Computational modelling and optimization of surface texturing in lubricated contacts

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Motivation

Plain journal bearings and linear slider bearings ideally operate in so-called full hydrodynamic lubrication regime. This implies, the opposing surfaces – which are in relative motion to each other – are fully separated due to the hydrodynamic pressure build-up in the thin lubricant film in between them. However, for a given target load, the thin lubricant film in such bearings is only sustained on condition of sufficiently high relative speeds of the surfaces and/or a sufficiently high lubricant viscosity. If these conditions re not met, direct contact between the surfaces occurs, which results in a dramatic increase of friction and wear. On the other hand, too high lubricant viscosities increase the frictional losses and heat generation in the lubricated contact, affecting as such the energy efficiency, while potentially degrading the lubricant quality.

Within the context of sustainable, durable and energy efficient machine design, adequate lubrication plays an extremely important role. Biodegradable, natural and ecological lubricants such as vegetable oils or water-solutions for application in aqueous environments, will become increasingly more important in the near future. The main drawback of many eco-friendly lubricants, and especially water, is their low viscosity leading to reduced load carrying capacity of the thin film.

In recent years, surface texturing of lubricated contacts has gained interest as a promising technique to increase the load carrying capacity of the lubricant film while maintaining - or even reducing - the frictional losses. However, it has been shown that the correct positioning and geometrical properties such as shape, orientation, dimensions of the texturing are crucial characteristics and are determinative for the success in terms of load-bearing capacity increase and friction reduction. Moreover, the optimal parameters highly depend on the operating conditions, which implies that proper design of surface texturing should be tailor-made to each individual application. Due to the high costs of manufacturing textured surfaces, most often, numerical simulations are carried out in order to find the optimal parameters for the texture geometry.

Objectives

The global aim of the project is the development of an efficient, accurate and reliable computational framework which enables to determine the optimal surface topography in thin film lubricated contacts, by minimizing e.g. viscous friction and maximizing the load-bearing capacity for a given lubricant and operating conditions. Three objectives are defined:

1. Development, implementation and validation of a comprehensive 3D Computational Fluid Dynamics model coupled to an efficient optimization algorithm.

2. Detailed analysis of the lubrication-mechanisms which occur in optimally textured hydrodynamically lubricated contacts to understand the physics that determine the success of the optimal texture.

3. Multi-scale parametrization and global optimization of the general surface topology, including surface texturing, waviness or roughness.

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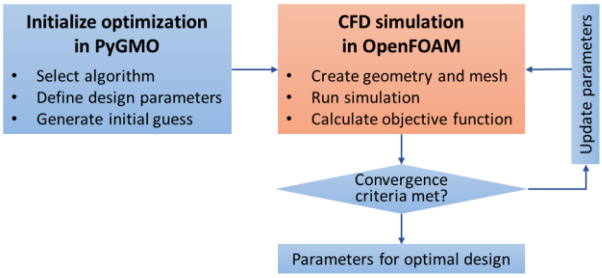

Figure 1 Flowchart of the optimization procedure

Approach

For the simulation of thin film lubrication in textured contacts, a 3D parallelized Computational Fluid Dynamics model is built in OpenFOAM, which relies on solving the classic Navier-Stokes equations in combination with a temperature equation for modelling heat transfer and its effect on the lubricant properties, such as viscosity and density. In order to account for the effects of gaseous and vaporous cavitation, a solver based on the homogeneous mixture model is selected.

In this work we aim at multi-objective optimization of any surface texture, i.e. maximize the load bearing capacity while minimizing friction. For the optimization of the surface textures the PyGMO optimization toolkit in Python is adopted, as it offers a wide range of local and global optimization algorithms, enables multi-objective and constrained optimization, and allows parallel computation.

Local methods are most often gradient-based techniques, e.g. Conjugate-Gradient Method or Least Squares Quadratic Programming. They start from one initial design point and tend to converge rapidly towards the local optimum at reasonable computational costs however, they do not guarantee global optimization.

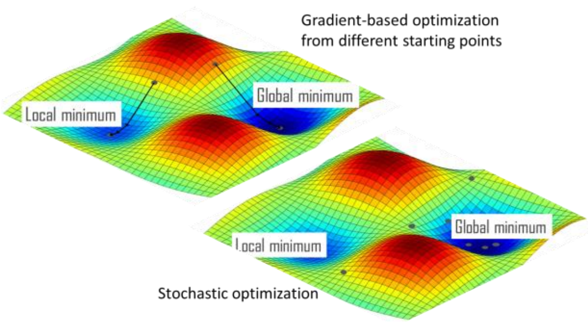

Figure 2 Local vs global optimization

Global methods, e.g. Differential Evolution, Particle Swarm Optimization, are stochastic algorithms which rely on quasi-random exploration of the design space starting from an initial set of design points. They succeed in determining the global optimum but they are liable to slow convergence around local optima. Several local and global optimization methods are studied and compared in terms of accuracy and computational time. Moreover, also hybrid techniques combining a local and global algorithms are studied in order to exploit the strength of the two types of methods.

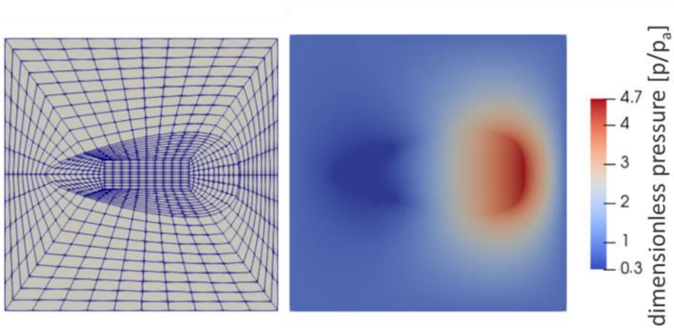

Figure 3 Pressure distribution over the top surface of the optimized dimple

Once the global framework is set up, the optimal design of textures will be found using an appropriate algorithm. Finally, a sensitivity study of the texture parameters around the optimum will be performed, allowing a Pareto analysis. Changes of performance in terms of load-bearing capacity, and frictional losses will be investigated when the parameters deviate from the optimum.

Finally, a multi-modal parametrization of the surface topology will be developed. The surface topology will be described by either global Fourier decomposition or either a variable height of all surface grid nodes within a region of interest. Such methods offer great flexibility in contrast to predefined texture shapes and offer the ability to explore more natural and flexible multi-scale surface topologies, leading to valuable information concerning the optimal surface roughness. The ultimate goal is to obtain novel advantageous texturing shapes for optimal design.

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