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A method for gear fatigue life prediction considering the internal flow field of the gear pump

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ABSTRACT

Gear pump is the most widely used volume type hydraulic pump, and it is the main power source of the hydraulic system. Its performance is influenced by many factors, such as working environment, maintenance, fluid pressure and so on. It is different from the gear transmission system, the internal flow field of gear pump has a greater impact on the gear life, therefore it needs to consider the internal hydraulic system when predicting the gear fatigue life. In this paper, a certain aircraft gear pump as the research object, aim at the typical failure forms, gear contact fatigue, of gear pump, proposing the prediction method based on the virtual simulation. The method use CFD (Computational fluid dynamics) software to analyze pressure distribution of internal flow field of the gear pump, and constructed the unidirectional flow-solid coupling model of gear to acquire the contact stress of tooth surface on Ansys workbench software. Finally, employing nominal stress method and Miner cumulative damage theory to calculated the gear contact fatigue life based on modified material P-S-N curve. Engineering practice show that the method is feasible and efficient.

1. Introduction

Gear pump is one of the basic unit of the hydraulic system and control system. It widely used in the field of mechanical engineering because the gear pump has the advantages of small size, light weight, not sensitive to pollution, reliable operation, good performance, and its price is relatively low [1,2]. The performance status of gear pump is affected by many factors, such as working environment, maintenance condition and so on, so it is more easily failure in operation. Therefore, in order to ensure the safety and reliable operation of gear pump and achieve proactive maintenance, it is necessary to predict the failure time to avoid the occurrence of accidents and reduce maintenance costs and extend equipment life.

The gear tooth surface bears large contact pressure for gear transmission system, which leads to tooth surface wear and fatigue [3]. For the gear as the supercharger components of gear pump immersed in working medium, the gear condition of lubrication is ideal state without considering the impurities of oil, and the gear fatigue failure is the main failure forms of gear pump. A large number of scholars have made a deep analysis on the fatigue failure analysis of gear teeth for gear transmission system [4–7]. Davoli et al. applied multi-axial fatigue criteria to spur gear contacts, assuming smooth and dry contact condition [4]. Qiao et al. and Snidle and Evans studied the lubricated gear tooth surface fatigue by treating any instantaneous tooth contact as an independent line contact of a cylinder pair [5,6]. Li presents a model to predict the crack formation fatigue lives of spur gear contacts operating under mixed lubrication conditions where surface roughnesses introduce intermittent metal-to-metal contacts and severe stress concentrations [7]. But the analysis above is limited to the gear transmission system, and the gear pump as an important part of the hydraulic system, the internal pressure of the working medium has a great impact on the working condition of the gear, and the

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phenomenon of trapped oil in gear pump is also a problem which can not be ignored [8,9]. A lot of analysis of the internal flow field of the gear pump at home and abroad, the phenomenon of trapped oil is one of the major concerns. Li Yulong investigation and analysis the effect of the phenomenon of trapping oil, and the static model and dynamic model of trapped oil of gear pump was established, and the results was compared with the actual test [10]. Hyun has carried on the analysis on the fluid in the flow regime, velocity field, pressure field under different side gap, rotation speed, pressure field based on the FLUENT software indicating that the gear pump does exist very high and very low pressure because of the trapped oil [11]. Therefore, ignoring the influence of gear pump internal working medium pressure on the gear can lead to large deviations in the prediction of the fatigue life of the gear. However, the internal flow field of gear pump is very complex, the theoretical calculation model is difficult to meet the needs of engineering practice, and the domestic and international research on related issues is less.

This paper presents the contact fatigue life prediction method of gear based on virtual simulation for gear pump, the method combining the FEA (Finite Element Analysis) method and the nominal stress method and follow Miner cumulative damage principle to predicate gear contact fatigue life. The FEA method not only avoids the traditional complex numerical calculation, but reduces the deviation caused by the simplification of the theoretical model. By constructing the unidirectional fluid-solid coupling model of the flow field and structure field, the problem that the contact stress analysis of the gear not considered the internal flow field of gear pump was solved. On the other hand, the method of combined with the nominal stress and Miner cumulative damage theory based on the modified P-S-N curve of material to predicate the contact fatigue life of gear simplify the difficulty of engineering application.

2. Finite element model of gear pump and fluid control equation

The typical structure of the gear pump including shell, gears, bearings, drive shaft, oil passage, oil filter as shown in Fig. 1. The gear parameters was shown in Table 1.

2.1. Finite element control equation of internal flow field of gear pump

On the description of the partial differential equations of fluid flow, the mathematical community has developed a number of methods to obtain the exact solution, but the exact analytical solution can only be obtained in a simple case [12]. For practical engineering problems, the method of numerical calculation is widely used. The first step of the numerical calculation method is to establish the control equation of the object.

2.1.1. Flow field control equation

For general compressible Newton fluid, the law of conservation was described by the following control equations [13].

$$\frac{\partial \rho_f}{\partial t} + \nabla \cdot \left(\rho_f \nu \right) = 0 \tag{1}$$

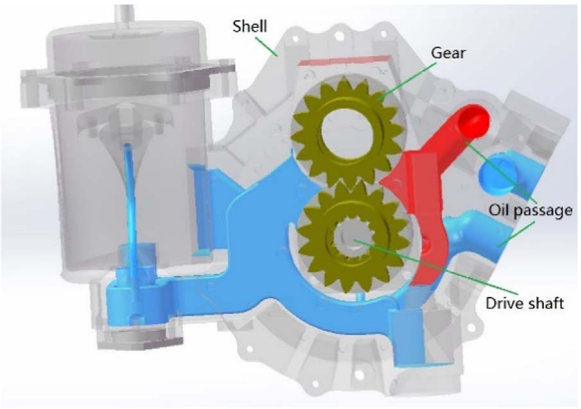

Fig. 1. A typical system of gear pump.

Table 1
Gear parameters.

Parameters	Z	m	Pressure angle	Tooth width/mm	Addendum circle/mm
Gear	16	4.75	32.5°	19.2	83.4