Friction Force of the Sliding Surface with Pores Having a Semicircular Cross Section Form

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ABSTRACT

A theoretical solution of the mathematical model is represented for obtaining the hydrodynamic pressure and friction force of the non-contacting sliding surfaces with pores having a semicircular cross section form. The expressions for the hydrodynamic pressure, shear stress, and friction force were obtained for a control cell that includes the inside and outside of the pore areas. The pore radii have been studied in the range from 0.5μm to about 18 μm. The parametric study of the pore performance is obtained with the specially written MATLAB program used the theoretically defined expressions. It is found that better performance in terms of positive hydrodynamic pressure and optimal friction forces can be achieved with proper selection of pore and outside of pore sizes. Better hydrodynamic pressures were observed at the gap-pore radii and cell-pore radii ratios range between 0.5 … 1 and 2.5 … 5, respectively. The maximal friction forces are achieved at pore radii values about 0.64 of the cell dimensions, which correspond to a r1 range of about 5 … 13 μm.

KEYWORDS

Cross Section Form, Friction Force, Hydrodynamic Pressure, Pores, Semicircular Pore Profile

1. INTRODUCTION

Sliding surface structure has been the object of study for a long time. In such investigations, the surface has been expressed by waves, grooves, or pores. Waved surfaces have been studied by Salama, 1952, Tonder and Christensen, 1972, Etsion, 1980, and Burstein, 2007, 2008, 2009, 2010, 2011, 2015. Surfaces with microgrooves have been studied by Hamilton, Walwit, and Allen, 1969 and Lai, 1994. Pored surfaces have been studied by Salama 1952, Anno, Walovitz and Allen, 1968, Etsion and Burstein, 1996, and Burstein and Ingman, 1999, 2000. In these studies, it has been demonstrated theoretically that the texture of the surfaces strongly influences the hydrodynamic pressure in the lubricating film separating the surfaces. Experimental studies in this direction have been reported by Etsion et al., 1999, 2004, 2004, Ryk et al., 2002, and Kligerman et al., 2005.

There are also stochastics methods, firstly described by Patir and Cheng (1978) for the hydrodynamic lubrication of the rough surfaces. The models of this direction cannot characterize adequately the local details such as the pressure fluctuations, the local film thickness, etc. and in addition, this method do not describe surfaces with pores. Therefore, the deterministic methods are used.

Reported studies demonstrate the importance of the surface geometry, its parameters for the design of rubbing mechanical parts: seals, pistons, piston rings, and other items with surfaces separated by a lubricant and in relative motion. Most studies show that one of the most perspective and realizable texturing forms is the pore. In this connection, it is important to have theoretically
grounded relations for calculating the hydrodynamic pressure in the lubricating film to reduce wear and increase machine service life. Etsion and Burstein (1996) studied surfaces with hemispherical pores and presented a numerical solution of two-dimensional Reynolds equations. The theoretical solutions of the two-dimensional Reynolds equations for cylindrical, exponential and semicircle pores, Burstein (1998, 1999, 2015), then appeared. Most of the theoretical works are dedicated to obtaining the hydrodynamic pressure and/or the load support expressions, with only a small number expressing the friction force. In the investigations where the friction force expressions were obtained, they ignore the pressure gradient in lubricating film and/or received by the numerical or experimental data, Etsion and Burstein (1996), Ronen, Etsion and Krigerman (2001), Razzaque and Faisal (2007), Menon, Anil and Kulkarni (2015). There are no theoretical studies regarding the friction force of the semicircle pore. Thus, the aim of the paper is to consider theoretical expression for pressure gradient and pressure distribution and on this basis define the theoretical friction force expression for the semicircular pore.

2. PHYSICAL MODEL AND GOVERNMENT EQUATIONS

Assume that the pores are arranged regularly (Fig.1,a) and the distance $2r_1$ between pores is sufficiently large so that the interaction between the pores can be neglected. Therefore, only one pore with the adjoining part, called the control cell, should be studied. A cross-section of the control cell on the sliding surface and opposite non-porous surface is shown in Fig.1b; each pore has radius $r_0$; the gap between surfaces equals $h_0$; and the direction of the friction force is opposite to the lower surface motion.

The shear $\tau$ and friction force $f$ for Newtonian fluid between parallel surfaces in one-dimensional interpretation are:

$$\tau = \mu \left( \frac{\partial u}{\partial z} \right)_{Z=h}$$  \hspace{1cm} (1)

$$f = 2r_1 \int_{-h}^{h} \tau dx$$  \hspace{1cm} (2)

Substituting the following dimensionless parameters into the above equations, $X=x/l_{r_1}$, $Z=z/r_0$, $H=h/r_0$, $U=u/u_0$, $\xi=r/r_0$, $\bar{\tau} = \tau h_0 / (\mu u_0)$, the dimensionless shear and friction force equations can be deduced.

$$\bar{\tau} = \left( \frac{\partial U}{\partial Z} \right)_{Z=H}$$  \hspace{1cm} (3)

$$F = \int_{-\xi}^{\xi} \bar{\tau} dX$$  \hspace{1cm} (4)

where the lubricant velocity at the sliding surface can be defined with the following dimensionless equation...
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