Numerical Model of Hydrodynamic Lubrication

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Abstract

Numerical model of hydrodynamic lubrication under a thin liquid film approximation is presented in this study. Hydrodynamic lubrication is obtained between two surfaces in relative motion completely separated by a cohesive film or lubricant. In order to simulate hydrodynamic lubrication, the Reynolds lubrication equation is used. Finite Area Method, a surface counterpart of the Finite Volume Method, is used to discretize the Reynolds lubrication equation over a curved surface mesh. Numerical model is implemented in OpenFOAM and validated by calculating hydrodynamic lubrication process in journal bearings.

1. Introduction

Lubrication is a process or technique employed to reduce friction between surfaces in close proximity and moving relative to each other, by interposing a substance called a lubricant between them. Lubricants can be in solid (graphite, lead), liquid (oil, water) or gaseous (air) state. Also, they can exist as solid-liquid or liquid-liquid dispersions.
Classification of lubrication regimes done by *Wilson (1979)* determines local regime by the ratio of the lubricant film thickness and total surface roughness.

$$z = \frac{h}{\sqrt{R_{q1}^2 + R_{q2}^2}},$$

where R_{q1} and R_{q2} are surface roughnesses of surfaces in motion.
In the full film hydrodynamic lubrication regime surfaces are completely separated by the lubricant. Here, thick film ($z > 10$) and thin film regime ($3 < z < 10$) are distinguished. In thick film regime smooth surfaces are assumed, while in thin film, asperities significantly influence the lubrication flow.
In the mixed lubrication regime ($1 < z < 3$), part of the pressure load is carried by asperities, while the rest of the load is carried by pressurized lubricant in the valleys.
In the boundary lubrication regime ($z < 1$) major part of contact is direct contact between surfaces. A lubricant film exists, but its chemical composition is different from the bulk lubricant.
In order to simulate the full film hydrodynamic lubrication regime, Reynolds lubrication equation is solved on a curved surface mesh.

2. Mathematical Model

Reynolds equation is a differential equation governing the pressure distribution in fluid film lubrication. Assuming incompressible, steady-state flow with rigid surfaces, the lubrication Reynolds equation is simplified to:

$$\nabla_s \cdot \left(\frac{\rho h^3}{12\eta} \cdot \nabla_s p \right) = \frac{\rho \mathbf{U}}{2} \cdot \nabla_s h$$

Finite Area Method, a surface counterpart of the Finite Volume Method, is used to discretize the simplified equation over a curved surface mesh.

3. Analytical Solutions

Sommerfeld (1904), using special boundary conditions, gave analytical solutions to simplified cases of Reynolds equation, which include infinitely-wide journal bearing solution:

$$p = \frac{\eta \, \omega_b \, r_b^2}{c^2} \cdot \frac{6\epsilon \sin\phi (2 + \epsilon \cos\phi)}{(2 + \epsilon^2)(1 + \epsilon \cos\phi)^2} + p_0$$

DuBois and Ocvirk (1953) gave an approximate analytical solution that takes into account the side leakage, enabling the calculation of pressure in short-width journal bearings:

$$p = \frac{3\eta \, \omega_b \, \epsilon}{c^2} \left(\frac{B^2}{4} - z^2 \right) \frac{\sin\phi}{(1 + \epsilon \cos\phi)^3} + p_0$$

4. Infinitely-Wide Journal Bearing

Hydrodynamic lubrication in an infinitely-wide journal bearing is simulated. Case is considered 1D in the Finite Area discretization. Bearing dimensions and lubricant properties are taken from *Mane and Soni (2013)*. Fig. 1 shows lubricant thickness and pressure distribution across journal bearing at eccentricity ratio ϵ = 0.5. Fig. 2 shows the comparison between analytically and numerically calculated pressure distribution for three different mesh resolutions. With increasing mesh resolution, the error between the analytical and numerical results is reduced. Fig. 3 depicts comparison of pressure distributions at different eccentricity ratios.

Figure 1: Lubricant thickness and pressure distribution at ϵ = 0.5

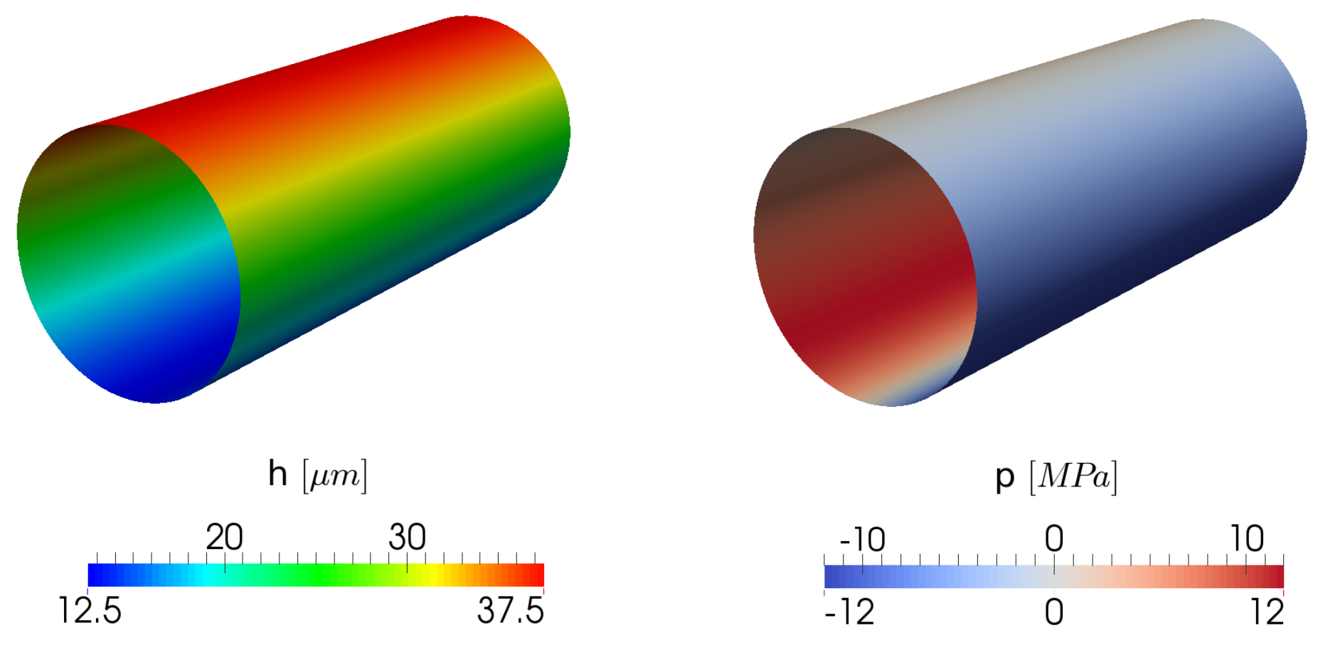


Figure 2: Comparison of analytically and numerically calculated pressure for three different mesh resolutions at ϵ = 0.5

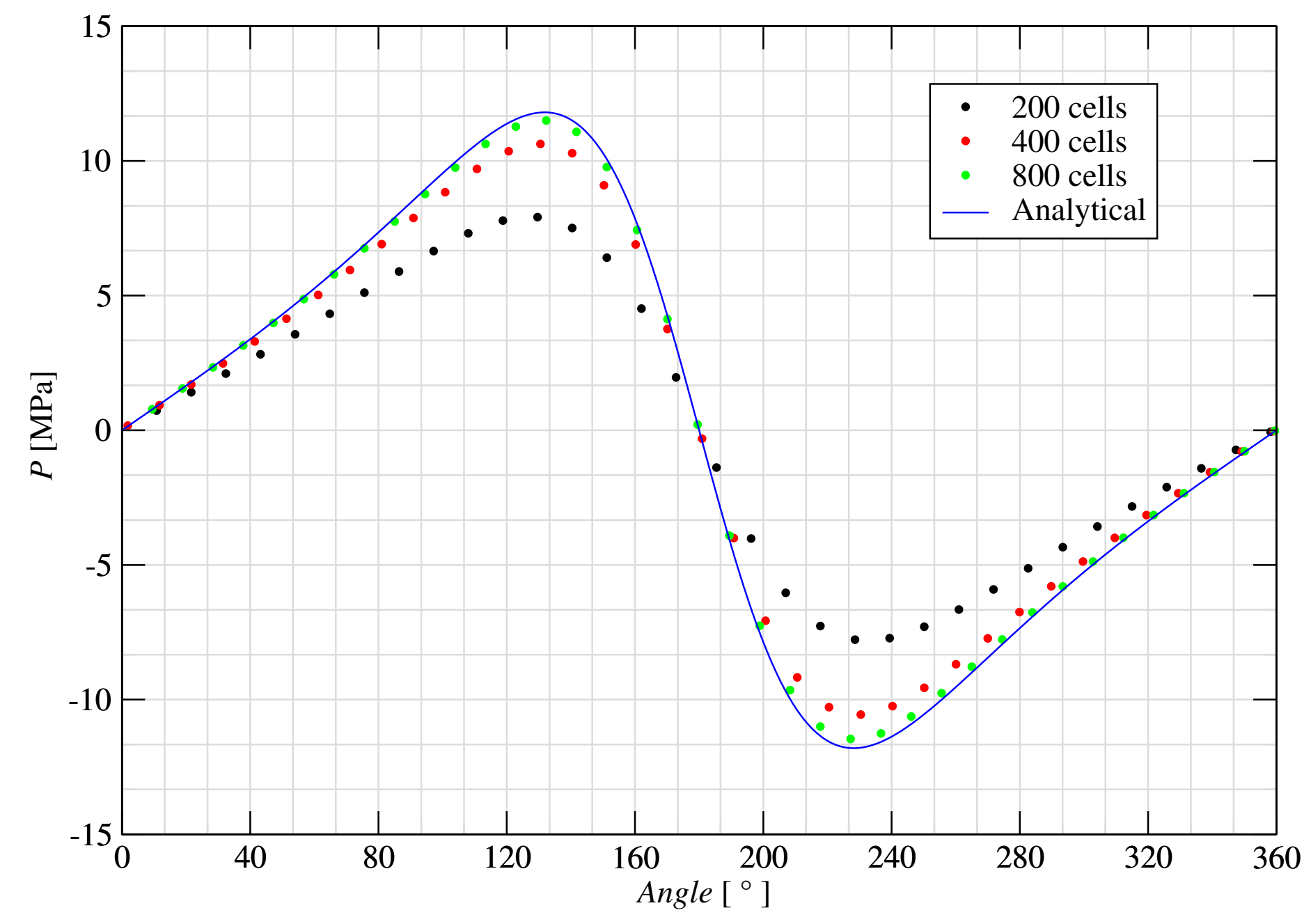
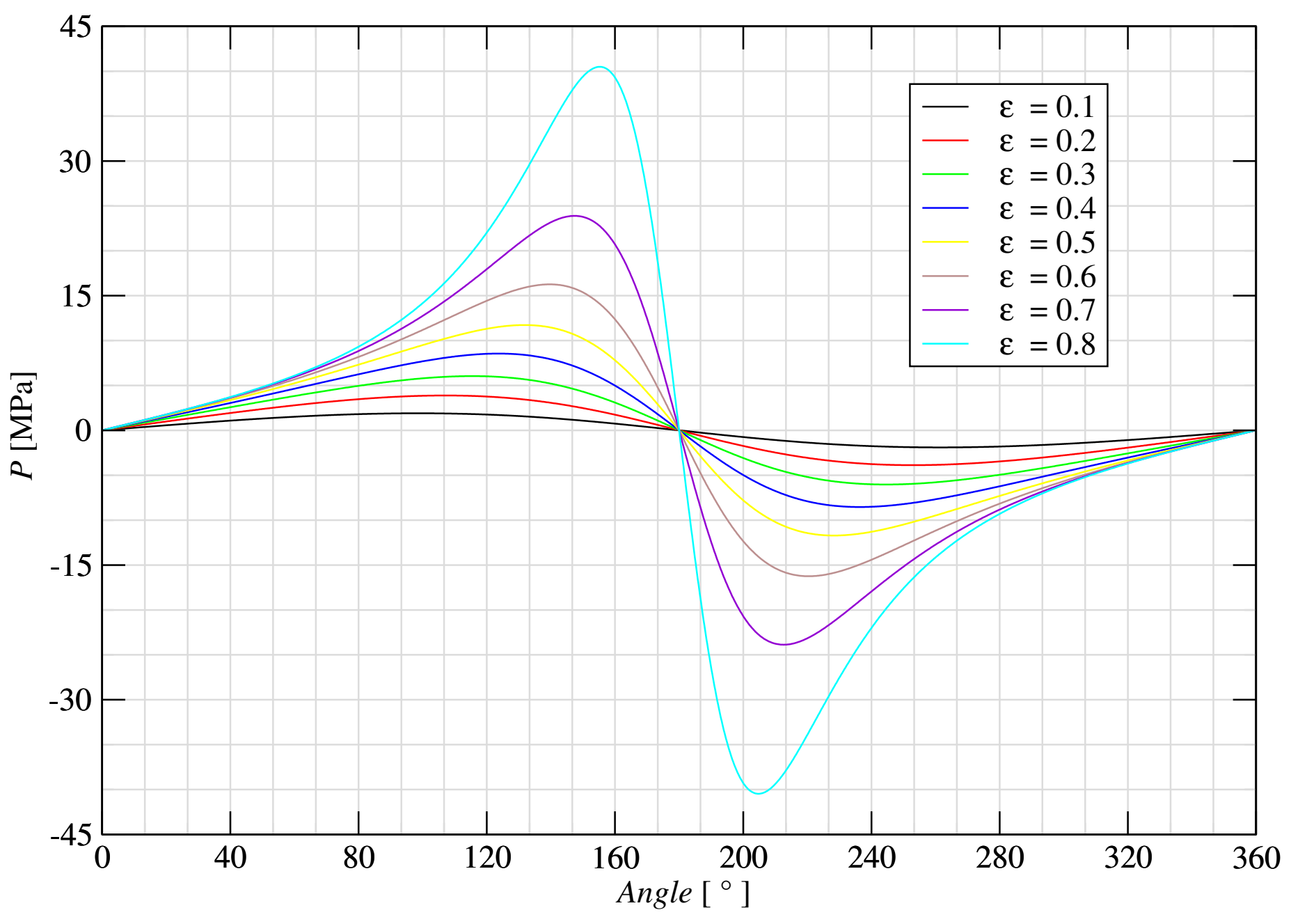


Figure 3: Comparison of pressure distributions at different eccentricity ratios



5. Short-Width Journal Bearing

Hydrodynamic lubrication in a short-width journal bearing is simulated. Case is considered 2D in the Finite Area discretization. Dimensions and properties are similar to the previous case. The difference is in the finite width of the bearing, with ratio between journal diameter and width equal to 5. Fig. 4 shows lubricant thickness and pressure distribution across short-width journal bearing at eccentricity ratio of 0.5. Fig. 5 shows the comparison between analytically and numerically calculated pressure for three sections in the axial direction. Relative distance z is measured from the center of the bearing.

Figure 4: Lubricant thickness and pressure distribution at ϵ = 0.5

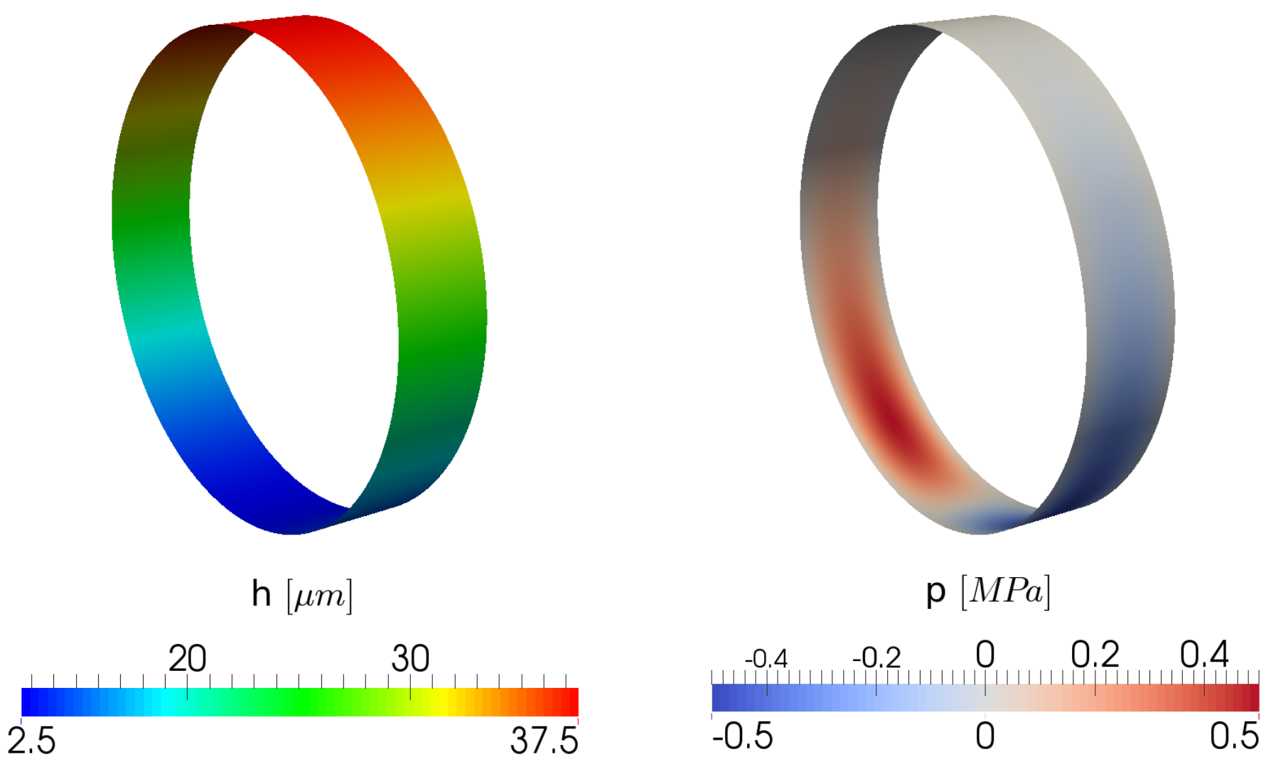
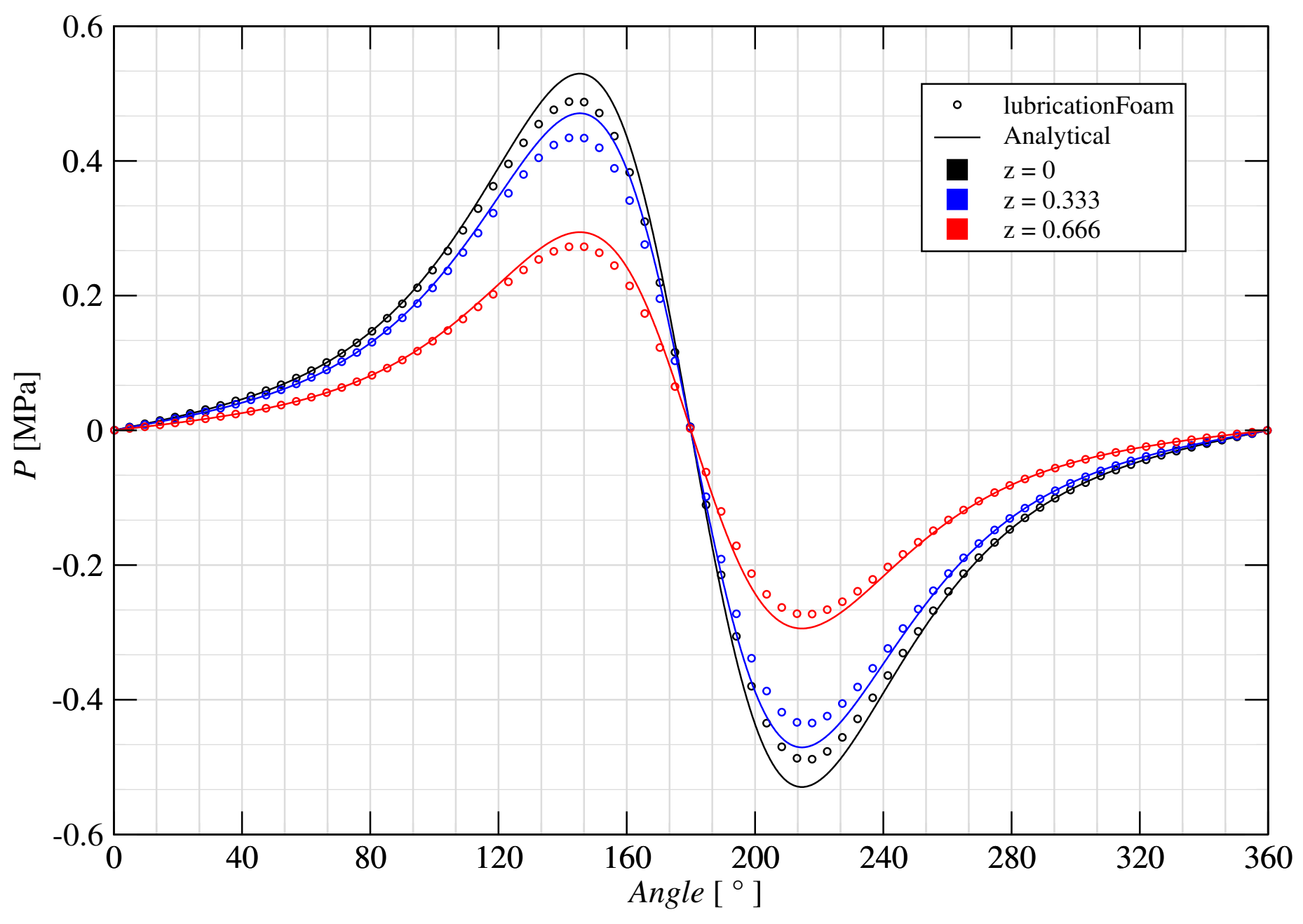


Figure 5: Comparison of pressure distribution for three different sections



6. Conclusion

Results from the numerical model presented in this study show very good agreement with analytical results. With increasing mesh resolution, error between the results decreases significantly. By using the proper boundary conditions, model is able to take into account side leakage and give good results for short-width bearings.

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