An Advanced Numerical Scheme for Simulation of Hydrodynamic Lubrication with Free Surfaces

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In this study, a numerical accuracy problem in the simulation of hydrodynamic lubrication with free surfaces was discussed. The cubic interpolated profile (CIP) scheme was employed to solve accurately lubricant flow with free surfaces. It was found that a widely used finite difference scheme could cause non-negligible numerical errors when dealing with the advection term of Reynolds equation. The results show that the high-order CIP scheme can reduce the errors of the advection term and obtain a more realistic distribution of inlet film thickness than the conventional scheme.

Keywords: hydrodynamic lubrication, starved lubrication, free surface, CIP scheme

1. Introduction

In hydrodynamic lubrication, it is important to estimate the lubricant flow outside the lubricated area as well as inside it. When lubricant is not well supplied into the lubricated area, lubricant starvation occurs, in which the precise treatment of lubricant flow with free surfaces is a critical issue. In this study, we propose an advanced numerical scheme of the cubic interpolated profile (CIP) scheme [1] for hydrodynamic lubrication with free surfaces. The numerical results calculated using the proposed scheme are compared with those calculated using the conventional scheme for discussing the importance of lubricant flow with free surfaces.

2. Modelling

A one-dimensional Reynolds equation of Eq. (1) is solved in this study.

$$\frac{1}{\Lambda}\frac{\partial}{\partial X}\left(H^3\frac{\partial P}{\partial X}\right)=\alpha\frac{\partial(\theta H)}{\partial X}+\frac{\partial(\theta H)}{\partial T},\ \alpha=\frac{1}{max(2\theta,1)} \quad (1)$$

where Λ is the dimensionless coefficient, α is the transport velocity. In starved lubricants, the transport velocity is 1/2 in fully filled region, but it becomes 1 in the partially filled region because the lubricant only attaches to the lower surface. The conventional numerical schemes are first examined and the CIP scheme [1] is applied to solve the convection terms at the right-hand side of Eq. (1). In this study, a moving textured surface with free surfaces of lubricant is solved. Table 1 presents the numerical conditions.

3. Results and Discussion

Figure 1 shows an example of numerical results. A non-negligible calculation error was found near the texture when using the conventional scheme and it was accumulated with the increase of time. On the contrary, the results of CIP scheme were always agreed with the assumed transport velocity model. The stored lubricant did not flow out from the texture before contact. At T = 3.2, a totally different inlet film condition was obtained when compared with the CIP scheme, it indicates that the starting position of the wetting region has been changed due to the numerical dissipation. In the prediction of pressure distribution, the conventional scheme overestimated the pressure because of inaccurate inlet film distribution. The CIP scheme gives an accurate pressure prediction due to the numerical dissipation problems are fixed.

Table 1: Numerical conditions

Parameters	Value
Calculation zone, l	4 mm
Sliding speed, u	0.4 m/s
Minimum film thickness, h_0	200 nm
Initial supplied film thickness, h_s	500 nm
Texture depth, h_d	4 μm
Texture radius, r_p	100 μm
Texture distance, d	2 mm

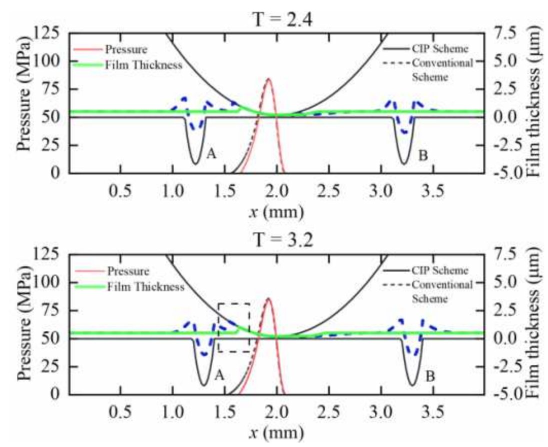

Figure 1: Comparison of simulation results between CIP scheme and conventional scheme.

4. Reference

[1] T. Yabe, et al., "An Exactly Conservative Semi-Lagrangian Scheme (CIP–CSL) in One Dimension," Mon. Wea. Rev., 129, 2001, 332–344.