# STRUCTURAL ANALYSIS AND OPTIMAL DESIGN IN THE END SURFACE OF THE AUTOMOBILE GEARBOX HOUSING

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*Aiming at the waviness of end surface of automobile gearbox housing in the practical processing case, this paper firstly uses acceleration sensors and PCI acquisition card for field data acquisition with the aid of Labview platform to realize the parameter measurement in end surface; Secondly, the structural strength analysis and modal analysis and harmonic response analysis are implemented to obtaine the vibration distribution of gearbox housing; Finally, combined with the actual processing conditions, the clamping positioning mode of gearbox housing is optimized to improve the vibration characteristics. The test results show that the machining vibration of gearbox housing in machining process is greatly reduced and the optimization design can ensure the machining performance of gearbox housing.*

**Keywords**: Gearbox; Clamping test analysis; Structure optimization design; End surface

## 1. Introduction

In the process of machinery, the process system often appears the phenomenon of vibration, which has great influence on the machining quality of the workpiece [1]. When the excitation frequency of the cutting force is equal to or as the integer multiples of the common fundamental frequency of the workpiece, the resonance phenomenon will occur. With the vibration intensifying, the normal cutting process of the process system is subject to interference and destruction. Thus there will be some chatter marks on the machined surface of the workpiece, which results in reducing the machining accuracy and surface quality.

Since the vibration phenomenon is inevitable during the metal cutting process, it is the premise to solve the vibration problem to make a good analytical preparation for the influence factors of vibration generation [2]. In general, according to different driving ways of vibration, the vibration modes can be divided into free vibration and forced vibration. Among them, the forced vibration is caused by a kind of periodic alternating excitation force from the outside of the

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process system. The vibration phenomena in the milling process are mainly classified as the forced vibration, which is caused by the non-uniformity of the cutting process itself. Every time the milling cutter tooth cut in or out the workpiece, due to the different in the number of cutting teeth simultaneously involved in the milling process, the shock and vibration will be generated. The milling vibration is one of the key factors that affect the machining quality and cutting efficiency of the automobile gearbox housing [3].

With the development of the automobile industry, the performance requirements of the automobile gearbox are becoming higher and higher, and then the machining accuracy and machining process of the end surface of the gearbox housing are also put forward higher requirements. This paper is aimed at the waviness of the end surface of the automobile gearbox housing in the actual processing case. Firstly, acceleration sensors and PCI acquisition card are used for field data acquisition, with the assistance of the graphical programming software Labview, to realize the parameter measurement in the end surface machining of the automobile gearbox housing. In the second place, the modern design method is applied for 3D solid modeling of the gearbox housing and fixture structure, as well as the load calculation of the actual processing conditions, so as to carry out the structural strength analysis and modal analysis. Following the above steps, the excitation response analysis in the processing vibration frequency range of the automobile gearbox housing is implemented by the harmonic response analysis, after which the vibration distribution of the automobile gearbox housing in the machining process could be obtained. In the end, combined with the actual processing conditions, the positioning mode of the end surface of the gearbox housing is optimized to improve the vibration characteristics in machining process, so as to make the inherent frequency avoid the vibration frequency, and then to reduce the resonance phenomenon.The test results show that, in the new positioning mode of the end surface of the automobile gearbox housing, the machining vibration of the automobile gearbox housing is significantly reduced. Meanwhile, the surface quality and the machining performance of the gearbox housing are improved greatly. Therefore, this study proposes a more practical optimization method for the structural optimization analysis of the parts prone to vibration, through the combination of the experimental test and finite element simulation technology, which can be more convenient to put forward the effective solution for the vibration problem of the parts in the processing of machining.

## 2. Vibration Test Analysis of the Automobile Gearbox Housing

Because it is the testing problem of the actual processing environment, we decided to use physical measurement mode rather than the computer analysis to get the vibration distribution of the workpiece in the processing environment.

In the acquisition process, we use the acceleration sensor and PCI acquisition card together to carry on the on-site data collection. The acceleration signal generated by the forced vibration of the workpiece is obtained by adsorbing the acceleration sensor on the machining parts of the workpiece. The collected data are analyzed and processed through the visualization program in the Labview environment to obtain the required vibration test data. The data acquisition process drawing is shown in Fig. 1.

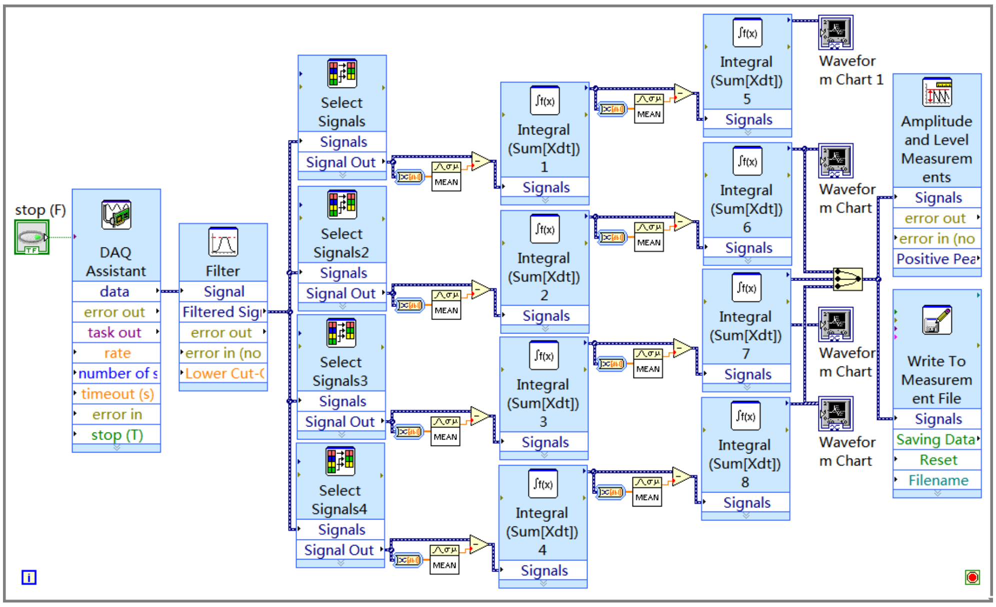


Fig. 1. Data acquisition process drawing

As can be seen from the above, we will divide the data acquisition program into four blocks. The first frame part is mainly used as the signal acquisition, whose function is to work in coordination with PCI acquisition card to collect the measurement data from the acceleration sensor; the second frame part is mainly used as the signal filter, whose function is to perform the preprocess of the obtained data to filter the environmental interference signal which obviously deviates from the vibration signal; the third frame part is mainly used as the integral processing, whose function is to transform the resulting data from the acceleration sensor to the displacement data of the workpiece through the integral computing unit; the final frame part is mainly used as the signal storage, whose function is to store the data signal in the Excel form for easy analysis.

According to the above vibration test analysis method, through the field testing of the automobile gearbox housing, we finally get the vibration spectrum of the workpiece. After the data processing, the vibration spectrum is shown in

Fig. 2. We can see clearly the vibration frequency in the end surface of the automobile gearbox housing during the manufacturing process is mainly concentrated in the 205-210Hz.

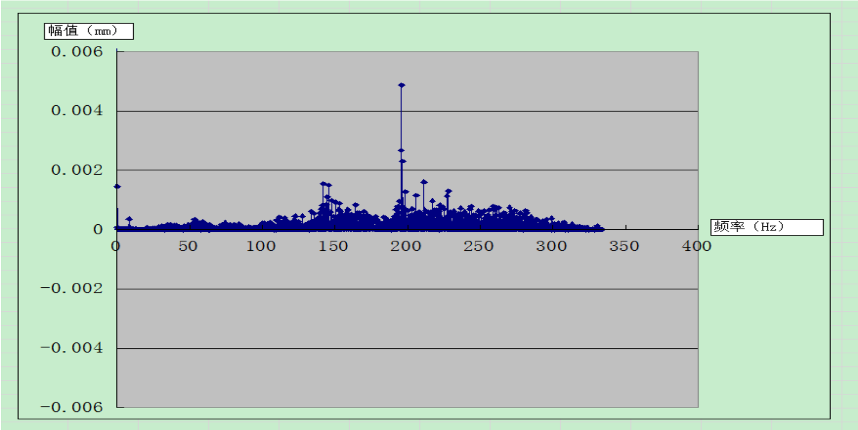


Fig. 2. Vibration spectrum in the end surface of the automobile gearbox housing

## 3. Vibration Characteristics Analysis of the Automobile Gearbox Housing

In this study, aiming at the vibration research of the workpiece during the manufacturing process, we firstly carry out the modal analysis for the solid model of the workpiece and then take the analytical results as the basis of the follow-up harmonic response analysis. The software Ansys, one of the current mainstream softwares of the finite element analysis, not only itself has powerful modeling and analysis ability, but also establishes the data interface with a large number of 3D modeling software such as SolidWorks, UG, Pro/E and so on, so as to realize the seamless connection between CAD and CAE. In addition, its precise meshing function and simulation optimization have excellent performance in the aspects of the architecture, mechanical design, aerospace technology and so on. Hence, this article will use the software Ansys to complete the vibration characteristics analysis of the automobile gearbox housing.

The research object of this paper is the end surface of the automobile gearbox housing. Considering that the overall structure of the transmission model is small and simple, although containing a certain amount of curved surface, the default reduced method in software Ansys modal analysis is applied for concrete calculation in the process of finite element modal analysis, for it has fast speed in the process of problem solving and relatively low requirements for the computer memory and processor. In spite of a certain degree of decline on its accuracy, it has reached the experiment requirements.

### 3. 1 3D Solid Modeling of the Automobile Gearbox Housing

In view of the powerful model building functionality of the software SolidWorks, with the internal integration of multiple modules, the software SolidWorks is used to perform 3D solid modeling based on the design parameters of the automobile gearbox housing, as shown in Fig. 3.

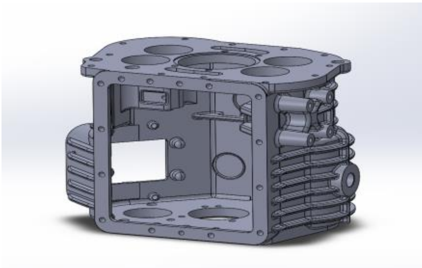

Fig. 3. 3D solid modeling of the automobile gearbox housing

### 3. 2 Modal Analysis of the Automobile Gearbox Housing

After obtaining the machining vibration spectrum of the workpiece and 3D solid model, the overall vibration performance of the automobile gearbox housing can be analyzed by modal analysis, which is the basis of the dynamic characteristics research of the object. By means of modal analysis, we can get the natural vibration frequency and modal vibration mode of the mechanical structure, which will be prepared for the following optimization process. Usually, modal analysis can be divided into the following processes: model import, material setting, mesh generation, boundary condition setting and analysis results.

The three-dimensional model of the workpiece drawn by the software SolidWorks is imported into the Workbench and then set the model material HT200 and other material properties as shown in Fig. 4.

Properties of Outline Row 3: ht200

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Property | Value | Unit | | |
| 2 | Density | 7200 | kg m^-3 | | |
| 3 | Isotropic Elasticity | | | | |
| 4 | Derive from | Young's Modulus and Poisson's Ratio | | | |
| 5 | Young's Modulus | 1.48E+11 | Pa | | |
| 6 | Poisson's Ratio | 0.31 | | | |
| 7 | Bulk Modulus | 1.2982E+11 | Pa | | |
| 8 | Shear Modulus | 5.6489E+10 | Pa | | |

Fig. 4. Material property setting of the automobile gearbox housing

After the completion of the material setting, next step is to enter the analysis interface for the mesh generation of the automobile gearbox housing. Due to the modal analysis of the whole automobile gearbox housing, the adaptive meshing method is applied to make the mesh be composed of a large number of tetrahedral structures, including 96354 tetrahedrons and 164719 nodes, as shown in Fig. 5.

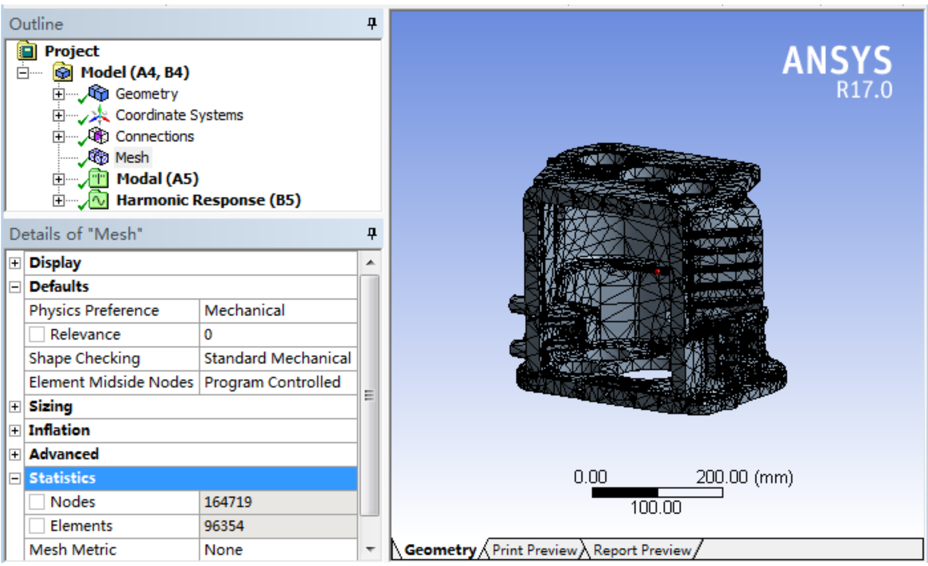


Fig. 5. Mesh generation of the automobile gearbox housing

After the completion of the mesh, the next step is to set the boundary conditions in the machining process of the automobile gearbox housing, which is mainly to set the initial positioning of the automobile gearbox housing. Through research analysis of the workpiece clamping way shown in Fig.6 and the fixture structure shown in Fig.7 under the actual machining conditions, it can be concluded that the positioning mode of one plane and two pins is applied in the processing of the automobile gearbox housing to achieve good localization effect. That is, the automobile gearbox housing is positioned through a circular pin, a cone pin and a plane composed of three-point location.

Fig. 6. The workpiece clamping way

Fig. 7. The workpiece fixture structure

After setting the boundary condition, we begin to implement the finite element analysis calculation of the automobile gearbox housing and obtain the first six order modal analysis results as shown in Fig.8.

From the results of the modal analysis, we can see that the first order modal frequency of the automobile gearbox housing is 212Hz, which is very close to the experimental result obtained above. It can be preliminarily ascertained that the reason for the decrease of the surface quality of the end surface of the automobile gearbox housing may be that the automobile gearbox housing was affected by the vibration frequency close to the natural vibration frequency of the automobile gearbox housing, which leads to the occurrence of a relatively large vibration and thus affects the machining quality.

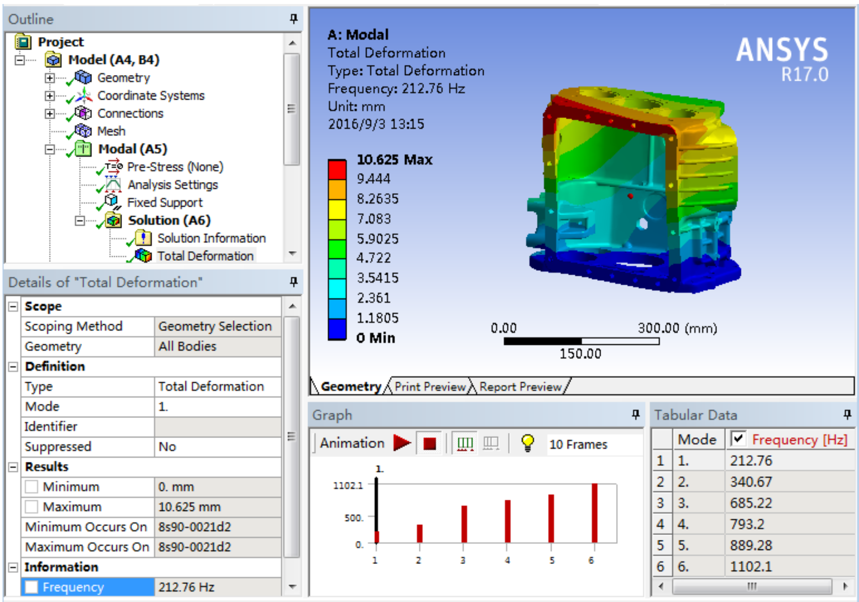


Fig. 8. Modal analysis of the automobile gearbox housing

### 3. 3 Harmonic Response Analysis of the Automobile Gearbox Housing

In this paper, based on the vibration analysis of the milling process system, the harmonic response analysis is used to further capture the vibration characteristics of the automobile gearbox housing. In general, harmonic response analysis is mainly used to determine the steady state response appeared in the object with linear structure under the action of simple harmonic load. In the process of harmonic response analysis, only the steady state forced vibration is calculated, and the transient vibration generated on the object at the beginning of the shock excitation is not required to be considered. The built-in harmonic response module in software Ansys can solve the response value of the structure in a certain frequency range in response to harmonic excitation, so as to predict the dynamic characteristics of the research object under the condition of different external motivation, and then further verify whether the structure can overcome the resonance, fatigue and other harmful effects caused by the forced vibration.

## 4. Optimization Design of the Automobile Gearbox Housing

### 4. 1 Original Positioning Mode of the Automobile Gearbox Housing

In this study, the main research object is the end surface of the automobile gearbox housing. More specifically, it is to apply a time-dependent harmonic excitation on the working surface and then to analyze the workpiece response. Since the harmonic response is mainly related to the frequency, in order for the observability of the results, we select a larger load value 10000N, so as to facilitate the result display. Considering the actual processing environment and experimental results, we intend to set the detection frequency to 150Hz-300Hz, and the frequency interval is 15 Hz.

After the model harmonic response analysis, we can clearly see that the maximum amplitude of 1.13MM appears at the vibration frequency of 210Hz as shown in Fig.9.

From the analysis results, we can draw the following conclusions: it is the inherent vibration characteristics of the automobile gearbox housing under the original positioning mode that leads to the obvious vibration of the workpiece in the machining process, and then further lower the workpiece surface quality and affect the processing performance.

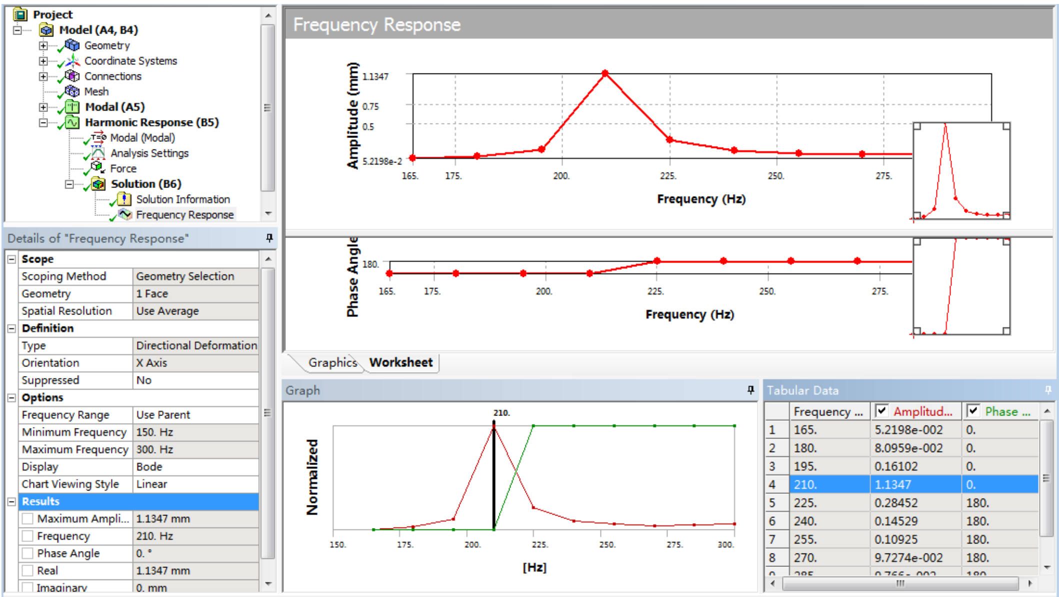

Fig. 9. Harmonic response analysis under the original positioning mode

## 4. 2 Postoptimality Positioning Mode of the Automobile Gearbox Housing

In view of the above existing problem, we try to change the workpiece clamping and positioning mode to adjust the vibration characteristics of the automobile gearbox housing in the machining process, so as to make the natural frequency offset the vibration frequency to achieve the purpose of reducing the vibration.

After the analysis of the structural characteristics of the workpiece, the positioning mode of the workpiece is initially modified as shown in Fig.10. It can be found that the whole workpiece is turned 180 degrees and then use the opposite plane as a positioning surface. We still use the positioning mode of one plane and two pins, which can well restrict six degrees of freedom of the workpiece, meanwhile, because the workpiece has good symmetry, we only need to make slight modifications of the original fixture to match with the new positioning mode of the workpiece, thereby reducing the cost of reproduction of the fixture.

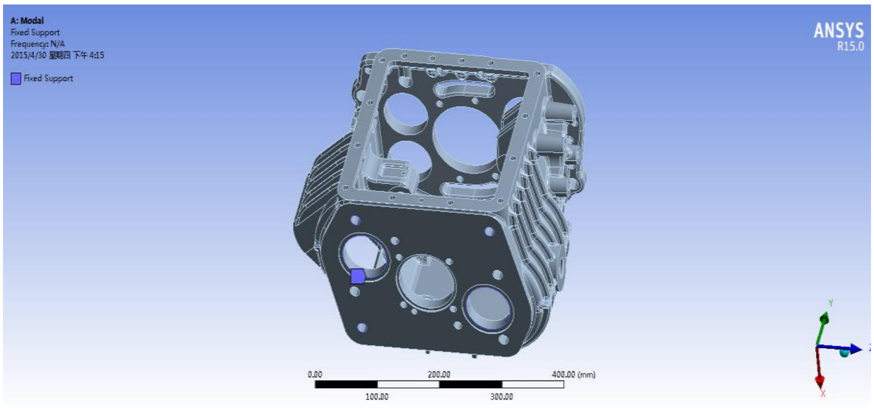


Fig. 10. Postoptimality positioning mode of the automobile gearbox housing

The modal analysis and harmonic response analysis are carried out again after the modification of the positioning mode of the automobile gearbox housing.

It can be seen from the modal analysis results shown in Fig.11 that the natural frequency of the workpiece has increased significantly after the modification of the positioning mode of the workpiece. Therefore, with the grid division and other parameters setting same as before, we still apply the harmonic load of 10000N on the end surface of the automobile gearbox housing, in order to achieve the harmonic response results of the automobile gearbox housing.

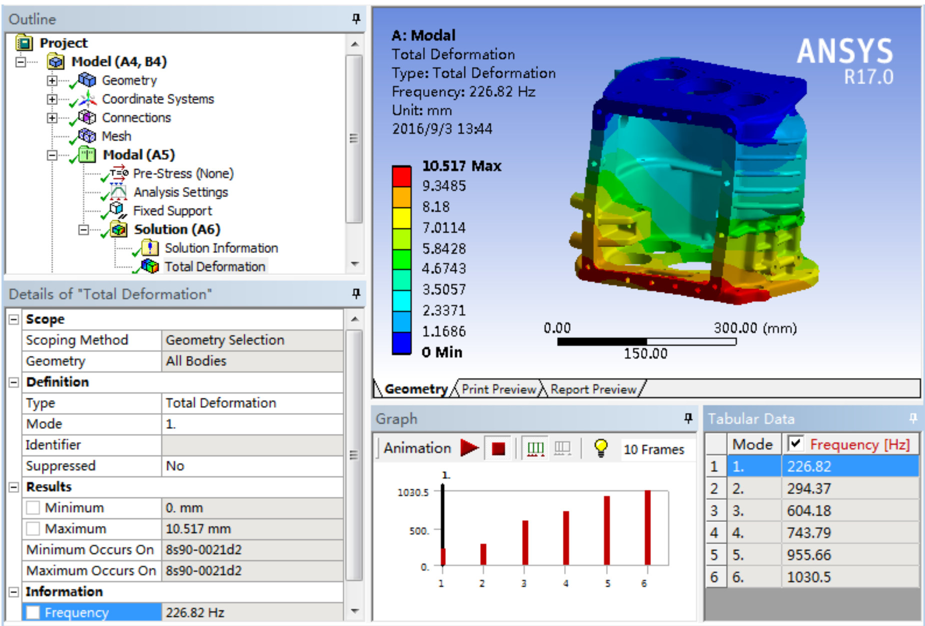


Fig. 11. Modal analysis after modification of the positioning mode

As shown in Fig.12, we can clearly see obvious changes in the response waveform of the workpiece after the modification of the positioning mode. Specifically, the maximum deformation of the workpiece of 0.131mm, occurring at the excitation frequency of 210Hz, is a significant reduction compared to the previous 1.13mm. So it is possible that the processing performance of the automobile gearbox housing can be improved by changing the positioning mode.

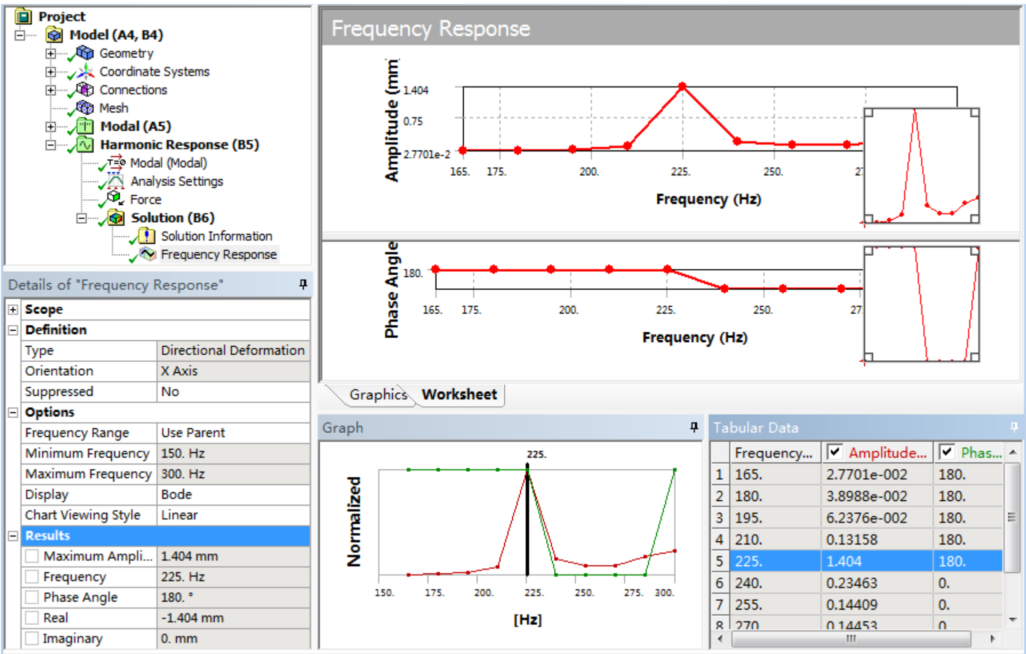

Fig. 12. Harmonic response analysis after modification of the positioning mode

## 5. Conclusions

This paper proposes a more practical optimization method oriented to the end face machining of the automobile gearbox housing easy to produce the vibration. Through using the effective combination of the experimental detection and modern finite element simulation technology, the experimental method is used to collect all kinds of processing parameters in the data acquisition stage, and the latter structural modeling and modal analysis are implemented by using 3D solid modeling software SolidWorks and the finite element analysis software Ansys respectively. This will not only ensure the reliability of the experimental study to a certain extent, but also reduce the demand of the experimental equipment, which can be more convenient to put forward the effective solution for the vibration problem of parts in the process of machining.

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