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Research paper

Investigation on temperature field of surrounding tooth domain with cracked tooth in gear system

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ABSTRACT

In order to study the temperature field of the gear transmission system with cracks, the stiffness load ratio of the cracked tooth and the surrounding tooth is derived. The temperature field of the surrounding tooth domain of cracked tooth is predicted by coalescent with the formula of stiffness load ratio and BLOK flash temperature theory. The influence law of the crack depth on the temperature field of the crack tooth and the surrounding tooth domain is revealed. The results of the theoretical analysis and the prediction of the temperature field are verified. In the analysis on the result of the finite element experiment, the tooth root's instantaneous fracture size of the gear system is found. By means of finite element simulation, various load tests were carried out for the gear system with cracked teeth, and then the change rule in the temperature field of the surrounding tooth domain of cracked teeth under different load conditions was found. Finally, the validity of the finite element method is verified by experiments.

1. Introduction

Gear transmission is the most important transmission in mechanical system. Gear transmission is widely applied in engineering because of its high efficiency, compact structure and stable transmission ratio. Most of the gear research is focused on gear stress, strain analysis, fault diagnosis, vibration reduction, noise reduction, and modification [1-4]. For many years, the research of gear crack failure has been carried out for many years.

The research of gear crack simulation and fault diagnosis has been carried out for many years. The finite element (FE) method [5–11], analytical method of cracked gear [12–26] and analytical-FE approach [27–29] have been used to calculate the TVMS of gears. Cracked gear considering the effects of the extended tooth contact has been analyzed by FE model [30].

The stress and strain of gear system have been studied for a long time. Richardson carried out an analysis of the dynamic loads and stresses in the gear system in 1958 [31]. In the same year, Utagawa studied the load and strain of gears [32]. These early studies laid a good theoretical foundation for later researchers. The stress theory of gear is mainly based on Hertz contact theory and Coulomb friction theory [33]. The research of modern gear stress is mainly carried out by FE simulation [34–37]. And the results of simulation analysis are very close to the theoretical results [38–42]. In recent years, the study of the temperature field of gear system has gradually increased. In 1974, Tobe and Kato studied the instantaneous contact temperature of the spur gear pair and the distribution of frictional heat between the meshing teeth pairs, and the influence of load, modulus, speed and profile modification on instantaneous contact temperature is also analyzed

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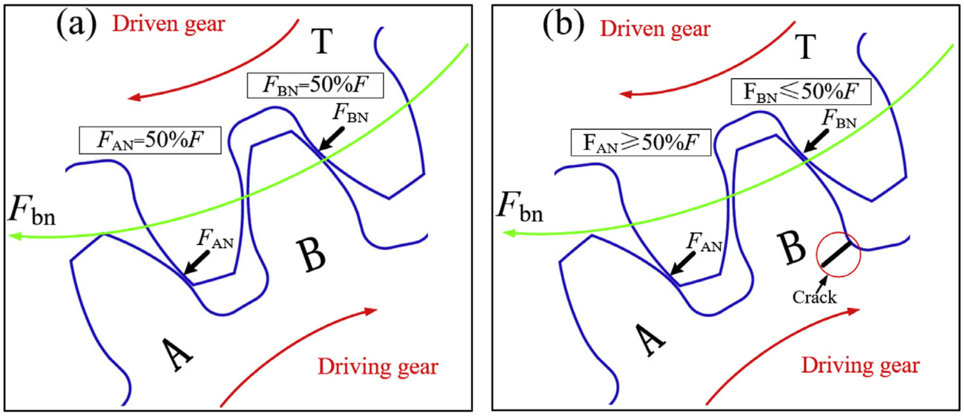

Fig. 1. Force analysis of double tooth meshing.

[43]. Around 1980, the FE method is gradually applied to the calculation of gear temperature field. Wang, Cheng, Patir and Townsend have developed the theory of gear temperature field analysis [44–46]. The boundary conditions of the convective heat transfer coefficient and the frictional heat flux of the gear teeth face are studied, the temperature field of gear FE is established. The magnitude and distribution of the body temperature in the meshing process of the gear system are obtained. The effects of input load, geometric parameters and lubrication characteristics on the gear temperature field are studied. Anifantis and Dimarogonas [47] established the FE model of two-dimensional temperature field, and studied the loading boundary conditions and the heat load distribution between the driving and the driven gears.

The study of gear dynamics and thermodynamics has been developing for many years, but the research on the temperature of gears with crack faults is extremely rare, and the study on the tooth domain around cracked teeth is not reported. In this paper, the relationship between the stiffness and the load is deduced. Besides, the total effective meshing stiffness equation of the double-tooth meshing between the healthy tooth and the faulty tooth is established. The change law of the temperature field concerning the cracked tooth and the surrounding tooth is studied by combining the Blok flash temperature principle and the stiffness load ratio formula [48–49]. Through the analysis on the thermal field of the cracked gear, the temperature of the cracked gear can be prejudged, while the temperature of the cracked gear tooth surface can be prejudged by analyzing the thermal field of the crack and the surrounding tooth domain. The FE experiments of the cracked gear system under various loads are conducted, and the influence of different loads on the temperature field of the cracked gear system is revealed. Finally, the correctness of FE method is verified by comparing experimental data with FE data. The research on the temperature field of the cracked tooth and the surrounding tooth domain provides a theoretical basis for the fault diagnosis and high quality design of the gear system.

2. Model and calculation

Theoretically, when the gear in a double tooth meshing, there is a certain moment ε that makes F_{AN} equal to F_{BN} as shown in the Fig. 1(a). M_t is the load from driven gear.

$$F = 2000\frac{M_t}{d\cos a_n} \tag{1}$$

where, d is the diameter of the dividing circle; a_n is the pressure angle.

When we analyze the cracked gear, we find that when the tooth B is cracked, F_{AN} is not equal to F_{BN} at the ε, but F_{AN} increases, F_{BN} decreases as shown in Fig. 1(b). Based on this phenomenon, the contact load and temperature field of the cracks and the surrounding tooth are studied.

2.1. Crack tooth model and stiffness load ratio

For the cracked tooth as shown in Fig. 2, only bending stiffness and shear stiffness change, then

$$\begin{aligned}\frac{1}{k_{b\_crack}} &= \int_{-a_g}^{a_2} \frac{12\{1+\cos a_1[(a_2-a)\sin a-\cos a]\}^2(a_2-a)\cos a}{EL[\sin a_2/R_{b1}\sin v+\sin a+(a_2-a)\cos a]^3}da \\ &\quad + \int_{-a_1}^{-a_g} \frac{3\{1+\cos a_1[(a_2-a)\sin a-\cos a]\}^2(a_2-a)\cos a}{2EL[\sin a+(a_2-a)\cos a]^3}da \end{aligned} \tag{2}$$