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FINITE ELEMENT MODELLING OF ELASTOHYDRODYNAMIC LUBRICATION IN THE FINITE DEFORMATION REGIME

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1. Introduction

In a variety of tribological systems, hydrodynamic lubrication is coupled with the large deformation of one or both contacting bodies. Contact problems of this kind are called soft elastohydrodynamic lubrication (soft-EHL) problems, and can be applied to analysis of elastomeric seals, various biotribological systems, and others.

In the modelling of hydrodynamic lubrication, the necessity to properly incorporate the cavitation phenomenon poses difficulties because the cavitation boundary is a part of the solution (free-boundary problem). The problem appears even more demanding if severe nonlinearities due to elastohydrodynamic coupling are additionally included. Fully coupled formulation for this class of problems, suitable for monolithical solution scheme in a FE framework, has been recently developed in [1, 2]. However, the analysis was only limited to two dimensional case, and the simple penalty method was used to enforce the mass-conservation condition only in approximate manner, see [3] for more detailed discussion.

2. Finite element treatment of the model

In this work, a mixed, two-field formulation of the mass-conserving cavitation model is developed, which is equivalent to the classical JFO theory. The two-field formulation is preserved is the consistently derived weak form, and is expressed in terms of the hydrodynamic pressure and a complementary variable λ related to the lubricant density. The corresponding complementarity condition is enforced using a non-smooth constraint function. This approach is similar to the augmented Lagrangian method [4] and primal-dual active set strategy [5]. The final discretized problem is solved for both variables in a monolythic scheme, using a semi-smooth Newton method.

3. Numerical examples

Several examples have been analyzed within this work. The convergence behavior and other properties of the proposed method have been checked, with the use of simple two-dimensional benchmark tests, cf. e.g., Fig. 1.

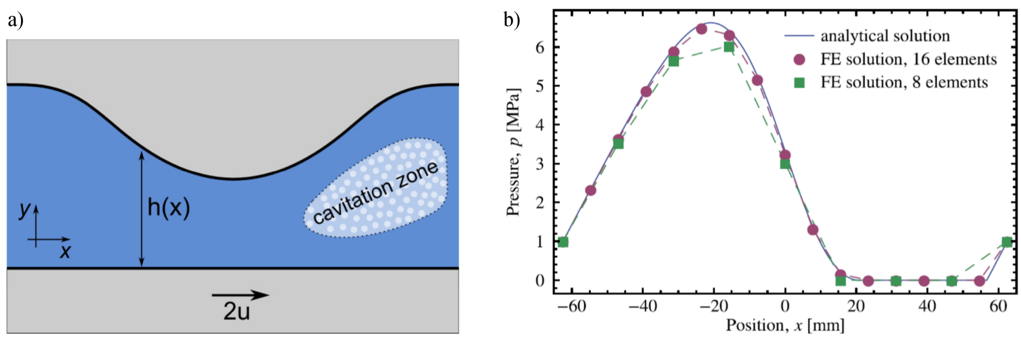

Fig. 1. EHL problem: a) 2D schematic and b) pressure field for simple 2D benchmark test.

One computationally demanding three-dimensional soft-EHL problem has also been analyzed, in which a hyperelastic ball is slid over a rigid flat. The proposed model proved to be suitable for a particular mesh refinement technique (hanging-node technique) used in the zones of high pressure gradients. The distribution of the lubricant film thickness, contact pressure, and void fraction in the cavitation zone is shown in Fig. 2. A characteristic ridge, seen in the film-thickness plots, i.e., Figs. 2a and 3a, is in a qualitative agreement with experimental observations, e.g., [6]. The analysis of the overall friction coefficient, for different velocities and different loads, cf. Fig. 3b, shows the effect of drop of the friction coefficient with increasing load.

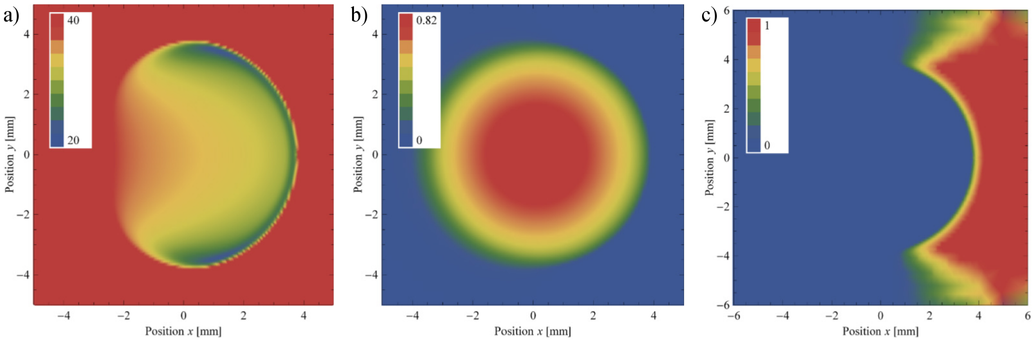

Fig. 2. Maps of: a) film thickness h [μm], b) pressure p [MPa], and c) complementary variable λ, obtained for $u = 400$ mm/s. In Fig. c, the region of $\lambda > 0$ constitutes the cavitation zone.

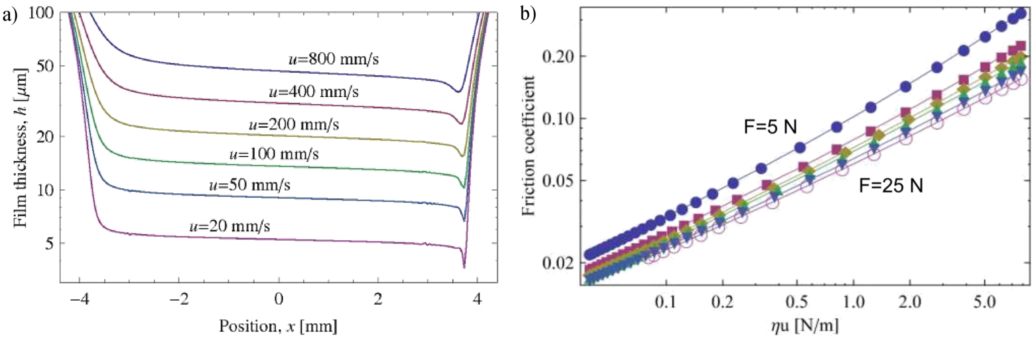

Fig. 3. 3D soft-EHL problem: a) film thickness at $y = 0$ cross-section for load $F = 13$ N for different velocities u, and b) friction coefficient for different velocities and different normal loads.

References

1. S. Stupkiewicz, A. Marciniszyn (2009). Elastohydrodynamic lubrication and finite configuration changes in reciprocating elastomeric seals, *Tribol. Int.*, **42**, 615–627.
2. S. Stupkiewicz (2009). Finite element treatment of soft elastohydrodynamic lubrication problems in the finite deformation regime, *Comp. Mech.*, **44**, 605–619.
3. J. Lengiewicz, M. Wichrowski, S. Stupkiewicz (2014). Mixed formulation and finite element treatment of the mass-conserving cavitation model, *Tribol. Int.*, **72**, 143–155.
4. P. Alart, A. Curnier (1991). A mixed formulation for frictional contact problems prone to Newton like solution methods, *Comp. Meth. Appl. Mech. Engng.*, **92**, 353–375.
5. M. Hintermueller, K. Ito, K. Kunisch (2003). The primal-dual active set strategy as a semismooth Newton method, *SIAM J. Optim.*, **13**, 865–888.
6. L. Mourier, D. Mazuyer, A.A. Lubrecht, C. Donnet (2006). Transient increase of film thickness in micro-textured EHL contacts, *Tribol. Int.*, **39**, 1745–1756.