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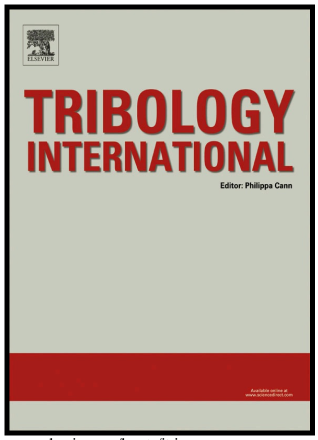

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The lubrication approximation of the friction force for the simulation of measured surfaces

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Abstract

Models of the friction force are assessed by direct comparison with two-dimensional Navier-Stokes results. A three-term formula obtained from asymptotic expansion provides a reasonable estimate of the hydrodynamic friction of rough runners even at sub-micron clearances.

Simulations of a measured honed surface are then reported using the conservative time-dependent Elrod-Adams model with spatial resolutions as fine as 0.25 μm per cell (4000×800 mesh). Mesh convergence of the numerical method is observed. Cell sizes between 0.5 μm and 1 μm appear as a reasonable compromise of accuracy and cost for the simulation of honed runners. The significance of each term of the friction formula is discussed, so as to assess the error involved in neglecting terms of the friction formula.

Keywords: Hydrodynamic lubrication; Friction force; Measured-surface simulation; Mass-conservative model; Honed surface.

1 Introduction

Theoretical and numerical studies of lubricated devices often represent the contacting surfaces as smooth. While this approximation stands under some conditions, this is not the case when the film thickness is comparable to the roughness amplitude, as in heavily loaded journal bearings, seals, piston ring/cylinder liner contacts, among others. The introduction of surface roughness into lubrication models can be traced back to the stochastic model of Tzeng and Saibel [1]. In their work, a probability distribution is adopted for the surface roughness and formulas of the expected values of pressure, friction force and load-carrying capacity are deduced for a one-dimensional problem. A more encompassing model was given by Christensen [2], who presented a modified (stochastic) Reynolds equation in which the coefficients were expected values. These results were limited to transverse or longitudinally oriented variations in roughness.

Later, Patir and Cheng [3, 4] introduced a new approach. An average Reynolds equation for rough surfaces was defined in terms of pressure and shear flow factors, which were empirical functions of the non-dimensional roughness. Elrod [5] later extended this model to account for roughness anisotropy.

All of these techniques are based on the intuitive idea of decoupling the global length scale, corresponding to the whole bearing, from the local length scale of the roughness. Homogenization theory formalizes this intuition. It develops an average equation valid throughout the domain, with its coefficients computed from solutions of local problems. The homogenization method has been studied in depth both for incompressible ([6, 7]) and compressible ([8, 9, 10]) fluids. It exhibits good accuracy when the roughness is periodic in space and its period is much smaller than the bearing size. Unfortunately, no rigorous homogenization model considers general roughness shapes with cavitation effects.

A current trend is to study the hydrodynamics of lubrication devices resolving all scales of the problem down to the roughness scale, using the measured topography and without resorting to averaged or stochastic models. These so-called *deterministic* or *measured-surface* simulations [11, 12, 13, 14] avoid ambiguities in the definition of average coefficients at the expense of solving Reynolds equation with a discretization finer than the resolution of the measurements. A central result of the simulations is the