Original Article

EHL AND HELICAL GEARS: A DETAILED STUDY OF POINT CONTACT FRICTION CHALLENGES

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Abstract: Gears, as fundamental components of mechanical transmission systems, play an integral role in various machinery applications. Among the plethora of gear types, helical gears stand out for their remarkable attributes such as high bearing capacity, minimal axial load, and smooth transmission. These qualities make them ideal for high-speed and heavy-load operations, positioning them as vital drive components in aero-engines, crane structures, and marine power transmission systems. As gear drives advance towards higher speeds, heavier loads, and greater precision, there is a growing emphasis on enhancing lubrication performance and mitigating friction and wear on tooth surfaces. In theory, the elastohydrodynamic lubrication (EHL) of helical gear drives occurs as an on-line contact phenomenon, disregarding processing errors, installation inaccuracies, and gear modifications. However, real-world industrial production often necessitates the modification of helical gears to evenly distribute lateral loads across the tooth surface, diminish offset loads, reduce rodent impacts, and ultimately mitigate vibration and noise. When dealing with modified helical gears, the conventional linear contact EHL model becomes inapplicable. Consequently, there is an essential need to delve into the realm of Point Contact Elastohydrodynamic Lubrication (PC-EHL) in the context of helical gears.

Keywords: Helical Gears, Elastohydrodynamic Lubrication, Gear Lubrication, Point Contact Lubrication, Friction and Wear Reduction

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1. Introduction

Gear, as the basic part of mechanical transmission, is widely used in machinery. Helical gears, with the advantages of high bearing capacity, small axial load and smooth transmission, can adapt to high speed and heavy load and become the core drive components of aero-engine, crane structure and marine power transmission system. With the development of gear drive towards high speed, heavy load and precision, more and more attention has been paid to the research on improving lubrication performance and reducing friction and wear on tooth surface.

Generally, EHL of helical gear drive is theoretically on-line contact without considering the processing error, installation error and modification of helical gear. However, in industrial production, helical gears usually need to be modified to distribute the lateral load on the tooth surface evenly, reduce the offset load, improve the impact of rodent and thus reduce the vibration and noise. For modified helical gears, linear contact elastohydrodynamic lubrication is no longer applicable. Therefore, it is necessary to study Point Contact Elastohydrodynamic Lubrication of helical gears.

2. Development of Elastohydrodynamic Lubrication Theory

Elastohydrodynamic lubrication (EHL) combines Hertz contact theory with Reynolds equation, as in (1) and takes into account the elastic deformation of the contact surface and the influence of lubricant pressure on the viscosity and density of the medium. Elastohydrodynamic lubrication (EHL) is a very active research content in lubrication field in recent years. It widely exists in machine parts with high contact stress, such as gears, cams, bearings, etc.

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{\eta_e}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\rho h^3}{\eta_e}\frac{\partial p}{\partial y}\right)=12\frac{\partial(\rho^* u_R h)}{\partial x}$$

The classical elastohydrodynamic theory is based on isothermal Newtonian fluids. Quite a few scholars have predicted the oil film thickness and the oil film shape with the classical lubrication theory. Because of the rapid development of modern industry, the requirement for comprehensive mechanical performance is getting higher and higher. More and more machines need to operate under high speed and heavy load conditions. In order to make the theory of elastohydrodynamic lubrication better applied in modern industry, researchers have established a lubrication model which is more suitable for actual conditions, and the modern elastohydrodynamic theory has been well developed. In addition, the development of lubrication science and the improvement of numerical algorithm also promote the development of lubrication theory.

Jiang et al. studied the point-contact hybrid lubrication of rough surfaces [1] using fast Fourier transform and multi-grid technology. Yang and Hen studied the unsteady thermoelastohydrodynamic lubrication of non-Newtonian fluids with roughness considering both the transient effect and the rheological effect of lubricants. In 2000, Zhu and Hu adopted a unified equation description for fluid lubrication and dry contact and proposed a unified Reynolds equation..In 2004, Damiens et al. studied the influence of oil depletion on the distribution of oil film pressure and oil film thickness in contact area when studying the elastohydrodynamic lubrication model of elliptical contact [2]. In 2005, Dowson et al. considered the effects of thermal effect and non-Newtonian flow when studying the problem of unsteady-state elastohydrodynamic lubrication [3]. Afterwards, Bair studied the effect of compressibility on the formation of oil films in the contact circles of thermoelastohydrodynamic lubrication. Long Tao et al. carried out numerical analysis on the elastohydrodynamic lubrication of different rheological models and compared the friction coefficient of different rheological models at low viscosity. Recently, Chai Yufeng and Zeng Liangcai have studied the heterogeneous interface of point contact EHL and analyzed the influence of particle debonding on oil film pressure and thickness.

3. Development of Elastohydrodynamic Lubrication Theory in Gear Drive System

Reasonable gear lubrication system can alleviate pitting, gluing and wear of tooth surface and prolong service life of gear. The wide application of gear drive and the importance of lubrication promote the research of gear lubrication theory. Elastohydrodynamic lubrication of gears was first applied to spur gears. Compared with spur gears, the study on elastohydrodynamic lubrication of helical gears started late. Tong Hui et al. studied the Isothermal Elastohydrodynamic Lubrication of helical gears, neglected the curvature change along the tooth width direction, and adopted the Line Contact Elastohydrodynamic Lubrication model. His research could not reflect the lubrication characteristics of helical gears very well. Later, Yang Pingping and Yang Peirun equivalent helical gear drive to two opposite conical contacts, established a finite length thermal elastohydrodynamic lubrication model, and discussed the oil film pressure, film thickness and temperature variation rule of helical gear elastohydrodynamic lubrication [4]. This research represents the highest level of gear lubrication theory research at that time, especially helical gear lubrication theory. For this type of structural form,Simplified model as Fig. 1.

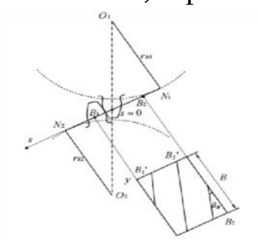

Figure 1: Example Diagram of Helical Gear Engagement

Wang Wenzhong also used the finite-length line contact model to analyze the difference between the steady-state solution and the unsteady solution of helical gear, and found that the steady-state solution and the unsteady solution had little difference in the stage of rodent and rodent, but had slight difference in the middle part. Afterwards, Ebrahimi et al considered helical gears as a series of spur gears with very narrow tooth width.[5] Considering surface roughness and thermal effect, hybrid elastohydrodynamic lubrication of helical gears was studied. Elastohydrodynamic lubrication of helical gears based on real rough surfaces has also been studied successively. Recently, Shapir Dry proposed a new algorithm to solve point-by-point contact NHL[6] in order to further reduce the amount of calculation and improve the efficiency of calculation.Yan Hongzhi and others took helical bevel gears as research objects and established an Elastohydrodynamic film thickness equation considering tooth surface roughness. Reynolds equation was solved by finite element method and central oil film thickness was obtained. The influence of true tooth surface roughness on lubrication and life of helical bevel gears was revealed [7].

4. Calculation method of point-line Contact Elastohydrodynamic Lubrication

As shown in Figure 2,Multigram method: the basic idea is to divide the solution area into several layers of mesh with dense differences. According to each layer of mesh partition format, the partial differential equation to be solved is discretely constructed into a group of equations. The algebraic equations are solved iteratively on the dense grid by turns, and approximate solutions and deviations are transferred layer by layer and eliminated. Finally, a numerical solution meeting the accuracy requirement is obtained on the densest grid layer. This method can increase the maximum solution load to 6 GPa when solving, and is also applicable for solving light load problems. Because of its good stability of numerical solution and the wide range of load solution, this method is highly recommended in the study of elastohydrodynamics scholars. However, this method needs to establish a more complex mathematical solution system, which makes programming difficult and difficult for general engineering designers to understand and master in practical application. Moreover, because the advantages of the multi-grid method are only outstanding when the number of grid nodes is large, the convergence efficiency of the solution is not high enough. Moreover, the method must be combined with the multi-grid integration method to give full play to its advantages, which is also a reason for the high complexity of the mathematical system..

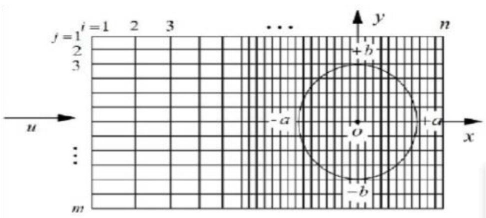

Figure 2: Multi-grid method for grid partition of regions

Direct iteration method: Reynolds equation is discretized by finite difference method. As shown in Figure 3,Film thickness, density and viscosity of corresponding nodes are calculated according to the assumed pressure distribution curve. After substituting the values into the discrete Reynolds equation, the linear equation group of unknown pressure unit is constructed by combining the elastic deformation equation and solved repeatedly by iteration method until the pressure value meeting the convergence accuracy is obtained. This method is simple and direct in mathematical theory, takes up less memory, has wide application range of parameters and has room for improvement in computational efficiency.

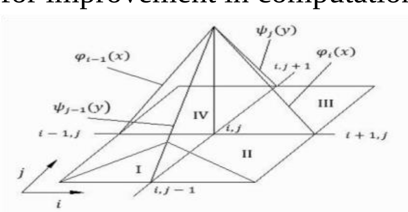

Figure 3: Matrix Microelements Required by Direct Iteration Method

5. Conclusion

Tribology is an interdisciplinary and broad-ranging scientific research field, which has been paid special attention by researchers in engineering for a long time. Elastohydrodynamic lubrication is a phenomenon commonly found in rolling bearings, gears, cams, rolls, etc. and transmission parts in point contact. Elastohydrodynamic lubrication can not only effectively reduce friction, prevent wear, glue, improve the service life and working efficiency of parts, but also have an important influence on the dynamic properties of friction pairs and systems such as vibration and noise. Therefore, the study of elasticity is not only of theoretical significance, but also of great engineering practical value. Elastohydrodynamic lubrication, because of the concentrated load of the friction pair, the contact pressure in the contact area may reach several gigapa. Therefore, the viscosity of the lubricant on the surfaces of two contacts in the contact area is many times higher than that of the lubricant at normal room temperature, and the oil film formed in the contact area is small and very thin, generally only 0.1-1μm; Due to the great pressure variation on the very thin oil film and the great elastic deformation of the elastomer, the pressure distribution on the oil film is also determined by the specific geometrical shape of the lubricating oil film, which makes the solution of the elastohydrodynamic lubrication problem a difficult problem to solve.

References

Jiang X, Hua D Y, Cheng H S, et al. A mixed elastohydrodynamic lubrication model with asperity contact.[J]. Journal of Tribology, 1999, 121(3):481-491

B. Daniens, C.H.Venner, P.M.Cann, A.A.Lubrecht. Starved Lubrication of Elliptical EHD Contacts[J]. ASME Journal of Tribology,2004,126:105-111.

P. Yang,J.Cui,Z.M Jin,D.Dowson.Transient Elastohydrodynamic Analysis of Elliptical Contacts, Prart 2: Thermal and Newtonian Lubricant Solution [J]. Proceedings of the Institution of Mechanical Engineers,Part J,Journal of Engineering Tribology, 2005, 219: 187-200.

Yang Ping and Yang Peirun. Thermoelastic Lubrication Theory of Bellow Cylindrical Gear. [J]. Journal of Mechanical Engineering, 2006,42(10): 43-48

Ebrahimi S A, Akbarzadeh S. Prediction of performance of helical gears under mixed lubrication regime. [D]. Modares Mechanical Engineering, 2014, 14(10):167-176

Xia Boqian, Fang Baojiang, Guo Hong, Zhang Shaolin. Direct algorithm for point contact ejection problems. [J]. Lubrication and Sealing, 2021, 46 (3): 2-4

Yan Hongzhi, Huang Guobing, Li Chao, etc. Effect of tooth surface roughness of helical bevel gears on their lubrication life with waste oil. [J]. Lubrication and Sealing, 2016, 41 (8): 1-5