very close to the non-Newtonian results shown on Figure 1.

\[
A_{d,\text{nyr}} = A_i - (A_i - A_{d,\text{newt}})e^{-\kappa(X+1)}
\]

CONCLUSION

The amplitude reduction of an isotropic harmonic pattern and a non-Newtonian lubricant behaviour can be predicted by the new set of dimensionless parameters, which extend the existing Newtonian parameters.

REFERENCES