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Finite Element Method for Starved Hydrodynamic Lubrication with Film Separation and Free Surface Effects

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Abstract

This paper proposes a numerical method for determining the evolution of lubricant film thickness and pressure in partially and fully flooded regions of a hydrodynamic contact between two non-conformal rigid surfaces. The proposed method accounts for the classical Reynolds equation within the fully flooded region and for film separation with surface tension driven flow in the partially flooded region, while at the same time it resolves the a priori unknown boundary between the two regions. Additionally it deals with transitions between wetted, partially flooded regions to dry regions, where the film thickness is zero. Both pressure and film thickness fields are considered as unknowns to solve for in each time step and they are approximated through quadratic B-spline finite elements. The geometry of the gap between the rigid surfaces delimiting the lubricant is accounted for in the form of a unilateral contact condition. Appropriate complementarity conditions with respect to separation or no penetration and no slip between the lubricant and the rigid surfaces are enforced by means of a weighted residual formulation.

Keywords: hydrodynamic lubrication, surface tension, partial flooding, B-spline finite element

1 Introduction

The thin film and laminar flow approximate of the Navier-Stokes equations, known as Reynolds equation (Reynolds, 1886), is regarded as the fundamental equation of hydrodynamic lubrication. Hydrodynamic lubrication along with its extensions to deformable solids and thermal phenomena is relevant for a multitude of important engineering applications, which justify the extensive effort put into deriving robust and efficient numerical models based on Reynolds equation. With the treatment of fully flooded regions of a hydrodynamic contact, either with the original or with the generalized version of Reynolds equation (Dowson, 1962), being in the meanwhile rather straightforward, most of the relatively recent research efforts in this field deal with the transition to and the flow inside partially flooded regions.

In standard terminology, a fully flooded region of a hydrodynamic contact is also denoted as a pressurized zone, while partially flooded regions are normally referred to as starved or

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