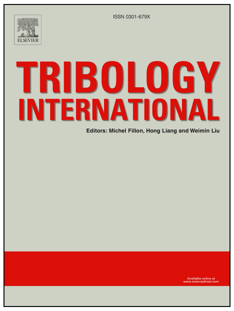
Accepted Manuscript



An effective Navier-Stokes model for the simulation of textured surface lubrication

Michael Rom, Siegfried Müller

PII: S0301-679X(18)30198-1
DOI: 10.1016/j.triboint.2018.04.011
Reference: JTRI 5190

To appear in: *Tribology International*

Received Date: 7 February 2018
Revised Date: 6 April 2018
Accepted Date: 10 April 2018

Please cite this article as: Rom M, Müller S, An effective Navier-Stokes model for the simulation of textured surface lubrication, *Tribology International* (2018), doi: 10.1016/j.triboint.2018.04.011.

An effective Navier-Stokes model for the simulation of textured surface lubrication

Michael Rom[a,*], Siegfried Müller[a]

[a] *Institut für Geometrie und Praktische Mathematik (IGPM), RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany*

Abstract

For a wide range of applications in the context of textured surface lubrication, both the Reynolds equation and the Stokes system are not valid. When it comes to flows with high velocities and surfaces with deep textures of moderate length, the Navier-Stokes equations have to be solved instead. For this kind of applications, a new effective model is presented which is derived from an upscaling technique applied to the incompressible Navier-Stokes equations. It provides more accurate results than the Reynolds or Stokes problem. In addition, the computational cost compared with solving the Navier-Stokes system is reduced significantly. Numerical results for two- and three-dimensional test cases demonstrate the accuracy and efficiency of the approach.

Keywords: surface texture, hydrodynamic lubrication, numerical analysis, journal bearing

---

1. Introduction

Whenever tribological optimization of surfaces is investigated, textured surfaces can be considered to improve the hydrodynamic performance, for instance by reducing friction. Many experimental and theoretical works have demonstrated the potential of texturing, e.g., [1, 2, 3, 4, 5]. Since the microscale effects induced by the textures are not fully understood yet, textured surface lubrication is an open research field [6]. For a particular application, it is usually not clear in advance how to choose the texturing for an optimal result. There is a large number of parameters influencing the fluid behavior, e.g., the geometry (shape, length, width, height) or the distribution of the textures but also the operating conditions. Hence, numerical investigations usually require a large number of simulations, often with highly resolved computational meshes, leading to the demand of fast and accurate solution schemes.

The Reynolds lubrication equation [7] can be used for the numerical investigation of fluid film lubrication between two surfaces. It is derived from the Navier-Stokes equations by assuming a negligible pressure variation over the small fluid film thickness and by neglecting inertia forces. These assumptions lead to a reduction of the spatial dimension by one. Furthermore, the resulting Reynolds equation is linear. Hence, solving the Reynolds equation is much less expensive than solving the nonlinear Navier-Stokes equations. When rough or textured surfaces are considered, a further reduction of the computational effort can be achieved by applying averaging techniques such as the *average flow model* by Patir and Cheng [8] or the mathematical concept of homogenization, see for instance [9, 10], instead of resolving the microscale effects with very fine computational meshes. In the approach by Patir and Cheng, shear and pressure flow factors are computed on the microscale, characterizing the differences between the flow behavior of rough and smooth surfaces. Subsequently, the macroscale behavior can be resolved using these flow factors. The homogenization approach, which is similar, in addition allows for capturing microscale effects. However, it was shown in numerous studies that the Reynolds equation and, hence, also the averaged models are not valid for many relevant applications involving textured surfaces, see for instance [11, 12, 13]. In particular, deep textures lead to recirculation of the flow in the textures, and high flow velocities induce inertia effects. Both phenomena cannot be captured by the Reynolds equation, resulting in the computation of inaccurate pressure distributions. The Stokes system is recommended for applications with deep textures but also fails for high flow velocities [6].

Based on the average flow model by Patir and Cheng, many extensions were implemented, especially to account for surface contact [14] or cavitation [15]. However, approaches for improving the validity regarding recirculation or inertia effects are rare: de Kraker et al. presented a *texture averaged Reynolds equation* [16, 17] for which they modified the approach by Patir and Cheng by solving the Navier-Stokes equations instead of the Reynolds equation on the microscale. This allows for capturing recirculation and inertia effects on the microscale and leads to an adjustment of the flow factors for the macroscale computation. To the authors' knowledge, there has never been an evaluation of the method by a full simulation study to find out whether a substantial improvement of the validity compared with the average flow model by Patir and Cheng can be obtained. Instead, de Kraker et al. only compared

---

[*] Corresponding author