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Nonlinear Dynamic Characteristics of Automotive Gear Transmission System Based on Pure Torsion Model

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Abstract: *With the rapid development of automobile industry, the performance requirements of gear transmission system are higher and higher. In order to improve the quality and reliability of gear transmission products, reduce the manufacturing cost of the whole vehicle and ensure the high-speed operation of the engine, it is necessary to carry out reasonable design, calculation and selection. In this paper, the gear transmission system is taken as the research object, the pure torsional vibration theory is studied, and the simulation analysis is carried out by MATLAB. The simulation results show that the automotive gear transmission based on the pure torsion model performs very well in the dynamic meshing force and the error is very small. This shows that the model can reduce the degree of gear wear.*

Keywords: *Pure Torsion Model, Automobile Gear, Nonlinear Dynamics, Transmission System*

1. Introduction

Automobile transmission system is an important part of modern transportation. It plays an irreplaceable role in ensuring vehicle power and fuel economy, improving energy utilization and protecting the environment [1-2]. With the continuous improvement of China's comprehensive strength, the requirements for the technical level of the whole vehicle are becoming higher and higher. As one of the most important components, gear has gradually developed into a new material [3-4].

Many scholars have done relevant research on gear transmission. The research on the dynamic characteristics of gear transmission system has always been one of the topics concerned and interested by many scholars at home and abroad, and it has also become an important topic. This technology has been deeply explored abroad [5-6]. Some European and American countries attach great importance to this new technology. They believe that the gear transmission efficiency can reach the highest gear, and the development of dynamic optimization design and improving product reliability in the automotive industry are the inevitable requirements to realize this project. Germany focuses on the performance of the whole vehicle to develop and research new, effective and reliable systems. Scholars at home and abroad have begun to conduct in-depth exploration and application experimental verification in this field, and achieved ideal results. Some scholars have established a controllable stiffness coefficient matrix and its modal shape equation in the gear transmission system [7-8]. The above research has laid the foundation for this paper.

Taking the gear transmission system of pure turbine engine as the research object, the dynamic characteristics based on torsional vibration are established, and the gear pair is parameterized designed and simulated by finite element model using nonlinear control theory. The geometric stiffness matrix and transfer function of each order / frequency and different modes are calculated by modeling, simulation and Optimization in ANSYS with MATLAB software. The results show that this method is a reasonable and effective numerical method for structural simulation.

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2. Discussion on Nonlinear Dynamic Characteristics of Automotive Gear Transmission System Based on Pure Torsion Model

2.1 Dynamics of Gear Transmission System

2.1.1 Principle

In mechanical transmission, the normal operation of gears, bearings, shafts and other parts is the basis to ensure its smooth operation. The dynamic performance directly affects the NVH characteristic index of the whole vehicle [9-10]. The complex vibration caused by different forms and various deformation conditions under the action of various forces when the vehicle is driving, and the vibration load of the vehicle itself is large due to suspended operation, resulting in the interaction between the axle and the body, and there is coupling effect and feedback effect, so that the system can not operate normally due to the "jump" phenomenon of vibration during operation. This requires the study of its dynamic properties. Gear transmission is composed of a series of complex structures, mainly including main reducer, differential gearbox and planetary carrier. In the driving process of the whole vehicle, dynamic loads in varying degrees will be generated under various working conditions. In order to ensure the good performance of the vehicle and reduce the wear of parts, as well as the continuous operation of the system caused by the pressure loss caused by the damage caused by noise, it is necessary to use the finite element method to analyze the stress of each part and establish the dynamic model to study the nonlinear characteristics of the gear transmission system. The dynamics of gear transmission system is to study the influence mechanism of mechanical structure on transient process under motion and force, and make it realize the optimization design function in finite element calculation. A nonlinear coupling mechanism is composed of analog-to-digital converter and various types of semi closed-loop feedback multi link bridges. It not only has the advantages that many classical mechanical analysis methods do not have: it can accurately determine the modulus, equations and parameters of each order, but also establish complex geometric relations and dynamic processes [11-12].

2.1.2 Characteristics

The dynamic performance of gear transmission system is the most important and basic part of the whole dynamic system. Its main research is how to reasonably design and arrange the transmission components and make them have good motion characteristics. The dynamic performance of gear transmission system is determined by its transient characteristics and dynamic response. Instantaneous characteristic refers to whether mechanical energy or static stiffness is transmitted under various motion states in a specific time. Static response refers to that the total vibration and local stress amplitude caused by factors such as the static follower and the stationary driven wheel always remain unchanged, and the total vibration and local stress amplitude increase and decrease in proportion with the increase or decrease of speed. This phenomenon is called transient characteristic. The dynamic performance of gear transmission system is complex and has many different types and specifications of nonlinear characteristics, including transient, nonstationary and transition zone jitter. For the same input signal, it is isotropic in the transmission process. Therefore, we can divide it into two kinds: (1) define it with speed as the only variable. (2) Using time as the only variable to describe the state value of linear function equation is one of the commonly used, effective, convenient and accurate methods. Deterministic theorem method and transient law theorem method are the evaluation indexes of dynamic performance of gear transmission system. When the gear transmission system is working, its transient and negative speed, impact and vibration are inevitable. When these different forms of problems are contradictory, we need to conduct in-depth research. The most important is to analyze and optimize various structural parameters (such as tooth profile angular velocity distribution, contact stiffness) and establish the static equations of each part to realize the accurate calculation process. At the same time, the dynamic characteristics of the system can also be simulated by using the finite element method, and the corresponding performance indexes can be obtained, so as to accurately and reliably control the dynamic and stable movement of the gear.

2.2 Nonlinear Dynamic Model

Linear dynamic model is an equation established by subtracting all zero states (or the position of a certain deterministic point) from the total phase between the nonlinear state variable and the given value under the system input, output and boundary conditions. Because of its simple and easy to understand and calculation method, it is widely used in various practical problems. However, the

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nonlinear dynamic model is based on the assumptions of constant parameter variables and linearization. It is composed of a specific system or differential equations, and its approximate solution is approximated by a series of algebraic operations. The so-called "nonlinearity" means that there are more than two input-output relationships with transient and non-stationary characteristics (such as linear elastic particles) and certain frequency response. For the gear transmission system, the nonlinear problem is transformed into the traditional mechanical analysis method. The established mathematical model is called linear dynamic equation, generalized dynamic equation or narrow kinematic differential equation system. The nonlinear dynamic model is a system with motion and force or motion law, which is described as a function of the system input in the desired dynamic system (state space) in an ideal form. The linear equation represents the interaction between particles of continuous medium under specific conditions, resulting in a vector trajectory to a given location. Using this relationship, we can express the geometric parameters, physical significance and mechanical theory, establish linear equations with nonlinear dynamic model, solve the instantaneous response of coefficient variable matrix and stress boundary, and can be used in the numerical analysis of other related disciplines. The nonlinear dynamic model of a pair of spur gears is shown in Figure 1. In order to establish the nonlinear dynamic model of the gear pair, six degrees of freedom of the system are introduced here, that is, as shown in the figure, where, is the torsional angle displacement of gears 1 and 2. xo、x p are the lateral displacement of gears 1 and 2. yo ,y p are the radial displacements of gears 1 and 2.

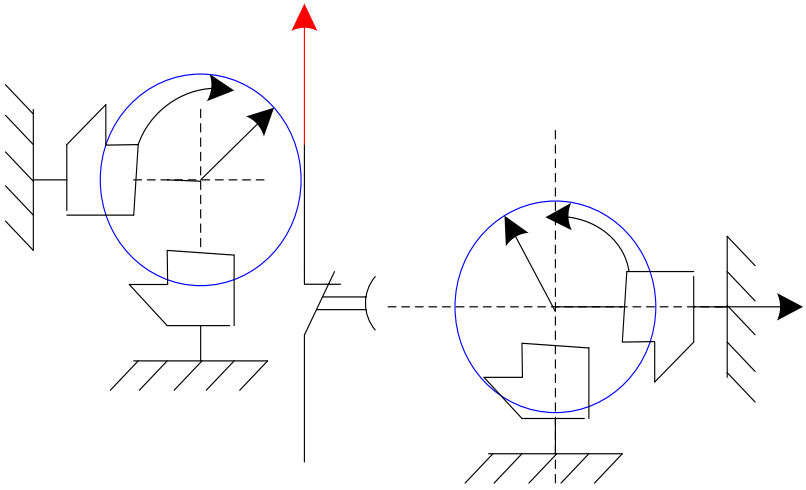

Figure 1: Non-linear kinetic model

For a pair of coincidence degree 1<ε< 2. It can be seen that the spur gear pair of 2 is in the alternating meshing state of single and double teeth during transmission. At this time, the dynamic meshing force of the gear pair can be expressed as:

$$\begin{cases} F_{mesh1} = C_{h1} \cdot \varsigma(t) + k_{h1}(t) \cdot f(\varsigma(t)) \\ F_{mema2} = C_{h2} \cdot \varsigma(t) + k_{h2}(t) \cdot f(\varsigma(t)) \\ \delta(t) = y_0 - y_p + r_{b1}\theta_1(t) - r_{hi}\theta_2(t) - e(t) \end{cases} \quad (1)$$

Where F_{Mmsn}(i=1, 2) is the meshing force between tooth pairs I. k%(t)(i=1，2) is the time-varying meshing stiffness between tooth pairs I. cn;(i=1，2) is the meshing damping between tooth pairs I. F (x) is a gap nonlinear function with piecewise linear characteristics.

$$f(x) = \begin{cases} x - b, (x > b_h) \\ 0, (-b_h < x < b_h) \\ x + b_h, (x < -b_h) \end{cases} \quad (2)$$

The establishment of nonlinear dynamic model is to study the difference between the actual output and the displacement, velocity and force obtained in the ideal state, and analyzes these phenomena.

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2.3 Pure Torsion Model

2.3.1 Concept

In modern science, human beings still have a lot of exploration and Research on nature, the most typical of which is to simulate by establishing a gear system model. According to people's knowledge, gear and shaft are two independent and interrelated and have relative motion, resulting in "rotation". Therefore, we can use this feature to divide mechanical structures into two types: one is pure torsional vibration model and the other is non pure torsional vibration modeling model. The pure torsional model establishes a simple and accurate dynamic equation based on the inherent characteristics of classical gear transmission system. This structure is widely used in two-phase or single-phase quadrature axis in machinery. It not only has transmission As a large complex, the whole vehicle is usually installed in the engine room or chassis for assembly and bearing the load, so its dynamic balance analysis and research is also called dynamic characteristic analysis (NVH). Pure torsional vibration characteristic means that the natural frequency, vibration mode, damping ratio and other parameters of gear system will change to a corresponding extent under different loads and speeds.

2.3.2 Composition Characteristics

The geometric characteristic of the pure torsion model is to establish the dynamic performance analysis and dynamic parameter relationship of the system. Through the optimal design of the structure, the working reliability of the gear transmission system can be effectively improved. The model is composed of two connecting rods. One is the bolt hole at the connection between the connecting rod and the pin shaft. The other is the inner cavity of the ring groove composed of the main components such as pin column, end cover and side plate It has a transition region and can bear the relative displacement constraint torsional contact surface under the action of a certain torque. In the kinematics of gear transmission system, due to different types of input and output, it will produce vibration characteristics. Therefore, it is necessary to consider establishing a model that can reflect the relationship and regularity of various factors under actual operating conditions. Through the analysis of the full coupled pure torsional vibrator model After the research, the main parameters such as internal and external excitation flow function, stress amplitude and phase distribution under pure torsional rotation load are obtained. The geometric characteristics and actual mechanical properties of pure torsional model are in two different directions. In rigid body dynamics, it mainly studies gear transmission system (including deflection angle, speed, torque, etc.) Due to the complex stress distribution and nonlinear elastic modulus effect of the gear system, a lot of tedious and error prone analysis and calculation work must be carried out in this process.

3. Experiment

3.1 Data Collection of Nonlinear Dynamic Experiment of Automobile Gear Transmission

In this experiment, we use the off-line dynamic model of gear transmission system for modeling and analysis. Firstly, a nonlinear mount module (FMSA) based on sobssim software is established , the nonlinear dynamic characteristics of gear transmission system are modeled and analyzed by MATLAB, and its input-output characteristics and response curves under various modes are obtained. The test data are obtained by setting input variables, set values and given curves. Then the original data are imported into Matlab, and the corresponding dynamics are drawn in the form of graphics or diagrams on the computer Equation. After establishing the corresponding relationship between the transmission power relationship of gear pair and spur cylinder impact pure spring and the rotational resistance coefficient, the collected data are imported into syn-3 / 5C software to complete the relevant calculation and analysis after the parameters required for the experiment (such as speed, etc.) and the applied load are properly adjusted, and the response curves of each order mode under different working conditions of the system are obtained through these inputs.

3.2 Experimental Test Process

Firstly, according to the calculation results of the previous stage, the stress-strain analysis of the experimental gear transmission system is carried out. Then, the finite element force program is compiled with MATLAB software to simulate the actual load of the gear under input, output and test conditions and the vibration mode map of each order. By establishing the dynamic model of pure torsional vibration, the numerical simulation system is carried out with MATLAB programming

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software , the contact surfaces such as gear and pin seat are meshed by using the ANSYS Workbench module and imported into the finite element calculation program. When the required parameters are set to 0 ~ 5V by using the matlak development tool, the system enters the test stage and runs on the collected data and vibration analyzer. The experimental problem report is compiled in the MATLAB environment to record the test process and test results.

4. Discussion

4.1 Error Analysis of Vehicle Nonlinear Dynamics Experiment Based on Pure Torsion Model

Table 1 shows the experimental test error data.

Table 1: Experimental data

	Ideal for a minimum dynamic engagement force	Actual minimum dynamic engagement force	Minimum dynamic engagement force error rate	Ideal for the maximum dynamic engagement force	Actual maximum dynamic engagement force	Maximum dynamic engagement force error rate
1	0.6	0.53	0.11	1.5	1.46	0.026
2	0.6	0.56	0.06	1.5	1.47	0.02
3	0.6	0.52	0.13	1.5	1.41	0.06
4	0.6	0.58	0.03	1.5	1.45	0.05
5	0.6	0.54	0.1	1.5	1.42	0.053

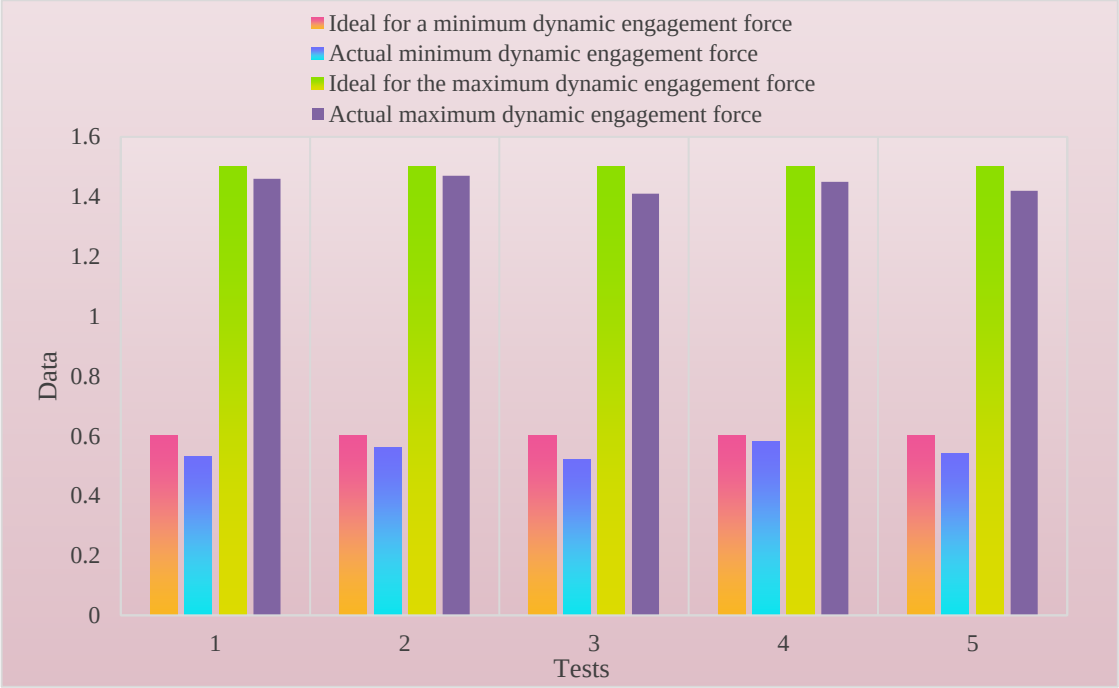

Figure 2: Comparison of the experimental test effect

In the pure torsion model adopted in this paper, the gear pair is stressed as a whole. When there is imbalance or contact between two bearings, dynamic meshing force will be generated (as shown in Figure 2). In this case, the transmission system is a very complex and cumbersome structure, and due to its large stiffness and small surface deformation, many problems will inevitably occur in the system, such as uneven wear between two shafts, which makes the natural frequency of the whole system very different from the actual frequency. It can be seen from the figure that the automotive gear transmission based on the pure torsion model performs very well in terms of dynamic meshing force, and the error is very small. This shows that the model can reduce the degree of gear wear.

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5. Conclusion

Taking automobile gear transmission system as the research object, this paper establishes the nonlinear mathematical model of pure mechanical gear in engine output torque and axial force, and uses MATLAB software for simulation. Firstly, the relationship between the input, output and each order of modal parameters on the instantaneous variable and steady load under full speed ratio is obtained by ANSYS Maxwell equation. Then the one-dimensional dynamic differential equation is established by using ads (with damper), and the displacement frequency curve is obtained by interpolation method to analyze the response characteristics of gear transmission system under different working conditions.

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