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Research on anti-flutter processing of aeroengine casing

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Abstract: Due to the thin and rigid wall of aeroengine casing, it is easy to reduce the machining accuracy due to the vibration of machine tools and cutting tools. Therefore, this paper designed an auxiliary fixture that can suppress such vibration.According to the vibration absorption principle of the tuned mass damper, this fixture is designed to transfer the vibration energy of the casing to the auxiliary fixture so as to reduce the vibration of the casing itself.According to Ansysworkbench analysis, this fixture can significantly reduce the vibration of the casing.The results show that the maximum vibration amplitude of the casing is reduced by 60%, and the average vibration amplitude is also significantly reduced.The auxiliary fixture has many advantages such as simple installation, simple disassembly and installation, strong expansibility and so on.

Key words: Thin-walled casing;Vibration;Tuned mass damper;jig

1. Introduction

Vibration is an unavoidable problem in the process of machining. The source of vibration is generally the vibration of the machine tool or the machining center and the contact vibration between the workpiece and the cutting tool system. This vibration will not only affect the surface quality of the workpiece but also greatly reduce the service life of the tool and machine tool system. Then the cause of vibration has a great relationship with the characteristics of the machine tool itself, the characteristics of the workpiece, and the processing method, processing route, etc. This makes the suppression of machining vibration a difficult problem to solve.

From the principle of vibration control, vibration suppression can be divided into three methods: vibration isolation, vibration reduction and vibration absorption. Vibration isolation is a method of vibration isolation which is installed between the vibration source and the workpiece or machining center. The study of vibration isolation needs to study and establish the dynamic model of the system and then analyze and calculate the dynamic equation.Karadayi[1] first established the nonlinear vibration isolator model. On this basis, Venkatesa[2] proposed a method to optimize the system parameters. Tang Jinyuan[3] used energy iteration to obtain the dynamic theoretical equation of cubic nonlinear stiffness. Damping method is a damping method to reduce system vibration energy by installing damping structure on main structure. Damping materials are usually non-metallic plastic rubber, etc., and their forms vary according to different vibration reduction scenarios.In recent years, active damping technology has gradually replaced the traditional passive damping technology due to its wide range of application and good vibration reduction performance. Vibration absorption is a method to transfer the vibration energy of the main system to the damping system by means of appropriate frequency modulation technology.This method has always been the focus of scholars' research.Based on the vibration absorption principle of the tuned mass damper, this paper designs a set of auxiliary fixtures for the casing through finite element analysis of the casing, three-dimensional modeling of auxiliary fixtures, and modal testing of the casing and fixture.

2. Tuning the vibration absorption principle of mass damper

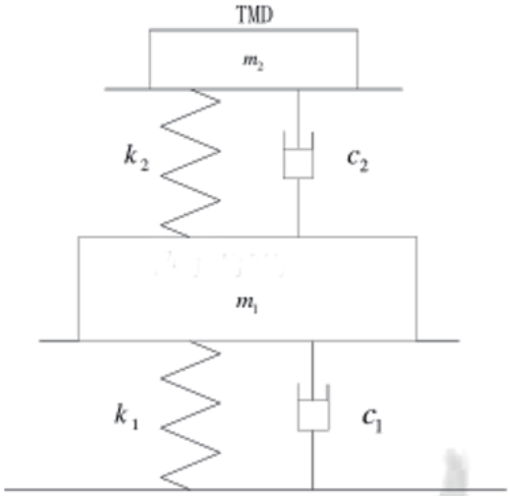


Figure 2-1. Schematic diagram of tuned mass damper

The damping principle of TMD is that TMD is attached to the main structure as a substructure, By passive resonance, the vibration energy of the main structure is transferred to the substructure, that is, the damper, so as to suppress the vibration of the main structure. The damping performance of TMD lies in accurate frequency modulation. If the natural vibration frequency on the damper is close to the main structure, the vibration of the substructure will be very strong, and a fierce external counteracting force will be generated on the main structure, thus reducing the vibration of the main structure. TMD is a second-order mass spring damping system, and its working principle is shown in FIG. 2-1.

The motion equation of the system is:

$$\begin{gathered} m_1 x_1''(t) + c[x_1'(t) - x_2'(t)] + \\ (k_1 + k_2) x_2(t) - k_2 x_2(t) = F_1 \sin(\omega t) \end{gathered} \quad (1)$$

$$\begin{gathered} m_2 x_2''(t) + c[x_2'(t) - x_1'(t)] \\ -k_2 x_1(t) + k_2 x_2(t) = 0 \end{gathered} \quad (2)$$

Among them, m_1 、 c_1 、 k_1 respectively represent the mass, damping ratio and spring stiffness of the main structure. m_2 、 c_2 、 k_2 respectively represent the mass, damping ratio and spring stiffness of the spring mass damper.

Based on the fixed point theory, when the mass of the main system parameter damper is certain and the damping of the main system is not considered, the optimal design parameter of the damper is as follows:

The optimal natural frequency ratio of the damper is:

$$\frac{\omega_a}{\omega_n} = \frac{1}{1+\mu} \quad (3)$$

The optimal damping ratio of the damper is:

$$\xi = \sqrt{\frac{3\mu}{8(1+\mu)^3}} \quad (4)$$

Among them:

ω_a -The natural frequency of the damper

ω_n -The natural frequency of the damper

μ -The mass ratio of the damper to the main structure

Can be seen from the formula (3), as long as the quality of the auxiliary fixture m_1 determined, and the main structure of the damper quality than μ is sure. Due to the natural frequency of the main structure of ω_n is certain, The natural frequency of the damper needs to be optimized without changing the quality of the auxiliary fixture so that it meets the optimal natural frequency calculated by formula (3). In the same way according to the formula (4) when μ to determine the optimal damper damping ratio ζ is sure.

3. Finite element analysis of casing

The current finite element analysis software provides an effective analytical method for theoretical modal analysis. By proper computer modeling, meshing and boundary condition setting, more accurate analytical results can be obtained, and a preliminary understanding of structural modal can be obtained before the test. BlockLanczos method is used to calculate the natural frequency and modal shape of thin-walled casings. 2219 aluminum alloy is the casing material with the elastic modulus of 73GPa, Poisson's ratio of 0.3, density of 2700kg/m³, casing mass of 93.54kg, diameter of 2.086m, height of 0.6772m, thickness of 5mm and up to 53mm.See Figure 3-1.

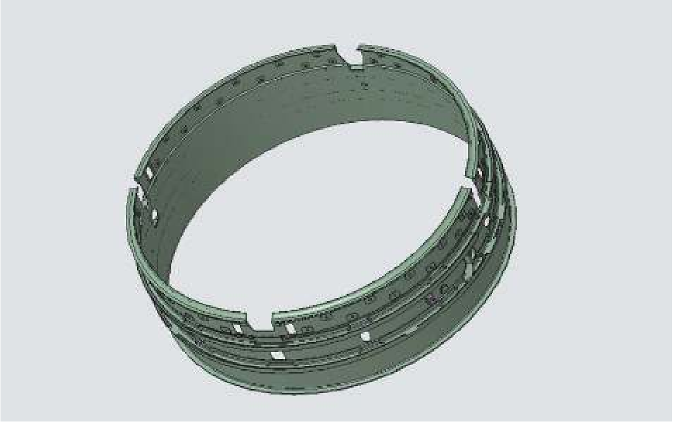


Figure 3-1. 3d model of the casing

3.1. Grid division of casing

The meshing method was adopted to divide the casing into 746,850 nodes and 388,760 regular tetrahedral units, with a moderate degree of smoothness and a fineness of 5.After grid division, the model is shown in Figure 3-2.

Figure 3-2. Mesh division of the casing

3.2. Setting of boundary conditions

In order to minimize the machining deformation, the boundary condition was set as the zero displacement constraint of the bottom plate (the constraint surface is close to the four open ends of the casing, a total of 8 surfaces). See Figure 3-3.

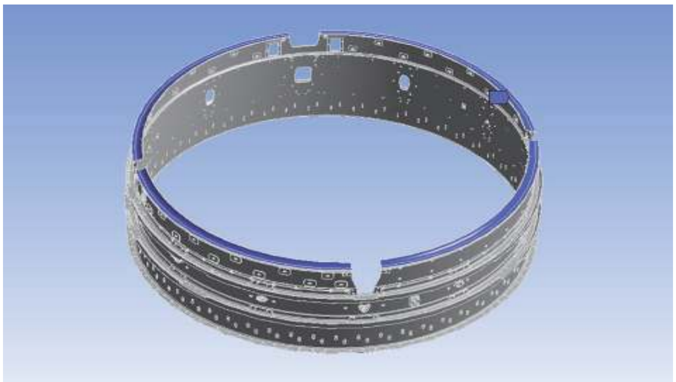
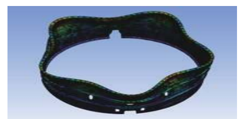
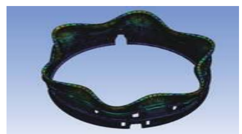
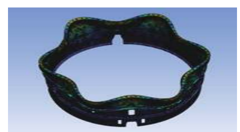


Figure 3-3. Setting of casing boundary conditions

Table 3-1. the 10 modes of the casing

Modal order number	Natural frequency (Hz)	Modal vibration mode	Modal order number	Natural frequency (Hz)	Modal vibration mode
1	223.28		6	253.38	
2	227.55		7	300.69	
3	245.97		8	304.26	
4	248.82		9	320.66	
5	252.98		10	347.84	

3.3. Modal analysis harmony response analysisAnsysworkbench was used for modal analysis and calculation, and the tenth mode of the casing and its corresponding frequency were obtained as shown in Table 3-1.

In order to determine the main mode of the object, harmonic response analysis is carried out on the basis of modal analysis.The alternating load of harmonic response analysis varies from 200Hz to 400Hz, and the solution interval is set at 20Hz.Table 3-2 shows the amplitude-frequency response of the casing.According to the icon, it can be seen that the amplitude of the timing box near the frequency of 230Hz is the largest, and the mode corresponding to this frequency is the main mode of the casing.The corresponding second-order mode of the casing is shown in Table 3-1, as shown in FIG. 3-4.

It can be seen from Table 3-4 that the amplitude of the casing near the frequency of 350Hz is also relatively large. In order to better design the auxiliary fixture, the vibration mode corresponding to this frequency is taken as the auxiliary vibration mode.See Figure 3-5.

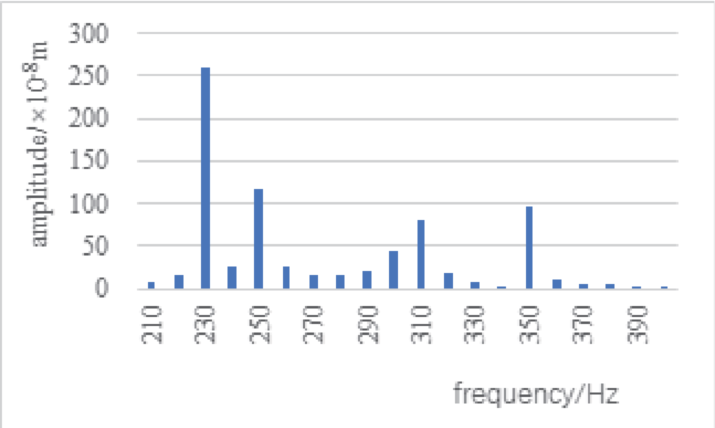


Figure 3-4 .Case Harmonic Response Frequency Response

Figure 3-5. Main vibration mode of the casing

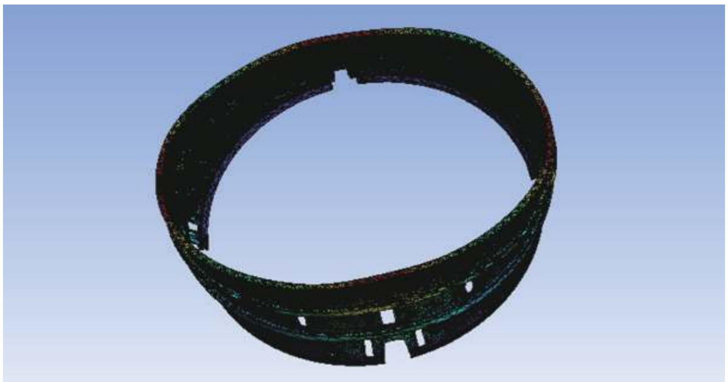


Figure 3-6. Auxiliary vibration modes of the casing

4. Assist fixture design

Through Ansys workbench harmonic response analysis, the main mode of vibration of the casing is shown in Figure 3-5. Considering that this mode is not conducive to fixture installation, the first auxiliary mode of vibration of the casing is shown in Figure 3-6.Combining the two models, the basic contour of the fixture is determined as an octagonal design.

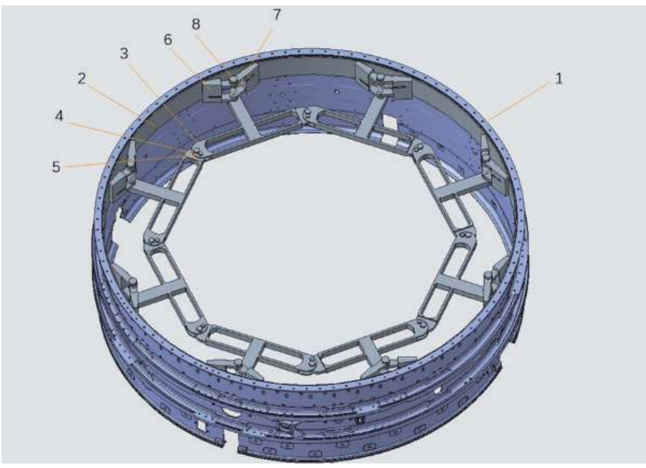


Figure 4-1. Fixture installation diagram

It makes the fixture easy to use and easy to disassemble and assemble. At the same time, no additional clamping device is needed. The clamping mechanism is designed as self-tightening mechanism.That is, the use of torsion spring torsion to make the fixture and the workpiece closely together.See Figure 4-1, 1 is the casing. In order to reduce the damage to the casing caused by the contact between the casing and the fixture, a rubber washer 2 is added between the casing and the fixture, In direct contact with the rubber washer, the pressure plate 6 is clamped on the concrete. A total of 16 identical pressing plates ensure adequate contact between the casing and the fixture. At the same time, in order to ensure the close contact between the casing and the fixture, twist spring 7 was added between the long bolt 8 and the pressing plate. Under the action of twist spring, the pressing plate was in close contact with the casing.

4.1. T-frame structure design

1,The basic outline size of the T-frame is determined by the casing diameter, the inner diameter of the casing is 1980.6mm, and the thickness of the rubber washer is designed to be 10.6mm. Then the specific maximum contour diameter of the clip is 1980.6-10.6=1970mm. According to the finite element analysis, the specific design of the clamp is a regular octagon. According to the geometric calculation, the specific maximum side length of the clamp should not exceed 2×1970×sin22.5°=753.88mm. In order to ensure the strength of the T-frame, the maximum outline size is 620mm ×270mm × 40mm. The T-frame is designed with weight reduction. On the premise of ensuring mechanical strength, two 205mm×100mm through holes are opened in the middle of the T-frame.

2, The three bolt openings are all 20mm, the dimensional accuracy is mm, and the fit between the bolt hole and bolt rod is F8/ H7.See Figure 4-2.

3, The 7005 aluminum alloy has good welding performance and can be strengthened by heat treatment. 7005 aluminum alloy extruded materials, often used in the manufacture of both high strength and high fracture toughness of welded structures, such as transportation vehicles truss, bar, container;Large heat exchangers and parts that cannot be fixed after welding;It can also be used to make sports equipment such as tennis rackets and softball bats.The Material of T-frame is 7005 aluminum alloy.

4, The upper and lower surfaces of the T-frame only bear vibration impact and partial torsion load, while the bolt holes bear large impact load. According to the requirements of the working conditions of the parts, the following surface roughness requirements are formulated.

(1) The roughness of upper and lower end faces and sides is 12.5.

(2) Bolt hole roughness is 6.3.

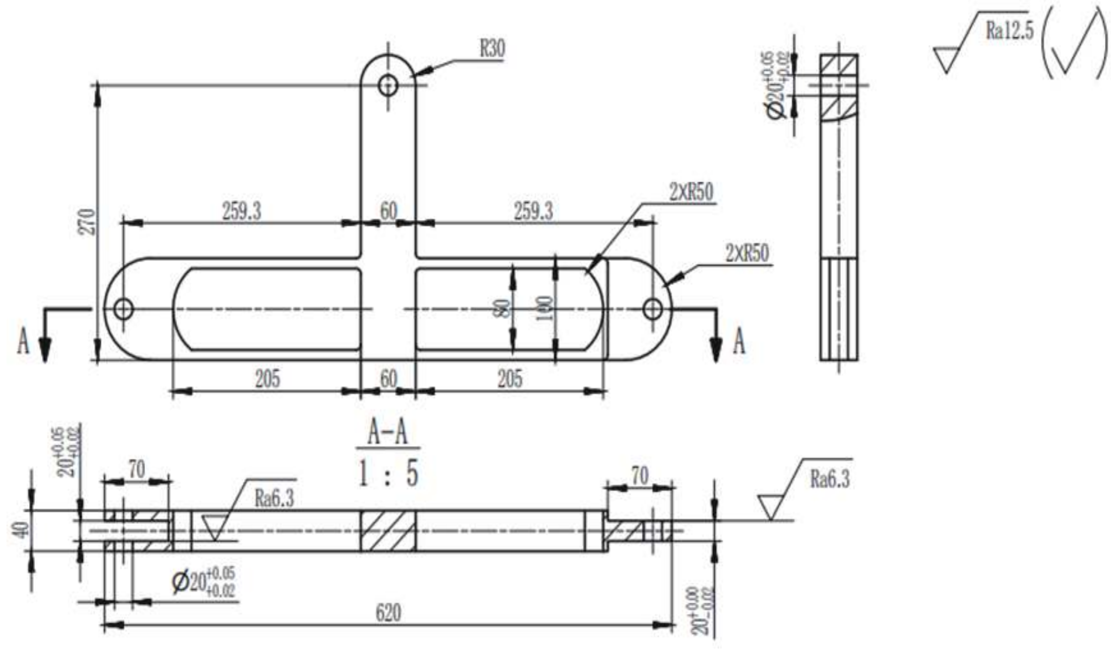


Figure 4-2. Parts drawing of T-frame

4.2. Platen design

1. The outer profile size of the pressing plate is mainly determined according to the deformation size of the casing based on the harmonic response analysis. Its width and height are 150mm×160mm.

2. A groove with an outer dimension of 60mm×8mm×8mm is cut at 40mm away from the top and bottom of the pressing plate respectively to place the torsion spring.

3, in order to ensure the clamp can carry on the Angle of rotation around the bolt, using clearance fit between, cooperate with the dimensional accuracy of $\Phi 20^{0.05}_{0.02}$,bolt hole circle degree of 0.02.See Figure 3-8.

4. The pressing plate material is 7005 aluminum alloy.The surface of the pressing plate bears vibration impact and the two bolt holes bear large loads. According to the requirements of the working conditions of the parts, the following surface roughness requirements are formulated.

(1) The surface roughness of upper and lower surfaces and side surfaces of the pressing plate is 12.5.
(2) The surface roughness at the slot of the pressing plate is 12.5.
(3) The surface roughness of the opening hole of the pressing plate bolt is 6.3.
(4) Concentricity between two bolt holes of pressing plate is 0.02.

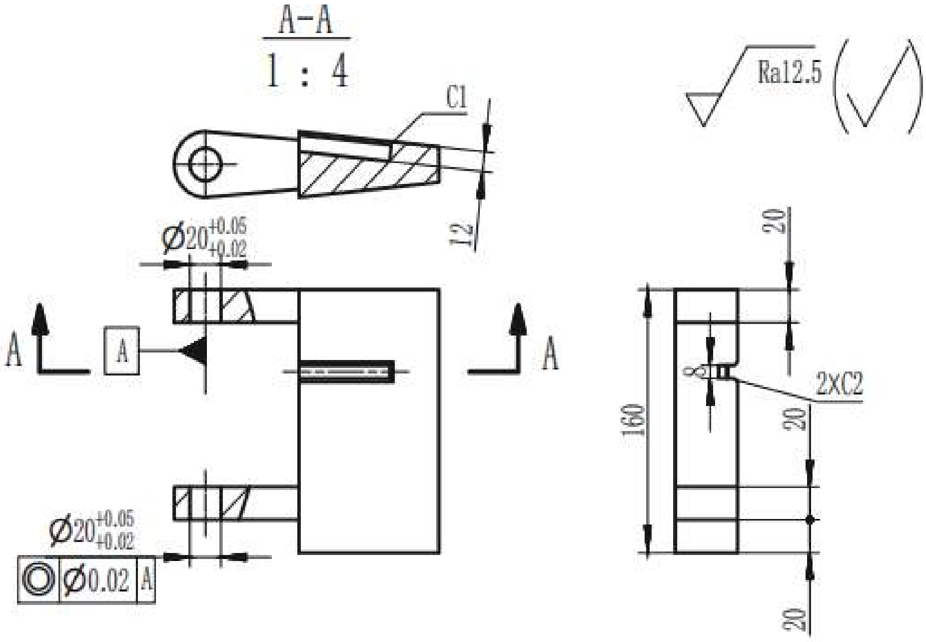


Figure 4-3. Drawing of pressing plate parts

4.3. Torsion spring design

The torsion force of torsion spring mainly depends on its elastic coefficient.And the size of the elastic coefficient mainly depends on: material, cross-sectional area, the number of turns per unit length.The calculation formula of torsion is:

$$F = \frac{E\pi d^4 \varphi}{3670DnL} \qquad (5)$$

E is the elastic modulus of the spring material (Mpa). The torsion spring material is 65Mn spring steel, and its elastic modulus is 198000Mpa. D is the diameter of torsion spring (mm), and the design size is 5mm;j designed for torsional spring torsion Angle, Angle of 50 °;L is the length of torsion spring torsion arm (mm), the design size is 60mm;D is the middle warp of torsion spring (mm), the design size is 25mm; n is the effective number of torsion spring, and the designed number of turns is 12.

Substitute in to calculate:

F=5000N

Looking up the table, it can be seen that the friction coefficient between aluminum alloy and rubber is 0.25, the total weight of the fixture is 120N, and the rubbing force of the pressing plate is 5000×0.25=1250N. The maximum static friction that can be provided is about 10 times of the total weight of the fixture, that is, it can be fully satisfied that the fixture is firmly clamped on the casing.

4.4. Design of rubber gasket

The rubber gasket mainly plays the role of evenly distributing the pressing plate force and protecting the inner surface of the casing. Its outer diameter is 1980.6mm in accordance with the inner diameter of the casing, and its thickness is designed to be 10.6mm.

4.5. Selection of standard parts

1, Long bolt GB/T 5780-2000, M20 ×230mm.

2, Bolt GB2165-80, M20×60mm.

3, Nut GB1670-2000, M20.

4, Gasket GB97.1, 20 A140.

5, Cylindrical pin GB2202-80, M15× 50mm.

5. Modal testing

In this design, simulated modal testing is adopted, that is, the finite element analysis software is used to assemble and simplify the casing-jig and conduct modal analysis. By comparing the casing-jig before it is assembled, the amplitude of the casing-jig is observed to see if there is a decrease, so as to verify the role of the jig in suppressing flutter in the processing of the casing.

In order to simplify the calculation, the casing and fixture were simplified and then imported into AnsysWorkbench, as shown in Fig. 5-1.

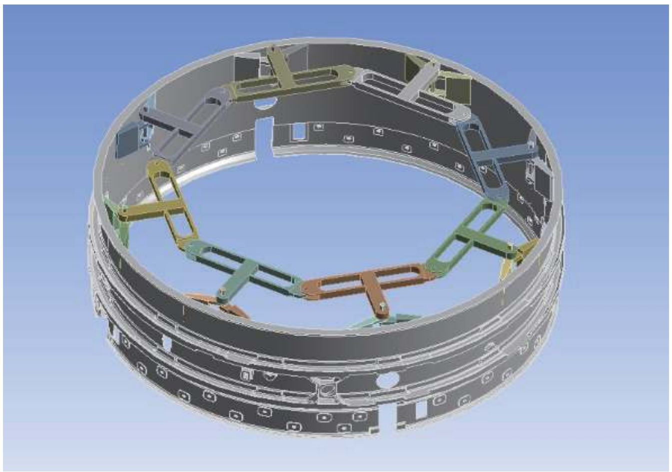


Figure 5-1. Simplified model of casing-fixture

After importing Ansyswoekbench, modal analysis and harmonious response analysis were carried out on the casing-jig model. The specific steps were the same as the finite element analysis of the casing-jig in Section 3.

The calculated frequency response of the casing fixture is shown in Fig. 5-2.By comparison with Figure 3-4, it can be seen that the maximum frequency response of the casing is 100×10-8m, and it is 250×10-8m before the fixture is installed, and the vibration amplitude is reduced by 60%.

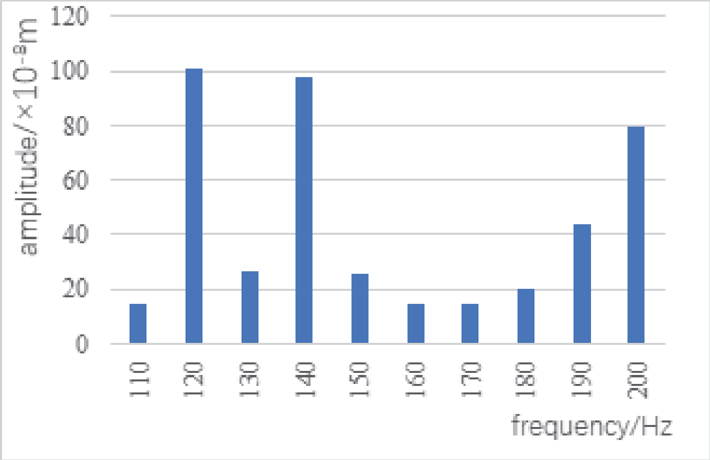


Figure 5-2. Case clamp harmonic response frequency response

6.Conclusion

1. Based on the vibration absorption principle of spring mass damper, an auxiliary fixture which can be used to reduce the machining vibration of gearbox is designed. The torsion spring is composed of a T-type clamp, a standard clamp, a T-type washer. The auxiliary fixture has the advantages of obvious damping effect, simple installation, convenient maintenance, and adapting to different damping scenarios.

2. Through the simulation modal test results, it can be seen that the auxiliary fixture reduces the casing vibration amplitude by 60%.

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