Analysis of Meshing Characteristics of Helicopter Main Reducer Planetary Gear with Shafts System Relative Position Change

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Abstract: Shafts of helicopter transmission systems are prone to come up relative location changes due to complex structures of"three axis and three gear reducers" and load actions of the main rotor and tail rotor, which affect the transmission characteristics of the whole transmission system. Taking the most representative structure - planetary gear ,in the helicopter main reducer as the object, the meshing characteristics of the planetary gear train are studied when the relative position of the shaft changes caused by the main rotor shaft tilts under variable load. At first, the dynamic model of the relative position change of the planetary gear train is established. Then, combined with the multi body dynamics software, the variation law of the meshing characteristics is analyzed emphatically under conditions of different shafts relative position change, different load and different speed.The research work of this paper can provide the theoretical basis for the monitoring of the running status of the main drive system of the helicopter, which is of great significance to improve the stability of the helicopter transmission system and ensure its safe and efficient operation.

Key words: Helicopter tail drive system; Relative position change of shafting; Meshing force; Condition monitoring

1 Introduction

The helicopter transmission system includes main reducer, intermediate

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reducer, tail reducer, main rotor shaft, power drive shaft and tail drive shaft, namely "three axis and three gear reducers", with the characteristics of compact structure, light weight, high precision, high power transmission and high speed ratio, which transmits the power of the engine to the rotor and tail rotor, is an indispensable key core components of helicopter. The typical structure is shown in Fig.1.

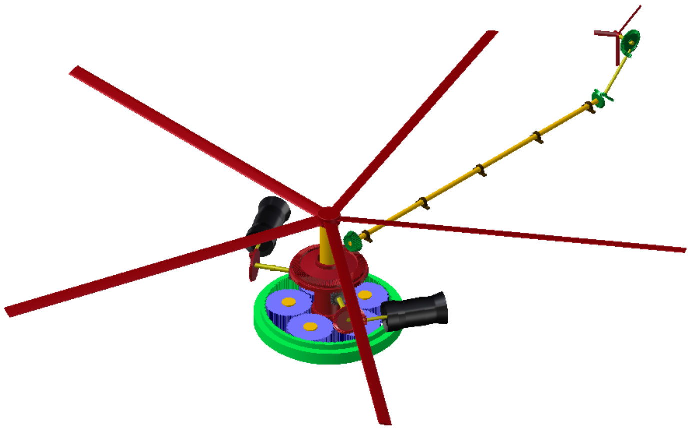

Fig.1. Typical helicopter transmission system structure.

"Three axis and three gear reducers" in the load of main rotor and tail rotor is easy to produce the relative position change of shafts because of helicopter flight environment is bad, suffered heavy load changes, reducer, shaft and rotor wing between the torsional vibration and transverse vibration. Such a complex shaft structure, any slight relative position change of shafts will lead to change the transmission characteristics of the entire drive system, which led to premature damage to bearings and shorten the bearings life. It will cause the gear meshing to produce a greater impact and tooth surface friction, resulting in vibration shock, affecting the performance of the transmission system. So that the drive system by the additional excitation force to significantly reduce the working life of the transmission system. It is important to study the dynamic response characteristics under the relative position change of the helicopter shaft system, which can provide the theoretical basis for the monitoring of the running condition of the helicopter transmission system. It is great significance to improve the stability of the helicopter transmission system and ensure its safe and efficient operation.

Domestic and foreign scholars have done a lot of work on the research of the dynamic characteristics of planetary train system. DONG et al. Established a dynamic

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model of planetary gear train, and studied the vibration characteristics of the model[1]. LIANG, et al. Considering the phase difference between meshing, the time-varying meshing stiffness of the sun wheel is studied when it produces cracks and the dynamic model of the planetary gear train is established[2]. Lei Yaguo, Luoxi, et al. Established a planetary gear train normal, crack and peeling three failure models, and analyzed its dynamic characteristics[3]. Wei Jing, Zhang Aijiang, Qin Datong, et al. Considering the flexible modeling of key components, studied the coupling vibration characteristics of planetary gear train[4]. PARKER et al. Mainly using the finite element method to analyze the vibration mode of the planetary gear system, focusing on the meshing stiffness, meshing phase, contact ratio and other factors to suppress the system vibration and noise[5]. Cheng Zhe, et al. Research on the dynamic characteristics of gear-rotor system under fault such as tooth breaking and pitting[6]. They mainly study the dynamic response characteristics of the planetary gear train from the tooth side clearance, time varying meshing stiffness, transmission error and local fault of the gear. In this paper, the dynamic response characteristics of the planetary gear train are studied from the relative position change of the gear shaft system. It is a supplement and perfect of the dynamics of the helicopter transmission system and the dynamics of the gear system.

2 Establishment of multi-body dynamics model under the change of main rotor shaft position

In order to suit the actual condition better, the rigid flexible coupling model of planetary gear train is established with all the gears are flexibly treated. After flexible processing the gear is divided into many small mass blocks, which can better express the change of gear meshing force caused by the change of shafting position.

First step, according to the gear parameters of planetary gear train in Table 1, 3D model is performed with CATIA software. When assembling, the axis of the planet carrier and the axis of the solar wheel are restricted to an angle of θ, then assume $\theta = 0, 0.1, 0.2 \cdots 0.9$, the fault model of ten sets of shafting tilt is established. Through the connection software between CATIA and ADAMS, which introduces ten groups of 3D models into the Adams software.

Second steps, all the gears are flexibly treated. The 3D model of the gear is saved as MODEL format and imported into the ANSYS software. Next, creating the cell body and the connection points, and setting the material parameters in the ANSYS software. Finally, meshing the body and the connection point respectively, establishing the rigid region and output the.Mnf file. The flexible bodies of the solar wheel, the planet gear and the inner gear ring are shown in Fig. 2 below.

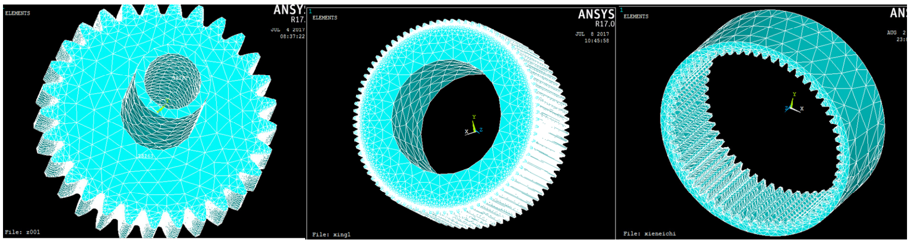

Fig.2. Flexible body of each gear.

Third steps, replacing the gear rigid body of introduced previously with the flexible body, and then the time-varying mesh stiffness is implanted into the gear contact pairs with the form of Fourier series. So the rigid and flexible multi-body dynamics model is obtained as shown in Fig.3 below.

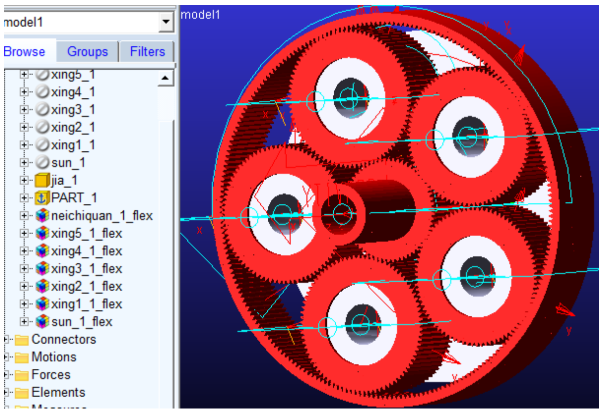

Fig.3. Rigid and flexible coupled multi-body dynamics model.

3 Response analysis of relative position change of helicopter planetary gear train shaft.

Based on the 3D model of the planetary gear trains of the relative positions change of shafting, the multi-body dynamics software ADAMS is used to analysis.

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Tab. 1. Gear parameters

Gear	No.of teeth	Module (mm)	pressure angle (°)	Tooth width (mm)
Zs	62	8	20	300
Zr	83	8	20	320
Zc	228	8	20	350

3.1 Model validation

According to the gear parameter in Table 1 and the load under certain working condition of the helicopter, (The torque of the main rotor shaft is $M = 87643.662 Nm$, drive speed is $v = 1207.5 r / \min$) the theoretical meshing frequency and meshing force can be calculated by use the following formula.

Gear-mesh Frequency

$$f_m = f_H \times z_c = (f_s - f_H) \times z_s \tag{1}$$

where, f_m is the meshing frequency between the sun wheel and the planetary gear and also the meshing frequency between the planetary gear and the annular gear, f_s and f_H are the rotation frequencies of solar wheel and planetary shelf respectively, z_s and z_c are the number of teeth of the sun wheel and annular gear. In the cylindrical spur gear drive, if the influence of the frictional force of the tooth surface is neglected, the formula for calculating the meshing force and the component force is as follows:

Tangential force $$F_t = \frac{2000T}{d_1} \tag{2}$$

Radial force $$F_\tau = F_t \times \tan\alpha \tag{3}$$

Meshing force $$F_n = \frac{F_t}{\cos\alpha} \tag{4}$$

where, T is the load torque(Nm), d_1 is the gear indexing circle diameter (mm), α is the pressure angle (°).

The multi-body dynamics software ADAMS is used for simulation analysis under the same load and driving conditions, and the results are as following table.2. By comparing the theoretical results with the simulation results, we find that the errors are within the allowable range, which shows that the multi-body dynamics model is correct and reliable.

Tab. 2. The error between theoretical and simulated values.

Name	theoretical value	Simulation value	error
The meshing force between the sun wheel and the planet wheel	16346N	17111N	4%
The meshing force between planetary gear and annular gear	16346N	17679N	6.5%
Gear-mesh frequency	980.4	980.9	0.5%
Solar wheel speed	1207.5r/min	1207r/min	0.4%
Planetary rack speed	258r/min	258r/min	0

3.2 Analysis of the influence of different inclination of shafts on gear system

When the main rotor shaft inclination of the planetary gear train is 0.1, 0.2, 0.9 degrees, the meshing force variation of the solar wheel with the planetary gear and planetary gear with annular gear are analyzed. The input speed and load of the helicopter in normal working condition are used as the simulation parameters. That is $v = 3319r/\min$, $T = 1474.4Nm$. The time domain diagram and spectrum of the gear meshing force and the orbit of the center of mass of the sun wheel are obtained as shown in the following fig.4.

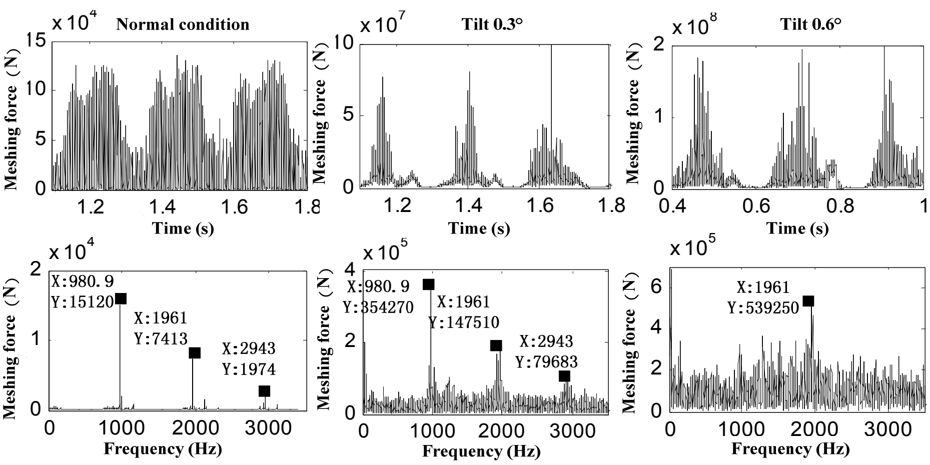

Fig.4. Time domain and spectrogram of meshing force between solar wheel and planetary wheel.

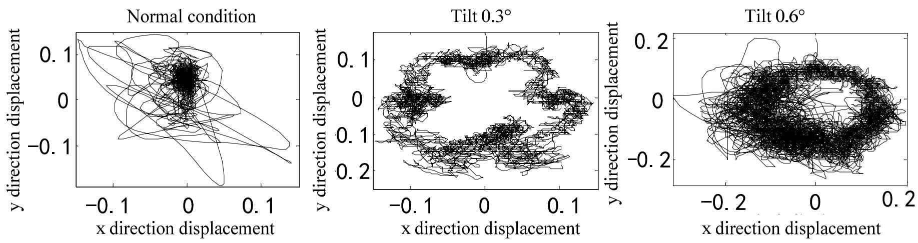

Fig.5. Centroid orbit of solar wheel.

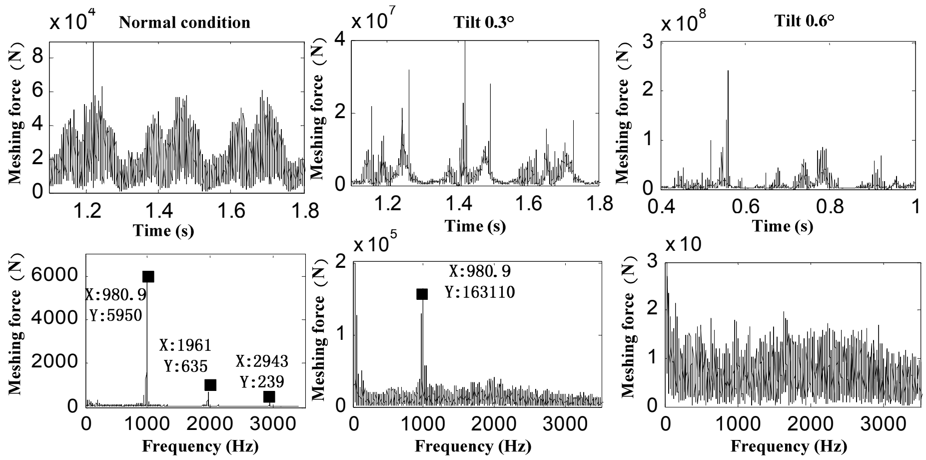

Fig.6. Time domain and spectrogram of meshing force between planetary gear and annular gear.

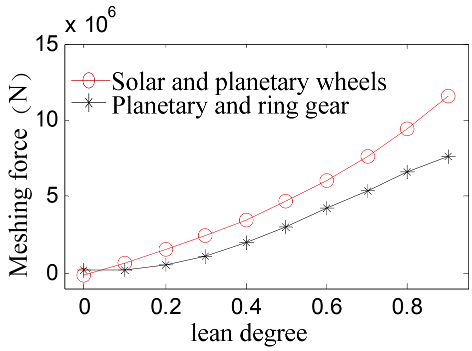

Fig.7. The change of gear meshing force with the increase of inclination.

As shown in Fig. 4-7, When the main rotor shaft of a helicopter is tilted, the gear meshing force of the planetary gear train varies obviously in time domain and frequency domain. It causes the gear average meshing force to increase with the increase of inclination, at beginning increase slowly then increases rapidly. The obvious edge frequency signals appear around the peak, and with the inclination continue to increase the peak value is gradually submerged. The center of gravity orbit of the sun wheel turns from a solid circle into a hollow circle with the increase of inclination.

3.3 Analysis of the influence of rotating speed on gear system when the shaft inclination is different

When the gear system of the helicopter transmission system occur relative position change, the meshing characteristics will affected by the change of the speed. It is known that the input speed and load of the helicopter in normal working condition are $v_m = 1207.5r/\min$ and $M_e = 87643.662Nm$ respectively. Defining $v = k_s v_m$, k_s is the speed coefficient, where $k_s = 0.1, 0.2 \cdots 0.9$, then the influence of the gear system with the change of the speed is simulated and analyzed when the shaft inclination is 0, 0.3 and 0.6.

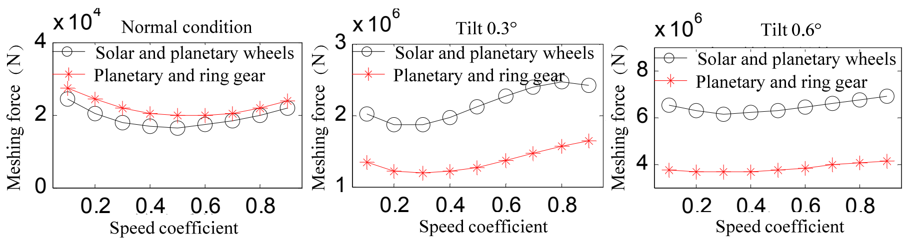

Fig.8. The change regulation of gear meshing force with the increase of rotating speed under the condition of shaft tilting.

As can be seen from Fig. 8, the average meshing force of planetary gear trains decreases first and then increases with the increase of speed. But as the speed increases, the difference of the meshing force between the solar wheel with the planetary gear and planetary gear with annular gear is getting bigger.

3.4 Analysis of the influence of load on gear system when the inclination of shafts is different

When the gear system of the helicopter transmission system occur relative position change, the meshing characteristics will affected by the change of the load. It is known that the input speed and load of the helicopter in normal working condition are

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$v_m = 1207.5 r/\min$ and $M_e = 87643.662 Nm$ respectively. Defining $M = k_z M_e$, k_z is the load coefficient, where $k_z = 0.1, 0.2 \cdots 0.9$, then the influence of the gear system with the change of the load is simulated and analyzed when the shaft inclination is 0, 0.3 and 0.6.

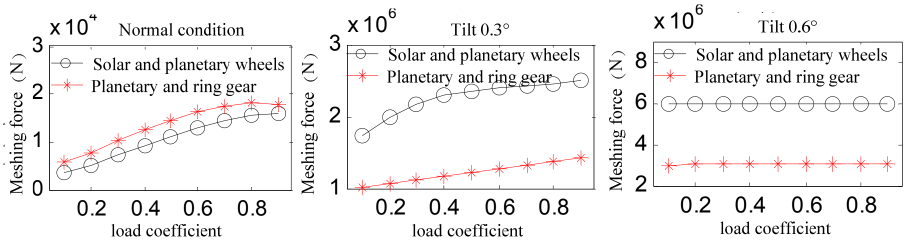

Fig.9. The change regulation of gear meshing force with the increase of the load under the condition of shaft tilting.

As shown in Fig.9, the average meshing force of planetary gear train increases with the increase of load under normal conditions or with minor changes of the inclination angle of shafting. But when the inclination angle of shafting changes greatly, the change of load has almost no influence on the average meshing force of gear.

4 Conclusion

This paper takes the planetary gear train of the main transmission system of a certain helicopter as the object, the variation of the meshing force of planetary gear train under the the relative position change of the main rotor axis is studied. A rigid flexible coupling dynamic model of planetary gear train with relative change of shafting is established by the method of modeling of gear flexibility. Then, the variation law of gear meshing force is analyzed in the case of different inclination angle of shafting,different load and different speed

Discover:

(1) The meshing force of the planetary gear train increases with the increase of inclination angle of shafting. At first, it increases slowly, and then grows faster.

(2) The meshing force of the planetary gear trains decreases at first and then increases with the increase of speed.

(3) When the inclination angle of shafting varies greatly, the change of load has little influence on the average meshing force of gear.

(4) Centroid trajectory of the sun wheel changes from the solid circle to the hollow circle with the increase of the inclination angle of shafting, and the radius increases.

The research work of this paper can provide a theoretical basis for the monitoring of the main transmission system of helicopters, which is of great significance to improve the stability of the helicopter transmission system and ensure its safe and efficient operation.

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