A Novel Approach for the Implementation of Non-Newtonian Fluids in EHL-Simulations – Derivation and Benchmarks

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In elastohydrodynamic lubrication (EHL) simulations, the Reynolds equation describes the hydrodynamic within tribological contacts for Newtonian fluids. However, many lubricants exhibit non-Newtonian behavior and thus require an extension of the Reynolds equation. This paper proposes a novel solution approach based on the generalized Reynolds equation as derived by Dowson and Yang and a semi-analytical calculation of the velocity distribution. This approach is benchmarked against two other approaches for a grease-lubricated reciprocating pneumatic seal.

Keywords: EHL simulation, Herschel-Bulkley fluid, lubrication, Reynolds equation, tribology

1. Introduction

In elastohydrodynamic lubrication (EHL) simulations the Reynolds equation is used to calculate the hydrodynamic pressure of a thin Newtonian lubricant film. However, many tribological contacts, such as gears or pneumatic valves, are lubricated with greases, which show non-Newtonian behavior like viscoplasticity and shear thinning. Their rheology can be described more appropriately by non-Newtonian material models such as the Herschel-Bulkley model [1]. For these fluid models, a modified Reynolds equation has to be used.

2. Methods

2.1. Solution Approaches

There are multiple approaches for applying the Reynolds equation to non-Newtonian fluid models. The easiest approach is to approximate the non-Newtonian fluid by a Newtonian fluid with a constant viscosity along the film height. Both Dowson [2] and Yang [3] proposed more accurate approaches introducing additional coefficients to the Reynolds equation. These coefficients are obtained by integrating the viscosity over the film height.

2.2. Calculation of the Viscosity

Due to the nonlinearity of non-Newtonian models, the coefficients cannot be obtained analytically. Therefore, they are typically calculated numerically by introducing an additional discretization along the film height. This paper introduces a semi-analytical solution method for calculating the coefficients of the generalized Reynolds-equation by Yang. This approach provides the exact mass flow and does not need an additional discretization along the film height. Thus, it saves computation time and avoids additional discretization errors.

2.3. Benchmark cases

The proposed approach is evaluated and benchmarked against two other methods regarding accuracy and computational efficiency. For that, friction and pressure distribution of a Herschel-Bulkley fluid within a grease lubricated sealing contact are calculated, see Figure 1.

3. Results

The comparison between the proposed approach and the approximations shows that there are considerable differences between the new approach and the approximations. Especially for high pressure gradients and low relative velocities, the new approach provides better accuracy than the approximated methods.

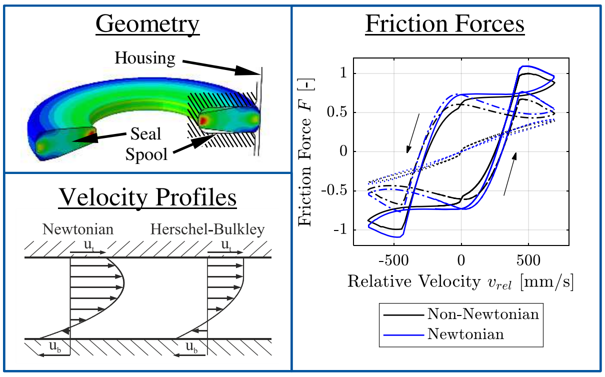

Figure 1: Investigated geometry, velocity profiles and calculated friction forces depending on chosen model.

4. Discussion

The differences between the new approach and the approximation can be attributed to the neglection of pressure induced shear rates. For typical greases, this leads to an underestimation of lubricant flow and an error when calculating the friction force. Based on these results, an error estimation as a function of the operating conditions is provided for the approximated models. With this estimation, it can be decided, whether an approximated approach is sufficiently accurate for a given operating condition or whether the proposed computationally more expensive solution with the exact mass flow needs to be used.

5. References

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