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THE ACCURACY OF ANALYTICAL MODELS FOR SQUEEZE OF RIGID SPHERES ON HIGHLY COMPRESSIBLE POROUS LAYERS IMBIBED WITH LIQUIDS

BY

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Abstract:

Fluid flow through highly compressible porous layers (HCPL) subjected to external loads is known as ex-poro-hydrodynamic (XPHD) lubrication. Several models have been proposed for squeeze in XPHD conditions and analytical solutions were obtained based on a significant number of simplifications. Consequently, an analysis of these simplifications effects is necessary to define the limits of applicability of the analytical solutions and the corresponding degree of approximation. The present study investigates the accuracy of these approximations by comparison with numerical solution of modified Reynolds equation based on finite difference method. The analysis is developed for sphere/plane configuration in two loading cases: constant force loading and impact loading, respectively. It is found that for almost all loading conditions and a large range of dimensionless parameters the two term approximation produces acceptable errors with respect to the exact solution.

Key words: hydrodynamic lubrication, porous layer, squeeze, spherical contacts, numerical solution

1. Introduction

Fluid flow through extremely compressible porous layers (HCPL) subjected to external loads is known as ex-poro-hydrodynamic lubrication [1, 2]. This lubrication process has been recently analyzed in parallel by the lubrication research team led by Professor M. D. Pascovici from Politehnica University of Bucharest and by Professor's Weinbaum research team from City College of New York.

The diversity of configurations, as well as the variety of possible applications, have made theoretical and experimental studies related to XPHD lubrication to grow in number and magnitude in recent years. Previous studies analyzed the XPHD lubrication for different pairs with tangential motion (wedge effect) or normal motion (squeeze effect). For each of these pairs various possible configurations were considered as: inclined slider or parallel step slider in the case of sliding motion and plane/plane, cylinder/plane or sphere/plane contacts in the case of normal motion, respectively. The studies of squeeze processes (normal motion) considered both constant velocity motion and motion with variable velocity by loading the mobile part with a constant force or by impact.

Theoretical studies published until present are characterized by simple modelling approaches leading to analytical solutions that enable the development of elegant parametric analyses. These studies [1-7] highlighted the main dependencies between the functional and dimensional parameters and the HCPL properties. The elastic compression forces generated by the solid matrix of HCPL were considered to be negligible compared to the hydrodynamic forces.

Several models have been proposed for squeeze in XPHD conditions and analytical solutions were obtained based on a significant number of simplifications. Consequently, an analysis of the effects of these simplifications is necessary to define the limits of applicability of the analytical solutions and the corresponding degree of approximation.

The present work is intended to be a first step in this direction and aims to investigate the accuracy of these approximations by comparison with numerical solution of modified Reynolds equation based on finite difference method. The analysis is developed for sphere/plane configuration in two loading cases: constant force loading and impact loading, respectively.

2. The model

For the sake of clarity the analyzed model is briefly reproduced in this chapter from [3-5]. The configuration of a normal squeeze of the imbibed HCPL laid on a fixed rigid support by a rigid sphere is presented in Fig. 1.

Assumptions applied in previous papers [2-7] will be considered for the present study:

1. The pressure across the layer thickness is constant and the liquid flow is described by Darcy law [8].
2. The elastic forces of HCPL are negligible compared to the liquid flow resistance [1, 9].
3. The HCPL permeability variation is correlated with compacticity according to Kozeny-Carman law [2-8]:

$$\phi = \frac{D(1-\sigma)^3}{\sigma^2} = \frac{D\varepsilon^3}{(1-\varepsilon)^2} \tag{1}$$