Study on Modal Test and Analysis of Planetary Transmission Mechanism

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Abstract. The planetary transmission mechanism is the core component for realizing the maneuverability of high-speed tracked vehicles. The modal test can determine the transmission characteristics of the planetary transmission system structure, and can check whether the dynamic characteristics of the planetary transmission system meet the design requirements. It is the basis of studying the dynamic characteristics of planetary transmission mechanism. In this paper, the free mode of the planetary variable speed mechanism is tested by using the free modal test method, and the modal analysis is carried out by using the finite element method. The results show that the vibration modes of the planetary variable speed mechanism are consistent with the results of finite element simulation, and the deviation between the measured modal frequency and the simulated modal frequency is less than 2%. The modal test provides the basis for the verification of the structural dynamic model and the dynamic coupling analysis of the planetary transmission system.

1. Introduction

Planetary transmission mechanism is the core component to realize the maneuverability of high-speed tracked vehicle [1]. The working environment of planetary transmission mechanism is bad and the load is complex. The structure and interconnection of the parts of the planetary gear transmission system constitute a complex elastic mechanical system. The planetary gearbox not only has many parts, but also its own excitation source is complex, at the same time, it is affected by external loads. The whole gearbox is easy to cause vibration coupling [2]. Modal test can determine the structural transmission characteristics of planetary transmission system, including modal frequency, modal mode shape, and modal damping ratio and so on, and can check whether the structural dynamic characteristics of planetary transmission system meet the design requirements. The defects of its structural design are found, which provides the basis for structural modification.

Researchers at home and abroad have done a lot of analysis and research on the modes of planetary transmission mechanisms. Mao [3] etc. proposed a modal analysis method of agricultural machinery gearbox based on the finite element method and introduced a stochastic finite element into the analysis method to improve the reliability of the analysis. The modal parameters and mode shapes of gearbox and shaft are obtained. Tang[4] etc., aiming at the helical gear of gearbox, the modal finite element calculation, and analysis are carried out by using ANSYS, and verifies it through the impact testing in LMS test. Lab. The finite element calculation results are compared with the test results, which
provides a theoretical basis for gear design and structure optimization. Ji [5] took the single gear two stage reducer box of an electric vehicle as the research object and carried out the modal analysis of the box body by using the finite element analysis software. The results show that there is a resonance frequency between the box body and the gear first order meshing. The purpose of this paper is to provide a theoretical basis for reducing vibration and noise of the box. Based on LMS Test. Lab software, Ren [6] and so on, the vibration exciter method is used to carry out the experimental modal analysis of the shell of a heavy-duty transmission. The research results lay a foundation for analyzing and improving the dynamic characteristics of the transmission assembly. Li [7] takes GETRAG Gear-box as the main research object, uses the finite element analysis software Abaqus to analyze the modal of the gearbox body, finds out the natural frequency of each order, and finds out the area where the vibration is greater to establish a theoretical basis for the improvement of the gearbox body. According to the fixed vibration frequency of automobile gearbox under specific working conditions, Wang [8] and so on, through the optimal design of gearbox structure, change the natural frequency of gearbox to avoid resonance.

In this paper, the free mode of the planetary variable speed mechanism is tested by using the free modal test method, and the modal analysis is carried out by using the finite element method. The modal test and analysis can provide the basis for the verification and modification of the structural dynamic model of the planetary transmission system, the response prediction, the vibration control, the stability analysis and the dynamic coupling analysis of the planetary transmission system. It is the basis of studying the dynamic characteristics of the planetary transmission mechanism.

2. Preparation for modal test

2.1. Test instrument
The instruments and accuracy requirements for modal tests are shown in Table 1.

| Serial number | Instrument name               | Quantity                      | Partial requirement                                                                 |
|---------------|-------------------------------|-------------------------------|-------------------------------------------------------------------------------------|
| 1             | Three-way accelerometer       | The quantity depends          | The frequency response range is not lower than the analysis bandwidth, and the measuring range should be greater than the vibration amplitude of the measured position. |
| 2             | Unidirectional accelerometer  | on the specific test          |                                                                                        |
|               |                               | requirements.                 |                                                                                        |
| 3             | Shielded cable                |                               |                                                                                        |
| 4             | Force hammer                  | 1                             | Select according to the piece to be tested                                           |
| 5             | Microphone conductor          | 1                             | Double head BNC                                                                      |
| 6             | Data acquisition instrument   | 1                             | The number of channels depends on the requirements of the measuring point.           |

Note: measuring instruments can be replaced by other testing instruments with the same or better performance. The error limit of the instrument is less than 1%.

2.2. Measurement and analysis software
The test software adopts LMS Test.Lab, the measurement and analysis software should include hammer test and exciter test (MIMO), has the ability to analyze experimental mode and working mode.

2.3. Test environment conditions
The test site is a special modal laboratory, the ground is flat, there is no other large vibration and noise interference, the test process is equipped with protective facilities, in line with the requirements of the modal test site.
3. Modal test method

3.1. Pre-test preparation
Before the test, the LMS simulation method is used to carry out the pre-test analysis, analysis and prediction of the test point layout and excitation point selection.

3.2. Arrangement of measuring points
The number and position of the measuring point layout should be able to ensure that all the concerned modes can be identified uniquely. The basic principle of the measuring point arrangement is to set up the geometric model according to the column coordinates and divide the measuring points uniformly along the circumferential direction. A total of 86 measuring points are arranged in the planetary transmission system, in which 6 rows and 60 measuring points are arranged on the inner hub and 26 measuring points are arranged on the shaft. There are 5 excitation points and 7 excitation directions, and the excitation direction is radial and axial.

![Figure 1. Layout diagram of measuring points for planetary transmission system](image)

3.3. Data acquisition
In the experiment, the single point excitation multi-point response mode is used to collect the signal, the average number of times collected at each measuring point is not less than 5 times, and the respective frequency function is calculated. Only when the coherence function value is greater than 0.85, the peak value of the frequency response function is highly reliable.

3.4. Considerations
When the accelerometer is fixed and the moving force hammer traverses all the measuring points, the installation position of the accelerometer should avoid the concerned modal nodes. The force hammer should be used as the excitation in the modal test, and the appropriate hammerhead should be selected in order to arouse the interested bandwidth.

4. Mode finite element method.

4.1. Dynamic equation
The dynamic equation equation of the structure is as follows:

\[
[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\}
\]  

(1)
In the formula, \([ M ]\) is the mass matrix, \([ C ]\) is the damping matrix, \([ K ]\) is the stiffness matrix, \(\{ F \}\) is the structural load vector, \(\{ \ddot{u} \}\) is the node acceleration vector, \(\{ \dot{u} \}\) is the node velocity vector, and \(\{ u \}\) is the node displacement vector.

4.2. Undamped analysis
When the structural damping is small, the influence of structural damping on natural frequency and vibration mode can be ignored. The dynamic equation of undamped analysis is as follows:

\[
[ M ] \{ \ddot{u} \} + [ K ] \{ u \} = 0
\]  \hspace{1cm} (2)

For linear systems, the solution of formula (2) is in the form of:

\[
\{ u \} = \{ \phi \} \cos \omega_i t
\]  \hspace{1cm} (3)

In the formula, \(\{ \phi \} \) is the mode eigenvector corresponding to the \(i\) order mode; \(\omega_i\) is the natural frequency of the \(i\) order mode; \(t\) is time.

Bring (3) into (2) and get the following formula:

\[
(\{ K \} - \omega_i^2 [ M ]) \{ \phi \} = 0
\]  \hspace{1cm} (4)

The condition for the solution of node amplitude \(\{ \phi \} \) is as follows:

\[
\det \left( \{ K \} - \omega_i^2 [ M ] \right) = 0
\]  \hspace{1cm} (5)

The eigenfrequency \(\omega_i\) of the \(i\) order mode can be obtained by the characteristic equation (5), and the eigenvector \(\{ \phi \}\) is the mode shape corresponding to the first order mode, and the natural frequency of the \(i\) order mode is obtained.

\[
f_i = \frac{\omega_i}{2 \pi}
\]  \hspace{1cm} (6)

5. Simulation and Test result Analysis of Planetary Transmission Mechanism
By using the undamped analysis method and using the Ansys software, the modes of the planetary transmission mechanism are analyzed, in which the 1-6 modes are rigid body modes and the vibration frequency is 0. The seventh order begins to be the vibration mode, and the comparison between the simulation mode and the test mode is shown in Fig 2. Through the comparison, it is concluded that the simulation mode is consistent with the test mode.
The comparison between the analytical modal frequency and the test modal frequency is shown in Table 2, and it is concluded that the error range between the measured modal frequency and the simulated modal frequency is less than 2%.

**Table 2. Frequency Test results of Planetary Transmission system**

| Order | Simulation frequency(Hz) | Test frequency(Hz) | Error   |
|-------|--------------------------|--------------------|---------|
| 7     | 61.34                    | 62.48              | 1.86%   |
| 8     | 61.39                    | 62.48              | 1.78%   |
| 9     | 340.52                   | 340.8              | 0.08%   |
| 10    | 341.4                    | 340.8              | 0.08%   |
| 11    | 577.67                   | 574.5              | 0.53%   |
| 12    | 720.67                   | 720.1              | 0.08%   |
| 13    | 721.19                   | 720.1              | 0.15%   |
| 14    | 893.65                   | 885.6              | 0.90%   |
| 15    | 998.7                    | 984.2              | 1.45%   |
| 16    | 1057.8                   | 1049.7             | 0.77%   |

**6. Conclusions**

In this paper, the modal test of the output shaft of the planetary variable speed mechanism is carried out by using the hammering method, and the finite element method is used to compare the modal test of the spindle with that of the analysis. The sensitivity and correlation of the modes are analyzed. The results show that:
1. After processing the test data and comparing with the finite element simulation results of Ansys software, the simulation mode is consistent with the test mode.
2. The error range between the measured modal frequency and the simulated modal frequency is less than 2%.
3. The modal simulation and test of planetary transmission mechanism can provide a basis for the verification and modification of dynamic model, response prediction, vibration control, qualitative analysis and dynamic coupling analysis of planetary transmission system.

References
[1] WANG Qinlong, WANG Hongyan, RUI Qiang. Research on parameter updating of high mobility tracked vehicle dynamic model based on multi-objective genetic algorithm [J]. Acta Armamentarii, 2016, 37 (6): 969-978.
[2] Ziegler P, Eberhard P, Schweizer B. Simulative and experimental investigation of impacts on gear wheels [J]. Computer Methods in Applied Mechanics and Engineering, 2008, 197 (51-52): 4653-4662.
[3] Mao Dandan, Wang Xiaozhi. Modal Analysis of Gearbox and Shaft of Agricultural Machinery Based on Stochastic Finite Element Method [J], Journal of Agricultural Mechanization Research. 2018, 40 (5): 62-66.
[4] Tang Liangbing, Hu Li, Yang Qiliang, et al. The Modal Analysis of the Helical Gear of the Input Shaft in the Gearbox [J], Noise and Vibration Control. 2018, 38 (z1): 372-375.
[5] Ji Yuying, Wang Hongxia, Fan Lingsong, et al. Modal Analysis of an Electric Vehicle Reducer Box [J], Journal of Hubei University of Automotive Technology. 2019, 33 (3): 17-20.
[6] Ren Bo, YANG Qiliang, HU Li. Analysis of dynamic characteristics of a heavy transmission housing [J], CHINA MEASUREMENT & TESTING TECHNOLOGY. 2019, 45 (7): 51-55.
[7] LI Qufang. Modal Analysis of GETRAG Gear-box Based on Abaqus [J], Mechanical Engineer. 2019, (1): 47-49.
[8] Wang Yudong. Vibration Signal Testing and Structural Modal Characteristics Analysis of Automobile Gearbox [J], Small Internal Combustion Engine and Motorcycle [J], 2018, 47 (5): 68-71.