Design of Seat Clamping Device for Automobile DOF Shaker

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Abstract. The clamping device is used to connect and fix the vibration table and the test part, as well as transmit vibration excitation in the vibration test. Taking the RX / ZDT-6-200 automobile DOF vibration table as the development platform, a clamping device suitable for a variety of automobile seats is designed based on the analysis of clamping device design key points. The 3D modeling of seat clamping device is completed in the Creo software environment, and its natural frequency is simulated and analyzed. It can be seen from the analysis results that the device can effectively avoid resonance. Finally, the clamping device is manufactured and tested. The test results show that the clamping device can meet the requirements of teaching experiment.

1. Introduction

The automobile vibration simulation test is used to simulate the vibration condition of the automobile driving on the actual road in the laboratory and monitor automobile response, as well as test the reliability of automobile components in vibration environment. These tests mainly relies on the experimental equipment of automobile DOF vibration table. In order to ensure the experiment carry smoothly, clamping device are needed to connect and fix vibration table and the specimen. Therefore, clamping device not only has good rigidity, but also has the characteristics of transmitting shock vibration and avoiding resonance. In addition, due to the vibration table mainly tests automobile parts or assemblies, it is better not to destroy the table surface when using the clamping device so that vibration table to undertake more experimental tasks. Considering above factors, a seat clamping device of automobile DOF vibration table is designed for teaching experiments.

2. Key points of clamping device design

Clamping device is the clamp that connects and fixes vibration table with specimen, as well as transmits vibration excitation in vibration test, which makes it different from the ordinary clamp. Compared with ordinary clamping device, the clamping device is in a dynamic vibration environment during the test process, which needs to withstand a large impact load without any additional impact on the seat. So the device is required to have high rigidity and low quality. At the same time, in order to get more accurate test data, the clamping device needs to have the following characteristics:

(1)The clamping device should have a better pre-tightening force to avoid the separation of the seat and the vibration table due to a large load during the experiment.

(2)The rigidity and mass ratio of the clamping device should be large enough to improve the natural frequency.
(3) The first order natural frequency of the clamping device should be as high as the maximum test frequency, to avoid vibration coupling between clamping devices and products.

(4) When the clamping device connects the seat and the vibration table, the connecting points should be evenly distributed to ensure that the impact load on each part of the seat is fairly uniform.

(5) Clamping device damping should be as large as possible, and clamping device motion perpendicular to the excitation direction should be small, so as to avoid disturbing the vibration test.

3. Overall structure design of clamping device

3.1 Clamping device design process
When designing automobile seat clamping device, we should first know the shape of automobile seat, its positioning and installation on the automobile, as well as master the shape and size of platform on the vibration table, so as to ensure space-layout rationality of the clamping device on the platform and restore the installation mode of automobile seat on the automobile. The design process is as follows:

1) Draw the model diagram of automobile seat clamping device in Creo software.
2) Then establish the finite element model of the clamping device in Creo software.
3) Carry on the modal analysis to get the vibration mode and modal frequency of the clamping device.
4) Judge whether the calculation results meet the test requirements.

If the calculation results meet the test requirements, we can draw 2D drawings and manufacture clamping devices. If it does not meet the design requirements, it is necessary to modify the clamping device partially until it meets the design requirements. The design flow chart of the clamping device is shown in Fig 1.

![Design Flow Chart of Clamping Device](image-url)
3.2 Structural design of clamping device

The structure of the clamping device is shown in Fig 2. This clamping device is mainly composed of screw clamping mechanism, T-groove guide rail and the main body of the clamping device, of which 2, 3 and 4 constitute screw clamping mechanism.

In the vibration test of automobile seat, it is necessary to fix the seat completely on the table and limit its six freedom degrees. In order to simulate the road conditions and restore the installation form of the seat on the automobile, the seat is fixed on the T-groove guide rail by four screw holes on the seat bottom plate. On the T-groove guide rail, the seat is positioned by the bolt holes. These bolt holes is processed through the size and position of four screw holes on the seat bottom plate. A sliding groove is arranged at the joint of the T-groove guide rails and the clamping device. Therefore, the clamping of multiple seats can be realized by adjusting the positions of the two T-groove foundation plates.

3.3 Materials and processing methods

Table 1. Material Properties

| Material          | Aluminum | Magnesium | Steel |
|-------------------|----------|-----------|-------|
| Modulus of elasticity $E$ (G Pa) | 71.5     | 44.1      | 205.8 |
| Density $\rho$ (g.cm$^{-2}$) | 2.8      | 1.8       | 8     |
| $E/\rho \times 10^6$ (m$^2$.Pa.kg$^{-1}$) | 25.5     | 24.5      | 25.7  |

The clamping device is in a dynamic environment during the test, and there is no or less resonance in the test frequency band. The factor controlling natural frequency is $E/\rho$, $E$ is elastic modulus, and $\rho$ is...
material density. Under the same structural conditions, the larger the ratio is, the higher the frequency is, and the material with large damping should be chosen. From Table 1, it can be seen that the value of $E/\rho$ of steel is the largest, but its density is too high, while the value of $E/\rho$ of aluminum is the closest to that of steel, but its density is much smaller than that of steel. Therefore, we should choose aluminum (aluminum alloy) as manufacturing material. In order to improve the universality of the clamping device, the design principle and concept similar to modular fixture are adopted, and the aluminum alloy material with T-groove is used as the manufacturing material. In the preliminary manufacturing model, 4.0T national standard 40 * 40 industrial aluminum profile is used as the production material.

The main manufacturing methods of clamping device include integral machining, screw connection, casting, welding, bonding, epoxy resin forming, etc. In the above manufacturing methods, the overall machining is preferable. Next is casting, but heat treatment or aging treatment should be carried out to eliminate prestress after casting, screw clamping device has poor high-frequency vibration performance.

The manufacturing method of the clamping device adopts the combination of welding processing and thread connection to give full play to their advantages. The main parts of the clamping device are joined by welding, while some parts are joined by screw connection, so that the clamping device can obtain higher damping. The fixing hole connecting bolt and the vibration table should be a flat-bottomed buried head hole, which aims to shorten thread length and increase stiffness.

4. Simulation analysis and test of three-dimensional modeling

4.1 Overall structure design and modeling of clamping device

In the vertical direction exciting vibration, the composite center of specimen and the clamping device will fall on the center line of the platform as far as possible, so as to avoid the shaking of the platform and lead to the distortion of the vibration waveform. In particular, the clamping device center of gravity or specimen is high, it is more important to design a clamping device with good balance performance. Therefore, the clamping device should be designed as symmetrical and low center of gravity. Such as cube, box, hemispherical and conical.

Fig.3. Clamping Device Model Diagram

In the structural design of the clamping device, the shape and dimension of the platform on the vibration table, the locating mode and the fixing mode of the seat are considered comprehensively. Finally, the structure of the left and right symmetry is used, and clamping device center of gravity is ensured to fall on the platform center line, and reduce clamping device center of gravity as far as possible. Complete the three-dimensional modeling of the seat clamping device in Creo software environment. The model diagram of the seat clamping device is shown in Fig.3.

4.2 Modal analysis

In order to test whether the main dynamic performance of the clamping device meets the requirements, it is necessary to carry out modal analysis before the vibration test. If it does not meet the requirements,
relevant measures should be taken to correct it. The first four modes are shown in Fig.4. The final design of the clamping device results are shown in Table 2.

![First Mode Vibration of Clamping Device](image1)

![Second Mode Vibration of Clamping Device](image2)

![Third Mode Vibration of Clamping Device](image3)

![Fourth Mode Vibration of Clamping Device](image4)

**Fig.4. Fourth Order Vibration Mode Diagram of Clamping Device**

**Table 2. The First Four Grades Modal Calculation Results of Clamping Device**

| Grade | Frequency (Hz) |
|-------|----------------|
| 1     | 228.648        |
| 2     | 229.401        |
| 3     | 267.024        |
| 4     | 765.374        |
As shown in Table 2, the natural frequencies of the workpiece modes increase with the order of mode shapes. This is because nodes of higher order vibration will increase with the order of mode, the load energy exciting workpiece higher order vibration will gradually weaken, and the excitation of higher order vibration will become more difficult. Therefore, the natural frequency of the workpiece at the first mode is the smallest. But in model research, the influence of low order natural frequency on vibration characteristics is greater than that of high order natural frequency, which means that the accuracy of first order natural frequency is one of the key factors of the reliability in this experiment. The range of test frequency of vibration table for automobile freedom degree is 0-50Hz. According to the analysis results of clamping device, first order natural frequency is 201.591Hz which is about four times the test frequency of vibration table for automobile freedom degree. So, the dynamic performance of the clamping device meets the design requirements.

4.3 Teaching vibration test

![Fig.5: The Real Object of Clamping Device](image)

The clamping device is fixed on the vibration table surface by screw clamping mechanism, and the seat whose translation and rotation are limited in the x y z axis is installed on the clamping device. Fig.5 shows the figure of clamping device. This device has no position excursion or slack shaking in the lasts-forty-minutes vibration test (it’s less than the time of experimental teaching) and there is no cracking at the welding point, which meets expectations we design.

5. Conclusions
A car seat clamping device that doesn’t destroy table surface is designed and it takes the vibration table for automobile freedom degree as the development platform. The clamping device can be used to clamp a variety of seats by adjusting the position of two T-groove baseplate and it has preferable versatility. The three-dimensional modeling of car seat clamping device was completed in the Creo environment and the clamping device can avoid resonance effectively by natural frequency simulation analysis. According to the design, the real subject made with aluminum was tested. The test results show that the clamping device has expected rigidity and reliability and it can be used in teaching.

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