Tribology International 121 (2018) 180–189

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Influence of oil injection methods on the lubrication process of high speed spur gears

Yanzhong Wang [a], Guanhua Song [a,*], Wentao Niu [b], Yanyan Chen [a]

[a] School of Mechanical Engineering and Automation, Beihang University, Beijing, China
[b] Beijing Institute of Aerospace Control Devices, Beijing, China

ARTICLE INFO

Keywords:
Spur gears
Oil injection methods
Lubrication
Influence mechanism

ABSTRACT

Computational fluid dynamics simulation is used to establish models for different oil injection methods: into-mesh and out-mesh injections. The simulation results concluded that when the gear pitch line velocity is higher than the velocity threshold, the oil jet cannot reach the meshing point when the out of mesh jet lubrication is used. When the ratio of the pitch velocity to the spray velocity is less than 5, better lubrication are obtained by out of mesh jet lubrication. When the ratio of the pitch velocity to the spray velocity is more than 5, into mesh jet lubrication can achieve better lubrication. Finally, the influence mechanism of different oil injection methods on lubrication process is revealed through theoretical analysis.

1. Introduction

Jet lubrication is mainly used in high speed gears to ensure proper lubrication and sufficient cooling. Gears operate under heavy loads and high pair meshing. The gears are in a state of elastohydrodynamic lubrication when there is sufficient oil supply [1–4]. The oil injection method is that the lubricating oil jet to gears in which direction. The study of oil injection methods began in the 1920s. Since H. B. Tostevin initially presented the concept of oil injection methods, two main viewpoints have been formed: into mesh jet lubrication and out of mesh jet lubrication (Fig. 1). Which method offers better lubrication and cooling effects is still under discussion. Currently, the manufacturers rely primarily on experience to determine the appropriate jet lubrication methods for different engineering applications. Therefore, the study of different oil injection methods is significant to guide the design of the jet lubrication and improve the oil jet lubrication cooling effect.

Under jet lubrication conditions, the high velocity lubricating oil is sprayed out from the oil nozzle and interacts with the surrounding air, which forms the gas-liquid multiphase jet. Because of the gear teeth obstruction, the oil jet only flows into the meshing region through the small clearance formed by the tooth surface. The amount of lubricating oil sprayed into the meshing region as well as the effect of lubrication and cooling on high-speed gears depends on the oil injection method adopted. However, this is still inadequate for the proper design of jet lubricated gears. The impact of jet lubrication was examined in Refs. [5,6], the impact and penetration depth of the oil jet were experimentally investigated using high-speed cameras. These experiments captured the effect of the gear rotating flow on a single drop of lubricating oil. The injection impact depth of the lubricated gear on the out of mesh side was contrasted by experiment in Refs. [7,8], and the impacts of different gear ratios and spray velocities were analyzed. Their results show that the injection impact depth increased as the spray velocities increased. The geometric analysis models of oil jet and spur gear were established in Refs. [9–11], and the impact depth of the into mesh lubrication at any spray angle was studied. However, the dynamics of fluid and gear meshing were considerably simplified. On this basis, they also carried out the geometric modeling and analysis of the out-mesh injection. The cooling process of the tooth surface was analyzed under jet lubrication conditions in Refs. [12,13]. They analyzed the gear tooth temperature using a finite element method combined with a calculated heat input and calculated oil jet impingement depth. The spiral bevel gear injection effect of different spray positions was analyzed in Refs. [14–16], and the temperature of each point on the gear tooth surface under different spray positions was tested by using infrared temperature sensor. These experiments obtained the influence of different spray positions and oil pressures on the gear tooth surface temperature. The effects of different additives on the lubrication performance were investigated in Refs. [17–20]. A back-to-back gear test was used to compare dip lubrication with spray lubrication regarding gearbox efficiency in Ref. [21]. Their experimental results indicated that spray lubrication showed a

* Corresponding author.
E-mail address: songuanhua@163.com (G. Song).

https://doi.org/10.1016/j.triboint.2018.01.062
Received 19 September 2017; Received in revised form 26 January 2018; Accepted 28 January 2018

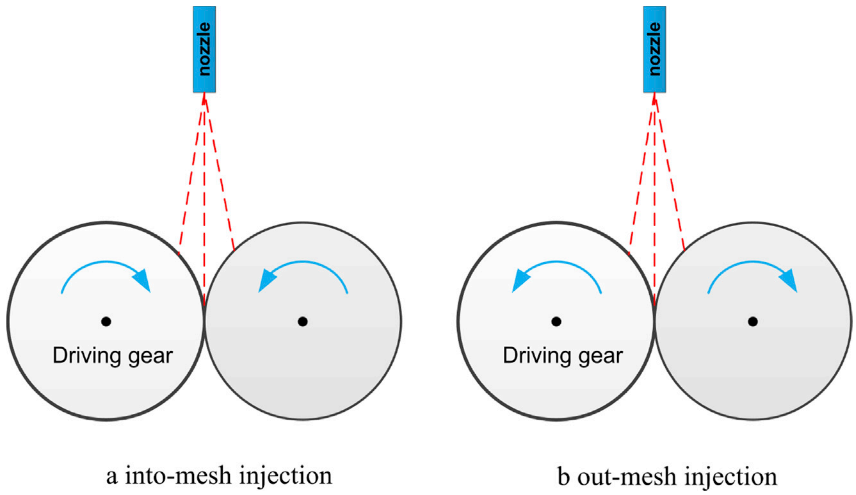

Fig. 1. Different injection methods.

significantly higher total gearbox efficiency at higher speeds. Their results indicate that lower bearing temperatures and higher power losses were obtained with oil-jet lubrication than with air –oil mist lubrication. The research results of the above scholars provide guidance for the research direction and methods for this paper.

Computational fluid dynamics (CFD), which is a new branch of fluid mechanics, has been widely used in engineering. With the continuous innovation and optimization of calculation algorithms and programs, CFD has emerged as an efficient and credible method for the computer simulation of fluid flow that has achieved reliable results.

The paper researches on the influence of oil injection methods on the lubrication process of high-speed spur gears using CFD software. The study aims to develop a design method of different oil injection methods under different gear operating conditions. The simulation models of different oil injection methods pertaining to lubrication processes are established. The lubrication status of each meshing point on the meshing trace is calculated under different jet lubrication condition. The influence of the different oil injection methods on the lubrication process are simulated and compared to provide guidance for the appropriate design of oil injection lubrication systems.

2. Analysis of oil injection lubrication process

The initial lubrication conditions at different meshing points differ with gear rotation, resulting in different lubrication states. When the gear parameter, gear speed and working load are given, the lubrication state of the meshing point is mainly determined by the oil-air ratio (oil mist concentration) at the meshing point that is affected by pressure. The jet lubrication process of into mesh lubrication is shown in Fig. 2. The oil nozzle is directed along the internal common tangent of the two pitch circles. The oblique line represents the meshing trace.

At the instant being depicted in Fig. 2a, Point A of the driving gear is just engaged with Point B of the driven gear. The lubricating oil can flow into the meshing point through the clearance formed by the tooth surfaces of the two gears above the meshing point, which have a relatively high oil-air ratio and total pressure. It provides a good condition for forming elastohydrodynamic lubrication in the meshing region. With the rotation of the gear, the gap formed by the tooth surface above the meshing point becomes smaller, as shown in Fig. 2b. Thus, the flow of the lubricating oil in the gap becomes more difficult. The lubricating oil at the meshing point has a low oil-air ratio and total pressure, which is unfavorable to the formation of elastohydrodynamic lubrication. This causes the gear to be in starved lubrication. Teeth A and B are not yet out of engagement, and the next pair of teeth C and D begin to engage as shown in Fig. 2c. The lubricating oil cannot reach the meshing point of teeth A and B as it is blocked by teeth C and D. The meshing zone can only

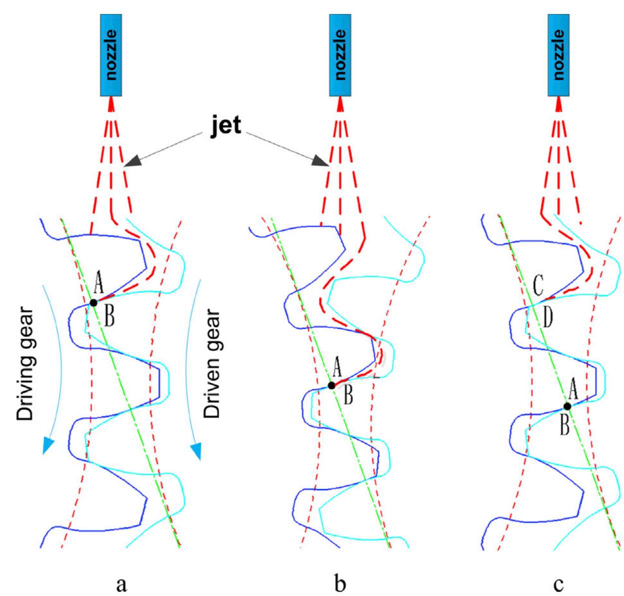

Fig. 2. Jet lubrication process.

rely on the lubricating oil film adsorbed on the tooth surface or the oil mist particles in the environment. The gear teeth C and D will repeat the meshing and lubrication processes of teeth A and B. The out of mesh lubrication process is the opposite of the into mesh lubrication described above.

According to the meshing principle, the entire meshing process of the gear should go through three stages, namely, double teeth, single teeth and double teeth, with the distances traveled by each phase being εp_n-p_n, $2p_n$-εp_n, and εp_n-p_n, respectively. Here, ε denotes the contact ratio of the gears. p_n denotes the normal tooth pitch. Based on the above mentioned analysis, when the meshing point is at the two stages closer to the nozzle side, the lubricating oil can flow directly into the meshing point through the clearance between the two teeth surfaces. When the meshing point is in the third stage, the lubricating oil cannot flow directly into the meshing point.

3. Model of oil injection lubrication

3.1. Quasi-steady state assumption

The oil injection lubrication state of the gear teeth during the meshing