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Analytical method for coupled transmission error of helical gear system with machining errors, assembly errors and tooth modifications

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ABSTRACT

We present a method for analyzing the transmission error of helical gear system with errors. First a finite element method is used for modeling gear transmission system with machining errors, assembly errors, modifications and the static transmission error is obtained. Then the bending-torsional-axial coupling dynamic model of the transmission system based on the lumped mass method is established and the dynamic transmission error of gear transmission system is calculated, which provides error excitation data for the analysis and control of vibration and noise of gear system.

1. Introduction

As a complicated elastic machinery system, gear system will produce vibration and noise under dynamic excitation. So it is a primary question for the dynamic characteristics of gear system to research the dynamic excitation in the gear meshing process and determine the type and features of the dynamic excitation. As is well known to all, gear transmission transmits power by the mesh force along the mesh line. The dynamic excitation along the mesh line will then be produced in the transmission process, which adds the displacement difference of pinion and gear in the direction of the meshing line. This is what is called transmission error, which can be divided into static and dynamic transmission error.

The displacement excitation depends greatly on the gear profile design, machining method and assembly error, and it is an important excitation source of the gear vibration and noise, which has an important influence on the dynamic characteristics. Therefore, the research about reduction of vibration and noise of gear transmission usually focuses on the reduction of displacement excitation along the mesh line [1], corresponding representatives are Velex and Kahraman. They studied the influence of modification, assembly error and profile error on the transmission error [2–5], summed up each factor's influence linearly to get the static transmission error [6,7], analyzed the correlation between the tooth load and transmission error [8], and verified their result by experiment [9,10]. At the same time, there are lots of researchers who took the single level gear pair, multi level gear pair and the planetary transmission system as study objects, and carried out many research works about the calculating method of error excitation. The method uses the machining error given by the gear accuracy

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grade, synthesizes the contact ratio and base pitch error to calculate the simplified tooth error excitation while assuming that the tooth error follows the half sine distribution from tooth root to tooth tip [11–15].

In conclusion, many researchers carried out lots of research works about the error excitation. However, there are many simplifications when simply linearly summing up each error's (machining error, assembly error and modification) influence on the static error, because the effect of interaction of each characteristic error on dynamic error excitation is hardly considered. Therefore, this work proposes a calculation method of static transmission error (STE) which considers the coupling of multi factors such as machining error, assembly error and modification. The bending-torsional-axial coupling dynamic model of transmission system is also established, and the dynamic transmission error (DTE) of gear transmission system is studied, which will provide error excitation data for the analysis and control of vibration and noise of gear system.

2. Model method for gear pair with error

2.1. Mathematical model of machining error

Because of the factors such as gear machining and machine tool accuracy, there is always a certain error between the actual tooth surface and theoretical tooth surface. The actual surface error is a comprehensive error, and can be divided into several single errors, such as profile error (involute incline error $f_{H\alpha}$ and profile shape error $f_{f\alpha}$), helix error (helix incline error $f_{H\beta}$ and helix shape error $f_{f\beta}$), and pitch error f_{pt}. As is shown in Fig. 1, the pitch error is 0 order error, involute incline error and helix incline error is 1 order error, and the profile shape error and helix shape error is high order error [16].

The gear machining error has a great effect on the transmission error of gear transmission system, and researchers have done a lot of research work about the machining error. However, most of them sum up each error linearly, which does not well reflect the combined effects on gear transmission error of the interaction of the individual errors. Therefore, we want to build a model of a gear pair with error based on the gear meshing theory to study the effect of the machining error on the static transmission error.

While deriving the equation of tooth surface with machining error, the machining coordinate system of helical gear with error is $O_p x_p y_p$ in the cutter coordinate systems S_p, as is shown in Fig. 2, which the coordinate origin O_p locates at the initial point of the straight line portion for cutter rack, x_p is along the vertical direction to the straight line portion for cutter rack, y_p is along the straight line portion for cutter rack.

The coordinate system and the modeling process were similar to our group's paper [17], which has the detailed explanations. The cutter error is assumed to be the sine function with the wave period of 1/W. The equation of cutter profile with error is

$$x_p = A \sin W y_p \tag{1}$$

where A is the amplitude of profile error function; W is the wave frequency of error.

The machining coordinate system of helical gear is shown in Fig. 3.

In Fig. 3, $S_0(O_0 - x_0 y_0 z_0)$ is fixed to the cross section of the generating rack, y_0, z_0 locates on the pitch plane, x_0 locates on the symmetric plane of the cross profile of the generating rack and is perpendicular to the pitch plane, and the coordinate

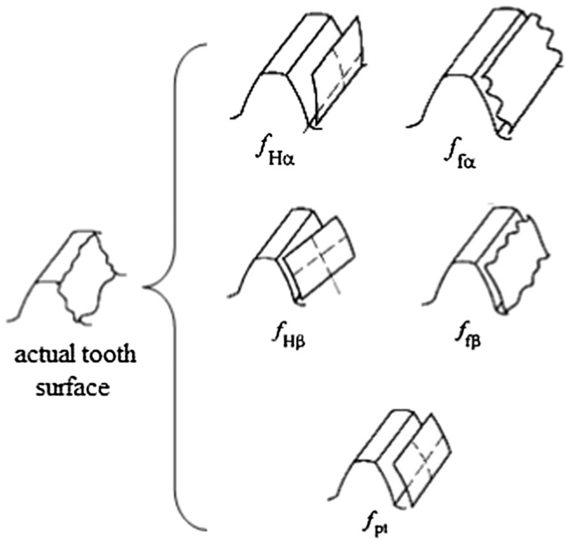

Fig. 1. The actual tooth surface with machining errors.