

REFINED MODELLING OF STARVED HYDRODYNAMIC LUBRICATION WITH TEXTURED SURFACES

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<https://hdl.handle.net/2324/7182442>

出版情報 : Kyushu University, 2023, 博士 (工学) , 課程博士
バージョン :
権利関係 :



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論 文 名 : REFINED MODELLING OF STARVED HYDRODYNAMIC
LUBRICATION WITH TEXTURED SURFACES
(テクスチャ表面を有する油不足流体潤滑の改良モデリング)

区 分 : 甲

論 文 内 容 の 要 旨

The use of textured surfaces, which have artificial patterns on the surface, has shown promise in the field of tribology. In a wide range of lubrication conditions, from boundary lubrication to fluid lubrication, there have been many reports of improved lubrication performance, such as reduced friction and improved scuffing resistance, due to textured surfaces. As a result, it is expected to be applied to various machine elements such as gears, piston rings and rolling bearings. There have also been many fundamental studies on the mechanism of lubrication performance improvement by textured surfaces, among which several lubrication performance improvement mechanisms based on the Reynolds equation, which is a lubrication equation in the fluid lubrication area, have been proposed so far. In recent years, as lubricant oil has become lower in viscosity and use has decreased, it has been reported that textured surfaces can alleviate oil shortage, which is expected to improve performance under starved lubrication. However, the mechanism is still unclear.

Therefore, this study aims to clarify the mechanism of fluid lubrication performance improvement by textured surfaces under starved lubrication. Modelling of fluid lubrication under starved lubrication is carried out in this study to clarify the mechanism. In addition to the Reynolds equation for the flow within the lubricated area, the model proposed in this study also considers the lubricant flow with free surface outside the lubricated area and the flow variation between outside and inside the lubricated area. The validity of the model is then verified by comparing the constructed model with experimental observations of lubricant flow. This thesis consists of seven chapters.

Chapter 1 introduces the previous studies on the use of textured surfaces in tribology and the mechanism of lubrication performance improvement. The research on the mechanism of lubrication performance improvement by textured surfaces under starved lubrication, which has been discussed in recent years, is then introduced to clarify the position of the research undertaken in this thesis and to describe the research objectives and the structure of this thesis.

Chapter 2 explains the mechanism of fluid lubrication based on the Reynolds equation, the governing equation of fluid lubrication. The boundary conditions of the lubricant flow when cavitation occurs are also explained.

Chapter 3 presents the modeling of fluid lubrication under starved lubrication. The theoretical model proposed in this study is based on the one-dimensional Reynolds equation for a stationary surface with curvature and a smooth surface, which is the moving side surface, and considers flow outside the lubrication area to represent the starved lubrication. The flow outside the lubricated area is modelled by the advection equation, but as the advection equation is prone to numerical analysis errors, the CIP-CSL2 method, one of the high-precision numerical analysis methods, is adopted. The analysis is carried out by considering the discontinuities in the lubricant oil flow between the outside of the lubricated area, where the lubricant oil moves at the same speed as the moving surface, and the inside of the lubricated area, where the flow is a mean flow between the two surfaces. The results show that the model proposed in this thesis is highly accurate, the flow is preserved over the entire computational domain and agrees with previous numerical results.

Chapter 4 conducts numerical analysis on a lubricated area with a textured surface, using the model constructed in Chapter 3. A concave texture shape is applied to the moving side surface and analyzed under unidirectional sliding conditions with an initial lubricant oil film. The results reproduce observations from previous experimental studies, showing that when the texture exits the lubricated area, lubricant oil is extracted onto the surface outside the texture. This extraction mechanism is attributed to the micro-wedge action by the texture.

Chapter 5 analyses closed cavitation occurring in the texture using the model proposed in Chapters 3 and 4. Numerical analysis under reciprocating conditions reveals that the pressure flow generated by the differential pressure between cavitation and atmospheric pressure outside the lubricated area creates a suction action, supplying lubricant oil to the inlet during reciprocating reversal and improving oil shortage.

Chapter 6 verifies the mechanism for improving lubrication performance by the textured surface through a comparison with experiments. In the experiments, an optical lens with curvature as the stationary surface and a steel rotating disc with a dimpled textured surface as the moving surface are used. The previously constructed model is extended to two dimensions for numerical analysis, and the lubricant oil flow is compared with experimental results. The results show that the lubricant oil extracted from dimples qualitatively agrees with the experimental results, and that the textured surface reduces the coefficient of friction by alleviating the oil shortage.

Chapter 7 summarises this thesis and presents the conclusions. It also discusses the prospects of this research.

In summary, this thesis aims to clarify the mechanism of fluid lubrication performance improvement by textured surfaces under starved lubrication. The proposed theoretical model successfully reproduces this mechanism, and the numerical analysis results qualitatively align with experimental observations, confirming the validity of the proposed theoretical model.