Design and Mechanical Performance Analysis of Vibration Reduction and Isolation Platform

Hongping Yang*, Xiaowei Che, Chen Yang, Wenwen Wang and Jiao Pu

College of Mechanical Electrical and Automotive Engineering, Tianshui Normal University Tianshui, Gansu Province, 741000, P.R.China

*Corresponding author’s e-mail: yanghp@tsnu.edu.cn

Abstract. Vibration reduction and isolation platform is a device that can effectively reduce or isolate vibration in space environment. It is widely used in precision equipment fields such as mechanical structure, precision machining, optical instruments. A three-stage mechanical active vibration reduction and isolation platform is designed. The static analysis is carried out using professional software. The research results show that when 3000N concentrated load is applied on the working platform, the maximum deformation is 0.0073mm, the maximum stress is 2.82MPa. And when 4000N asymmetric load is applied, the maximum deformation is 0.048mm, the maximum stress is 200MPa. The modal analysis results show that the first frequency is 40Hz and the sixth frequency is 180Hz. The product has certain engineering application value.

1. Introduction

With the development and progress of science and technology, the working environment requirements of precision instruments are constantly improving[1-2]. The micro vibration or disturbance in the working environment seriously affects the accuracy of precision instruments. How to effectively control the micro vibration of environment, instruments and equipment within a reasonable range is the key technical problem. So as it can improve the manufacturing technology level of high precision instruments and equipment.

Researchers [3-5] have conducted a lot of research in control and structure. They have developed a number of vibration reduction and isolation devices to control vibration. At present, the commonly used vibration reduction measures are to install vibration isolation devices between the main system and the vibration source. A modular precision active vibration isolation platform is developed by the HERZAN Company. The six degrees of freedom of this series of vibration isolators can achieve the performance of Hertz vibration isolation. The acceleration feedback is introduced, and the controller is designed for active control. The piezoelectric transducer is used as the actuator to provide driving force. To eliminate the influence of vibration disturbance on the load platform, it uses air spring as gravity compensation which provides positive system stiffness. At the same time, the vibration isolator is designed with negative stiffness structure. The positive and negative stiffness are connected in parallel to obtain structural stiffness close to zero. The natural frequency of the vibration isolator is close to zero, only 0.5Hz, and the system bandwidth is 10Hz[3]. The ETC series vibration isolators use metal springs as gravity compensation. It plays the role of passive vibration isolation. In the process of use, the vibration isolators rely on the inertia of the load to suppress the vibration disturbance in high frequency band. As an active vibration isolation platform, the absolute velocity signal of the table surface is used as the feedback. The absolute velocity signal of the ground is used as the feedforward...
to design the controller. Kim et al[4] used magnetic array to improve the permanent magnet structure. It improve the linearity of motor output force and enhance the dynamic response ability of the system. The vibration isolator is supported by metal spring, and the natural frequency of the system is about 10Hz. Through six acceleration sensors-measuring system information, four permanent magnet arrays are distributed in the vertical and horizontal directions as actuators [6-8].

Based on the performance of vibration reduction and isolation products, this paper designs a three-level mechanical active vibration reduction and isolation platform. The platform is modelled and analysed. Through the analysis, it provides a theoretical basis for the structural optimization design of vibration isolation platform, and has certain engineering reference significance.

2. Design of vibration reduction and isolation platform
The vibration reduction and isolation platform is divided into three parts. Each part has different functions. The flat has the function of supporting objects, and it has good stability, reliability and lightness. The honeycomb is designed inside, which is filled with sand or steel balls. The sand or steel balls will absorb vibration waves and forces during work. The middle part is a vibration reduction and isolation system, which consists of shock absorber, rubber pad and concave convex table positioning shock absorber. When vibration occurs on the workbench, the shock absorber transmitted to this part will actively reduce the vibration according to the signal of the sensor. The concave convex table positioning shock absorber not only can reduce the vibration, also can position the workbench and limit its horizontal movement. When the workbench environment vibrates, the concave convex bench positioning damper plays a role in vibration isolation. The support part of the vibration isolation platform is composed of rigid legs and rubber pads to reduce the force transmitted by the system to the ground and play the role of vibration isolation. Figure 1 is structural diagram of vibration reduction and isolation platform.

![Figure 1. Structural diagram of vibration reduction and isolation platform.](image)
1- Base plate, 2- Vibration isolation outrigger, 3- Support plate, 4- Shock absorber, 5- Sensor, 6-Working face, 7- Desktop base, 8- Concave convex desktop positioning shock absorber

3. Basic theory of finite element statics
Finite element analysis is widely used in machinery[9-10]. The theoretical equations are:
- Geometric equation

\[
\begin{align*}
\varepsilon_x &= \frac{\partial u}{\partial x} , \quad \gamma_{yz} &= \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \\
\varepsilon_y &= \frac{\partial v}{\partial y} , \quad \gamma_{xz} &= \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \\
\varepsilon_z &= \frac{\partial w}{\partial z} , \quad \gamma_{xy} &= \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}
\end{align*}
\]
Physical equation

\[
\begin{align*}
\sigma_x &= \lambda \theta + 2 \mu \varepsilon_x, \quad \tau_{xy} = \mu \gamma_{xy} \\
\sigma_y &= \lambda \theta + 2 \mu \varepsilon_y, \quad \tau_{yz} = \mu \gamma_{yz} \\
\sigma_z &= \lambda \theta + 2 \mu \varepsilon_z, \quad \tau_{zx} = \mu \gamma_{zx}
\end{align*}
\]  
(2)

Where, \( \theta \) is volumetric strain, \( \varepsilon = \varepsilon_x + \varepsilon_y + \varepsilon_z \); \( \lambda \) is elastic constant, \( \mu \) is Poisson's ratio. The relationship between Young's modulus \( E \) and elastic modulus \( G \) is

\[
G = \frac{E}{2(1+\mu)} \quad \lambda = \frac{E \mu}{(1+\mu)(1-2\mu)}
\]  
(3)

Equilibrium differential equation

According to the equilibrium relationship between volume component and stress component, the equilibrium differential equation of any point along the coordinate axis in the elastic domain:

\[
\begin{align*}
\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} + X &= 0 \\
\frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{yx}}{\partial x} + \frac{\partial \tau_{yz}}{\partial z} + Y &= 0 \\
\frac{\partial \sigma_z}{\partial z} + \frac{\partial \tau_{zx}}{\partial x} + \frac{\partial \tau_{zy}}{\partial y} + Z &= 0
\end{align*}
\]  
(4)

4. Static analysis of vibration reduction and isolation platform

4.1. Solid modeling and meshing

The solid modelling is carried out completely according to the actual given parameters. The three-dimensional solid model is established by SolidWorks software. This paper does not reflect some fasteners and transmission parts. Its equivalent mass is loaded on the vibration isolation platform. The material of vibration isolation platform is Q235, elastic modulus \( E = 235 \text{GPa} \), Poisson's ratio \( \mu = 0.25 \), elastic modulus of rubber pad damping material \( E = 7.8 \text{MPa} \), Poisson's ratio \( \mu = 0.47 \).

4.2. Analysis of static mechanical properties

4.2.1. Apply concentrated load 2500N

Figure 2 shows the stress and deformation of the vibration reduction and isolation platform applied the load to the working face is 2500N. It can be seen from the figure that the maximum deformation is 0.013mm. The maximum deformation occurs on the vibration reduction and isolation table. The deformation on the vibration isolation leg is small. Because the vibration isolation rubber pad can effectively reduce vibration. Fig. 3 is a cloud diagram of equivalent stress, from which it can be seen that the maximum stress is 0.235MPa.
4.2.2. Apply concentrated load 3000N

Figure 4 shows the total stress and deformation cloud of applying concentrated load 3000N. It can be seen from the figure that the maximum deformation is 0.0016mm. The support leg also has no obvious deformation, and the optimization effect of rubber pad is obvious. Fig.5 is stress cloud. It can be seen that the maximum stress is 2.82 MPa.

4.2.3. Apply asymmetric load 3000N

Figure 6 is the load of 3000N applied on the middle edge of the worktable. It can be seen that the maximum deformation is 0.0073mm. The maximum deformation is at the position where the load is applied, and the deformation on the side is significantly reduced. Figure 7 is the stress cloud. It can be seen that the maximum stress is 7.23 MPa located on the loaded side.
4.2.4. Apply asymmetric load 4000N

Figure 8 is the load 4000N is applied. The load is applied on an angle on the worktable. It can be seen that the maximum deformation is on the vibration isolation table, with a value of 0.048mm. The maximum deformation is at the position where the load is applied, and the deformation on the side is significantly reduced. Figure 9 is the stress cloud. It can be seen that the maximum stress is 200MPa located on the loaded side.

5. Modal analysis

Modal analysis is a modern method to study the dynamic characteristics of structures. It is the application of system identification method in the field of engineering vibration. Mode is the natural vibration characteristic of mechanical structure. Each mode has a specific natural frequency, damping ratio and mode shape. Vibration mode is the inherent and overall characteristic of elastic structure. If the characteristics of the main modes of the structure in a vulnerable frequency range are clarified by modal analysis method, it is possible to predict the actual vibration response of the structure under the action of external or internal vibration sources in this frequency band.

Table 1 shows the modal analysis values of the vibration reduction and isolation platform. It can be seen from the table that the first and second-order frequencies are 40Hz, the third-order 60Hz, the fourth-order 126Hz, the fifth-order 180Hz and the sixth-order 180Hz.
Table 1. The natural frequency of each modal order (Hz)

| Modal order | 1    | 2    | 3    | 4    | 5    | 6    |
|-------------|------|------|------|------|------|------|
| Natural frequency | 40.761 | 40.762 | 59.3 | 126.39 | 179.93 | 180.1 |

6. Conclusion
In this paper, a mechanical three-stage active vibration isolation platform is innovatively designed and theoretically analysed. However, the platform is only a mechanical structural design. The system structure needs to be further optimized. In the future, if the intelligent control system, vibration reduction and vibration isolation new materials, feedback systems, etc. can be used to design, the platform will greatly improve the accuracy and reliability of the platform in terms of performance and function.

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