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Research Article

Analysis for the Dynamic Characteristic of the Automobile Transmission Gearbox

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Abstract: Automobile transmission gearbox, as one of the major components, which will inevitably bring about the vibration and noise of automobile vehicle. The objective of this study to reduce the noise and vibration of automobile transmission by structural optimization of the gearbox in order to better control its functional operation and improve its performance. For this purpose, based on the working characteristics of the gearbox, modal analysis of automobile transmission gearbox is formulated using 3D graphics software Pro/E together with Finite Element Method. In addition, the modal test of gearbox is conducted also. Through comparing model analysis results to test results, test results verify the correctness of the finite element analysis results, thus provide the theoretic basis to analyze its dynamic characteristics of the gearbox structure as well as its improvement to reduce vibration and noise.

Keywords: Finite Element Method (FEM), gearbox, modal analysis, noise and vibration

INTRODUCTION

Automobile gearbox is a multiple degree of freedom vibration system. A variety of exciting force acting on this system is the power and source to make the gearbox produce complex vibration. The main factors to cause all kinds of exciting force can be generalized into two categories:

- The harmonic excitation induced by working stroke combustion pressure and piston reciprocating inertia force when the engine is running.
- The meshing excitation of the transmission gear pair in the gearbox.

If the excited frequencies of these exciting forces correspond to or are similar to a certain order natural frequency of automobile gearbox, it will cause resonance, generate large-scale resonant dynamic load on certain parts of the box body and produce strong noise (Cai *et al*., 2011; Huang *et al*., 2011; Rook, 1996). Therefore, the dynamic design of gearbox requires that the gearbox body has certain inherent frequency and modal shapes, which should avoid meshing frequency from internal gear of gearbox; only in this way can we ensure the gearbox assembly has good dynamic characteristics.

The finite element modal analysis can provide a powerful tool for structural design and performance evaluation of various products, its reliable experimental results often can be used as effective evaluation standard of product performance (Wang *et al*., 2007). Obviously, the finite element modal analysis on gearbox plays a very important role on vibration absorption, noise reduction of gearbox. The study gives a finite element modal analysis to the whole gearbox, studies on the inherent frequency and vibration condition of the gearbox body, as the same time, the effective test method for modal analysis of gearbox body was carried out to verify the correctness of the finite element analysis results. The research results offer foundation for the dynamics optimization design of the gearbox structure, give some rational improvement proposals for local structure of the gearbox with severe vibration, which aims at reducing vibration and noise.

ESTABLISHMENT OF THREE-DIMENSIONAL MODEL OF GEARBOX BODY

Simplification for gearbox body: The practical model of automobile gearbox is quite complex, distributed with various reinforcing ribs, bosses, oil drain hole, corners and fillets and all kinds of bolt connection holes and so on. The gear box comprises five forward gears and one reverse gear. The gear box adopts a constant mesh gear transmission. The synchronizer, as gear shift mechanism, can make the input power be transmitted through different gear pairs, while the realization of the different transmission ratio.

In order to exert the result of modal analysis to be close to the actual situation to the fullest extent, simplification of gearbox structure should be reduced to as little as possible, to ensure that the calculation results have high precision, can more truly reflect the vibration

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Fig. 1: 3D model of gearbox body

characteristics of gearbox structure. However, too small feature structure in the gearbox body has almost no effect on modal analysis, moreover, these small structures, such as small screw thread hole or sharp fillet, can generate thousands of nodes and elements when establishing the finite element model. Too small feature structure needs to divide into very small cell, thereby increasing the amount of data processing, can result from the inability of analysis. Therefore, simplification of gearbox structure is necessary. Considering that the mass matrix and stiffness matrix of 3D solid model of gearbox body could not completely accord with the actual situation, we will, based on the equivalence principle, establish a simplified model of gearbox body and give full consideration to the factors that play a dominant role in the modal analysis of gearbox body. The powerful wildfire 4.0 Pro/E software is applied to establish the three-dimensional entity model of the gearbox body as shown in Fig. 1.

Establishment of FEA model of gearbox body: The finite element mesh generation is the key technique of the Computer Assistance Engineering analysis (CAE). A large number results of test research indicates that the meshing density is a key step in Finite Element analysis, which has great influence on computing time and accuracy of Finite Element analysis, so both aspects must be weighed correctly while determining the meshing density. Generally speaking, the smaller the meshing density is, the higher the calculation accuracy is, but the longer the computing time is proportionately and otherwise, it will make a big difference. Under ideal operation condition, the needed meshing density may occur when the following conditions occur: the results of Finite Element analysis don't vary with the increase of the numbers of the mesh (Li *et al*., 2008, 2012). Based on such consideration above, the author gives a path breaking study of the model analysis of gearbox body in different meshing densities, which focuses on comparing all analysis results with different meshing densities.

In this study, the material parameters used in calculation are as follows: the material is grey cast iron HT200, material density is 7.2×10^3 kg/m^3, elasticity module E = 110 GPA, poisson's ratio μ = 0.28.

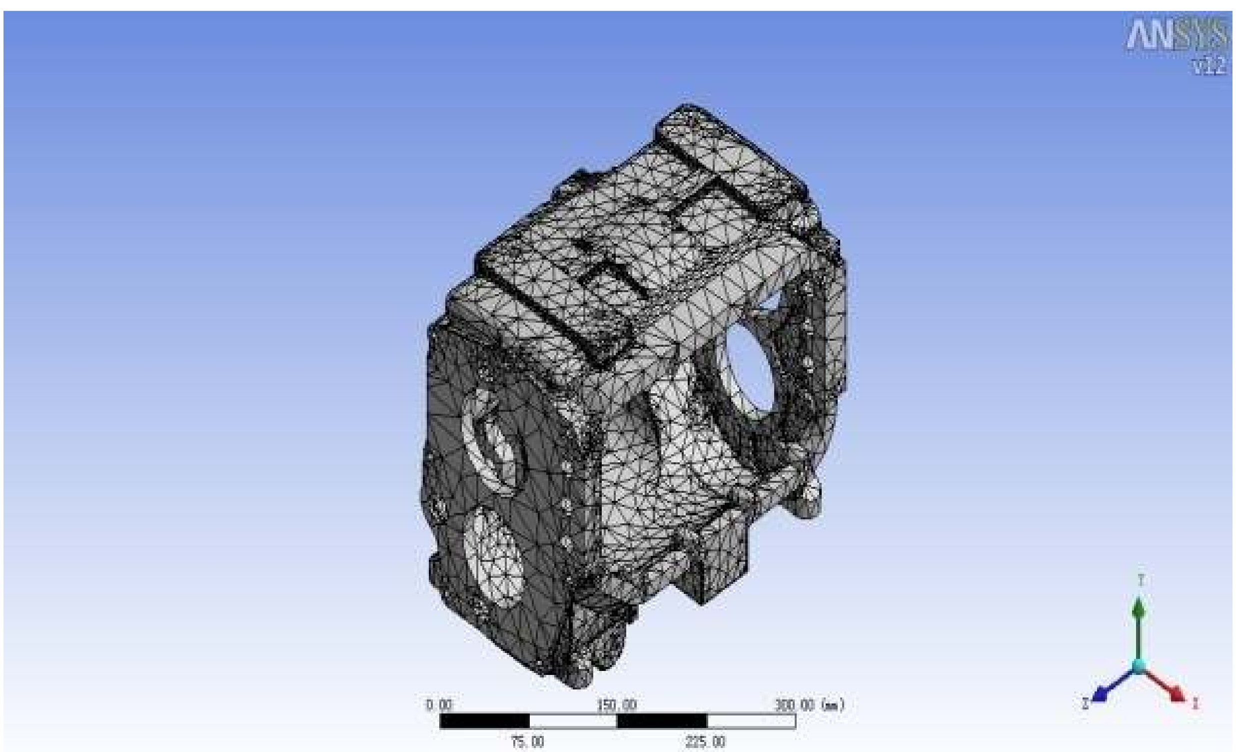

Fig. 2: Meshing the finite element model of gearbox body

Three-dimensional entity model from Pro/E software can be imported directly into FEA software, all kinds of property from entity model in the Pro/E can be inherited entirely, which includes initial position parameter and mass property of all component assembly of the gearbox body. The mesh generation of finite element model of gearbox body has a total of node 75642, element 129969, as shown in Fig. 2.

Solution of finite element model of gearbox body:

Modal analysis theory: In the structure dynamics problem, structural inherent frequency and vibration mode are the basis of dynamic analysis. In the case of undamped free vibration, structural inherent frequency and vibration mode can be converted to Eigen value and eigenvector problem. Free vibration of N degree of freedom undamped system can be expressed as:

$$[m]\{\ddot{q}(l)\} + [K]\{q(l)\} = \{0\} \tag{1}$$

Due to the free vibration of elastic body can be decomposed into a series of simple harmonic vibrations. So the solution of Eq. (1) can be assumed to be:

$$\{q(l)\} = \{u\}\cos(\omega t - \varphi) \tag{2}$$

In the equations:

ω : Real number, the frequency of simple harmonic motion

φ : Arbitrary constant

The Eq. (2) is substituted into Eq. (1) and then get:

$$[K]\{u\} - \omega^2[m]\{u\} = 0 \tag{3}$$

This is N variables homogeneous linear algebraic equations about {u}.

Necessary and sufficient condition of the equations with non-zero solution is that its determinant of the coefficients equal to zero, that is:

$$\left|k_{ij} - \omega^2 m_{ij}\right| = 0 \tag{4}$$

This equation is known as the system frequency equation, the determinant is called the characteristic determinant.

The determinant can be unfolded to get the n order algebraic expression about ω^2:

$$\omega^{2n} + \alpha_1\omega^{2(n-1)} + \alpha_2\omega^{2(n-2)} + \cdots + \alpha_{n-1}\omega^2 + \alpha_n = 0$$

It is assumed that the mass matrix and stiffness matrix is positive definite real symmetric matrix, it can be demonstrated in mathematics, n roots of the frequency equation $|k_{ij}-\omega^2 m_{ij}| = 0$ are all positive real root, which correspond to the n natural frequencies of the system. There into, if the roots are not equal, that is to say, there are no repeated roots, the natural frequencies are arranged in ascending order $\omega^2_1<\omega^2_2<\ldots<\omega^2_n$, each ω_r = (r = 1, 2…, n) is respectively, substituted into Eq. (3) to obtain the corresponding {u(r)}, this is the system modal vector or mode vector.

Modal analysis is used to determine the vibration characteristics of the structure or parts of the machine (inherent frequency and modal shape), the inherent frequency and modal shape are important parameters in the design of structure under the dynamic loads (Zhai *et al*., 2006). Considering that modal analysis is a linear analysis, any non-linear characteristics even definition also will be ignored. Modal analysis is determined by the inherent characteristics of the system and is independent on the external load, it is not necessary to set the boundary and loading conditions. Generally, zero displacement constraints are only applied to modal analysis.

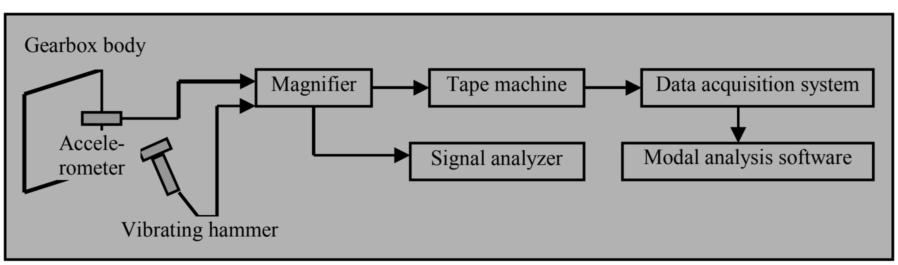

Fig. 3: Schematic diagram of test system

Table 1: Previous 8 orders modal frequencies of gearbox body

Modal order	1	2	3	4	5	6	7	8
Frequency (Hz)	371.21	520.32	706.60	915.48	1010.00	1088.60	1188.10	1264.70

Table 2: Results of the modal test

Modal order	1	2	3	4	5	6	7	8
Frequency (Hz)	377.85	549.90	733.08	968.92	1062.27	1149.27	1213.64	1397.71

Fig. 4: The supporting mode of gearbox body

Modal analysis results of gearbox body: Based on the modal analysis of gearbox, the natural frequencies and mode shapes of body are studied and gearbox vibration sensitive parts are also theoretically analyzed and calculated. In finite element analysis, in order to simulate test conditions of gearbox, zero displacement constraints are attached in the input shaft cover connecting section to go in for calculation of box constrained mode. In general, the main reason of causing engine resonance is the lower order frequency of gearbox body. Therefore, in the use of ANSYS solution and extension mode, it is enough to expands and extract the former 14 order frequencies of gearbox. When conducting modal analysis of body in the boundary condition, the first 6 order modes are close to zero; this is so-called rigid body mode. Therefore, the truly meaningful mode should be started from seventh order mode. In this study, ANSYS workbench is used to calculate the first 14 order modes, remove the first 6 order rigid body mode and extract the first 8 order non-zero modes as shown in Table 1.

EXPERIMENTAL MODAL ANALYSIS

Construction of test system: The whole modal test system consists of three parts: excitation system, data acquisition system and the modal analysis post-processing as shown in Fig. 3. In this study, the authors apply LMS SCM05 data acquisition and analysis system, modal special hammer and miniature three axis integrated circuit piezoelectric acceleration sensor, which can, through paste installation, simultaneously measure vibrations in the X, Y and Z directions and input the measured vibration signal to the computer.

Determination of supporting mode: In the modal test, supporting mode of the experimental structure has great influences on the experimental results. Supporting mode basically has two kinds, including free supporting and ground supporting. As for the gearbox body's experiment, free supporting can effectively avoid the effect of the environmental vibration and the support stiffness; keep the elastic mode without distortion. Hence, this test applies thin steel wire ropes through the spring to hang the gearbox body. The supporting mode of gearbox body is shown as Fig. 4.

Arrangement of measuring point: In view of the complex structure of gearbox body, as a casting, which has more reinforcing ribs and bosses, measuring point arrangement must be reasonable in the modal experiment, need to show the basic characteristics of the box, display correctly the modal characteristics of deformation within the experimental band and contains all the important nodes. At the same time, the sensors must be installed conveniently and measure. According to this principle, wire frame model of gearbox body is established as shown in Fig. 5, including a total of 57 measuring points.

ANALYSIS OF TEST RESULTS

Through the above-mentioned experimental method, the obtained results of modal test are shown as Table 2.

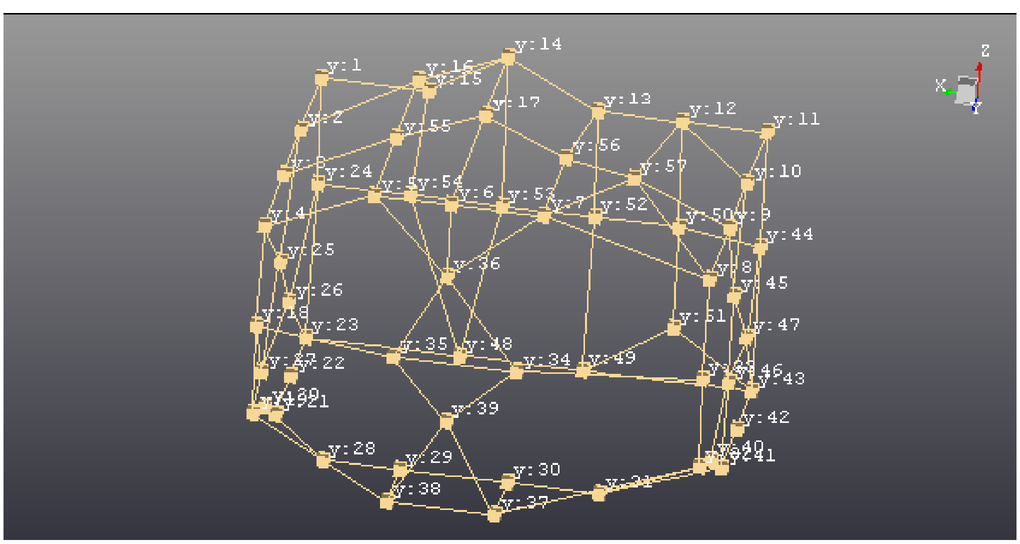

Fig. 5: Wire frame model of gearbox body

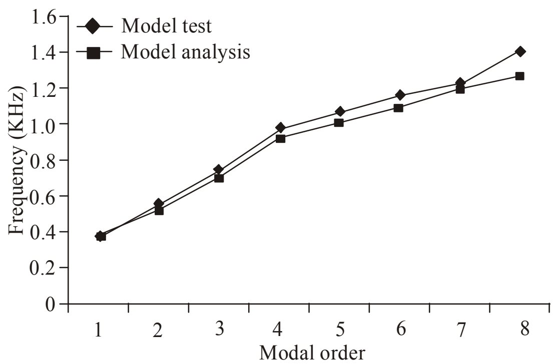

Fig. 6: Comparison results of modal analysis and modal test

The comparison results of modal analysis and modal test are shown as Fig. 6; we can draw the following conclusions: the biggest difference is 9.516%, the minimum difference of 1.75%, which meets the request of engineering calculation.

CONCLUSION

In this study, through the reasonable arrangement of vibratory response point, we put forward the effective test method for modal analysis of gearbox body, meanwhile, based on the establishment of the finite element model of gearbox body and its modal analysis, the result error between modal test and modal analysis is within the range of 10% and meets the request of engineering calculation. Therefore, the results of these studies will provide reference in the initial design stage of gearbox and has theoretical significance value to some extent for the dynamics optimization design of the gearbox structure.

Using above methods, the vibration analysis in the design process of gearbox can estimate natural frequency of the gearbox body, analysis results can be generated to find a gearbox vibration sensitive parts and provide the basis for design of structural optimization and then consciously changing the resonance frequency in the process of gear transmission will effectively avoid structure resonance problems and realize noise reduction.

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