Journal of Electrotechnology, Electrical Engineering and Management (2021) Vol. 4: 7-14 DOI: 10.23977/jeeem.2021.040102
Clausius Scientific Press, Canada ISSN 2560-6697

Design of Multi-Dimensional Damping Platform Based on MR Damper

Weijie Zhang, Cheng Qian*, Peiyuan Sun, Yucheng Ji

College of Information Science and Engineering, Jiaxing University,118# Jiahang road, Jiaxing, China

**Corresponding author*

Keywords: Multidimensional Damping Platform, Spherical Hinge, Magnetorheological Damper, Parallel Connection, Degrees Of Freedom

Abstract: Due to the multi-dimensional damping platform obtained by traditional vibration isolation technology can't meet the requirements of multi occasions, multi states and multi DOF, a multi-dimensional damping platform based on magnetorheological damper is proposed. By changing the link mode between the dynamic platform and the static platform to achieve the vibration reduction goal under different DOF, a multi-dimensional vibration reduction platform model based on the parallel structure design under 3-PRC is given. The spherical joint is connected in parallel with the static platform to meet the vibration reduction requirements of each branch under different directional excitation. In the meantime, the use of MR damper can achieve the purpose of multi-dimensional vibration reduction with continuous and forward and inverse adjustable damping force, large adjustable extent and fast reaction speed. It provides a more effective idea for the design of multi-dimensional damping platform working under variable excitation conditions.

1. Introduction

Mechanical equipment is often subjected to various multi-dimensional vibration and impact during operation [1]. If the vibration isolation is unfavorable, its working performance and service life will be seriously affected. Strong and continuous vibration will lead to the decline of the overall performance and level of electromechanical system, structure or equipment with poor dynamic characteristics; the airborne precision instruments and equipment carried by automobiles, ships, submarines and aircraft need to work in a stable and quiet vibration isolation environment. In order to avoid the influence of high amplitude, broadband and multi-dimensional random disturbances from the outside and meet the increasingly demanding requirements of broadband vibration isolation and attitude maintenance, more effective new methods and technologies different from the traditional vibration control methods must be adopted. In actual operation, vehicles, submarines, ships, aircraft and other machinery are bound to be subjected to various multidimensional random excitations or disturbances inside and outside the machinery, which makes their vibration and dynamic behaviour extremely complex. For example, bumpy and rugged roads can destabilize vehicles, and turbulent rolling waves can shake and roll ships, The unpredictable turbulence can induce the flutter of aircraft, which is mainly characterized by strong amplitude, multi-dimensional, broadband, random and nonlinear characteristics, resulting in the operation of airborne electronic equipment can't meet the control requirements, and the above external interference must be weakened or eliminated.

Traditional vibration isolation methods and technologies mainly use elastic materials such as spring and flexible rubber as vibration isolators, mainly for one-dimensional vibration isolation in a certain direction. For multi-dimensional vibration isolation, the usual way is to achieve multi-dimensional vibration isolation to a certain degree through the multi-dimensional deformation of special materials, or to achieve the purpose of multi-dimensional vibration isolation through the combination of single-dimensional vibration isolation systems. However, materials are prone to aging and unstable performance. In addition, multi-dimensional vibration isolation through the combination of single-dimensional vibration isolation systems often leads to very complex systems [2].

In recent years, many scholars have applied the parallel mechanism with the advantages of compact structure, strong bearing capacity and high stiffness to the field of multi-dimensional vibration isolation and achieved certain results [3-5]. A rubber like parallel mechanism damping platform proposed by Professor Ma Lvzhong is the most representative because of its simple structure and convenient operation. The platform adopts a three translational degree of freedom parallel mechanism supplemented by rare earth permanent magnet and floating elastic damping system, which can basically realize the relatively simple passive isolation of three-dimensional translational vibration, which shows the feasibility of parallel mechanism for vibration isolation [6]; Taking the three translation parallel mechanism as an example, literature [7] verifies the feasibility of applying the parallel mechanism to multi-dimensional vibration reduction, and lists some multi degree of freedom models suitable for multi-dimensional vibration reduction platform; Han Qinghua et al. Proposed a multi-dimensional damping damper suitable for long-span spatial structures, which has the characteristics of providing multi-dimensional stiffness and damping effect such as axial and bending at the same time [8].

From the research status that the design of multi-dimensional damping platform is mainly realized from the special structural model and the introduction of advanced functional materials. In order to further study how many damping platforms, this paper designs an actuator based on MR damper and multiple parallel branches to build a multi-dimensional damping platform, which provides a certain structural idea for multi-dimensional damping.

2. General Design of a New Multi-Dimensional Damping Platform

Stewart mechanism was proposed by German scholar Stewart in 1965. It is a six degree of freedom parallel mechanism, which is composed of two upper and lower platforms and six independently retractable rods. The two platforms are connected with each telescopic rod through two ball joints to realize multi-dimensional motion in space through the most compact structure, as shown in the Figure 1 [9].

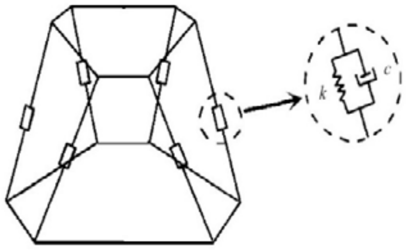

Figure 1: The diagram of Stewart

By controlling the controllable damping device at the follower of the lower platform (moving platform) of the damping platform, the active force system brought by the moving platform is attenuated, that is, the effect of the reverse driving force system to attenuate the active force system is realized. Common control damping devices can be divided into three basic types: passive damping device, semi-active damping device and active damping device. The passive damping device does not need external energy to achieve the purpose of vibration reduction, but because of its poor vibration reduction effect, this kind of damping device is not selected here; The semi-active damping device mainly takes the magnetorheological damper as the main device. Its main advantage is that it does not need external energy to provide large control force. It absorbs energy through its own internal magnetorheological fluid to lose external energy, so as to adjust and change the damping force of the branch chain structure to achieve the purpose of vibration reduction. This kind of semi-active damping device has low cost and simple structure, the damping effect is also significant, which can achieve the expected damping effect to a great extent.

The multi-dimensional damping platform model is designed based on the symmetrical 3-PRC parallel mechanism. The platform is composed of an upper platform (static platform), a lower platform (dynamic platform) and three identical motion branches linking the upper and lower platforms. Each motion branch is composed of a first buffer branch and a second buffer branch. The first buffer branch is composed of moving pairs (A1, A2) and rotating pairs (B1, B2, B3 and B4), and the second buffer branch is composed of two branch motion branches, each branch chain is independently equipped with a magnetorheological damper. The motion resistance can be adjusted through the magnetorheological damper to effectively attenuate the energy brought by the upper platform, to achieve the purpose of vibration reduction, so as to meet the requirements of vibration reduction under multi degrees of freedom of the new multi-dimensional vibration reduction platform.

The multi-dimensional damping platform based on MR damper in this paper is shown in Figure 2, including static platform 4, dynamic platform 1, first buffer branch 2 and second buffer branch 3; The moving platform 1 is circular, on which three first buffer branches 2 are installed; The first buffer branch 2 is fixed with the moving platform 1 through the first node 5; The second buffer branch 3 is movably connected with the first buffer branch 2; The second buffer branch 3 is fixed on the static platform 4 through the ball joint 6.

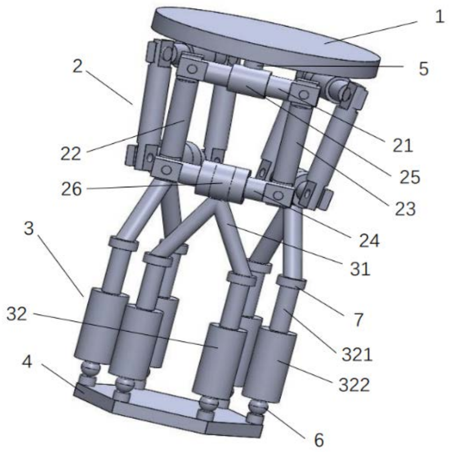

Figure 2: Overall structure of multi-dimensional damping platform

The first buffer branch 2 is parallelogram; Including a first connecting rod 21, a second connecting rod 22, a third connecting rod 23 and a fourth connecting rod 24; The first connecting rod 21 and the fourth connecting rod 24 are parallel; The second connecting rod 22 and the third connecting rod 23 are parallel; The first connecting rod 21 is provided with a first sleeve 25, and the first connecting rod 21 can rotate in the first sleeve 25; One end of the first node 5 is fixed with the moving platform 1, and the other end is sleeved in the first sleeve 25 and movably connected with the first sleeve 25; Both ends of the first connecting rod 21 are respectively fixed with the second connecting rod 22 and the third connecting rod 23 through pins; Both ends of the fourth connecting rod 24 are respectively fixed with one end of the third connecting rod 23 and the second connecting rod 22 through pins; The fourth connecting rod 24 is provided with a second sleeve 26; The fourth connecting rod 24 can rotate on the second sleeve 26; The second sleeve 26 is connected to the second buffer branch 3.

One end of the second buffer branch 3 relates to the second sleeve 2, and the other end is fixed on the static platform 4 through a ball joint 6.

The second buffer branch 3 includes a first branch 31 and a second branch 32; The first branch 31 is herringbone, one end is fixed on the second sleeve 26 and moves with the movement of the second sleeve 26; The other end of the first branch 31 has two forks respectively, and the second branch 32 is respectively connected through the second node 7.

The second branch 32 includes a piston rod 321 and a piston barrel 322; The piston rod 321 is matched with the piston barrel 322; The second node 7 is fixed with the piston rod 321; A magnetorheological fluid is arranged in the piston barrel 322; One end of the piston barrel 322 is fixed on the static platform 4 by a ball joint 6. The static platform 4 is hexagonal; the second branch 32 is respectively installed on the six corners of the hexagon.

3. Design of Key Parts of Multi-Dimensional Damping Platform

Compared with the traditional series damping structure, most of the new parallel damping structures have the characteristics of large stiffness, stable structure, strong bearing capacity, high precision and small motion inertia, and different multi-dimensional motions can be realized through the combination of different motion pairs, which provides the possibility for the design of the new multi-dimensional damping platform.

3.1. Design of Upper Platform, Lower Platform and Parallel Branch

In order to better improve the damping effect of the damping platform, the following principles shall be followed when selecting the upper and lower platforms and parallel branches:

(1) The number of moving parts and moving pairs of the selected branch should be as simple as possible, and the branch should have the same structural form as far as possible.

(2) The size of the upper platform (static platform) of the selected damping platform is determined according to its branch structure and the range of the lower platform (dynamic platform).

(3) The structural design of the upper and lower platforms shall be simplified as far as possible. Since the first buffer branch of the upper platform (static platform) is three parallel branches, cylindrical shape is selected here to realize the integration of beauty and simplicity; Because the second buffer branch of the lower platform (moving platform) is six parallel branches of MR dampers, the hexagonal platform is selected.

(4) In order to realize the simplicity of the whole mechanism, two buffer branches are used in turn, which can quickly reduce or eliminate vibration in the face of different excitation conditions.

(5) When designing the first buffer branch, the motion of the parallelogram is used to realize part of the damping function of the first branch, and the stability of the parallelogram is used to realize the first damping.

(6) In the second buffer branch, in order to prevent a branch from bending when subjected to strong external force, two magnetorheological dampers are used in parallel as the second buffer branch to achieve better stability and bearing capacity.

(7) As the link structure between the second buffer branch and the lower platform, the spherical joint realizes the multi degree of freedom movement. On the parallel branch, the rotating pair is used to achieve multi-directional rotation to reduce the damping, which can significantly improve the bearing capacity and stability of the lower platform.

3.2. Parallelogram Structure Design

In this paper, 3-PRC is selected as the main parallel structure to design a new multi-dimensional damping platform, supplemented by spherical joints and parallelogram structure to realize the realization of kinematic pairs.

During the design of the vibration damping platform, when the parallel structure is connected with the lower platform (moving platform), it is connected by welding. In the whole mechanism movement process, as shown in Figure 3, the moving pairs A1 and A2 can only move in the horizontal direction, while the rotating pairs B1, B2, B3 and B4 can only rotate relatively in the x-z direction, so it can not realize the movement problem of multiple degrees of freedom. In order to solve this problem, the simple structure of adding a spherical joint to the link node between the MR damper and the lower platform (moving platform) can realize the multi degree of freedom motion of the whole parallel mechanism in X-Y-Z space.

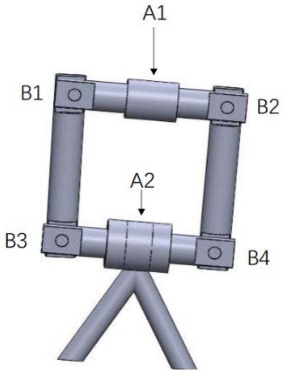

Figure 3: Schematic diagram of parallelogram structure.

3.3. Design of Spherical Hinge

In the design process, considering the connection between the spherical joint and the branch platform, if the spherical joint is welded with the lower platform (moving platform), the spherical joint will be used as the support and can't rotate in any direction of each branch. In order to solve this problem, a hemispherical shell is connected with a cylinder, and a sphere is embedded in the hemispherical body, the cylinder is welded with the lower platform (moving platform) to realize the relative rotation of the ball joint. At this time, if only the hemispherical shell is used, as shown in Figure 4, when the relative rotation occurs, the ball in the hemispherical shell may slip out and a series of link fixing methods may be missing. The open hemispherical shell is welded with the ball shell to achieve the fastening effect.

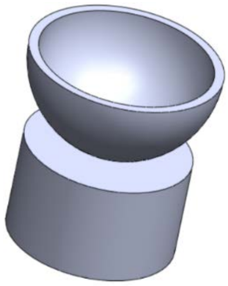

Figure 4: Schematic diagram of spherical joint.

3.4. Selection of MR Damper

Safety factors have been considered in the design of the multi-dimensional vibration damping platform. The applied force of the upper platform (static platform) does not exceed 600N. Due to its excellent vibration damping performance, the magnetorheological damper with maximum output of 600N is selected. The specific parameters are as follows:

Model: MRD006
Maximum output: 600N
Adjustable multiple: 4
External diameter: 60mm
Installation length: 493mm
Power: 1.5W

4. Motion Principle of the New Multi-Dimensional Damping Platform

4.1. Basic Principles

When the upper platform (static platform) r=500mm, take a vertical force F=400N, the vertical force will produce force on the upper platform, and the binding force of each parallel branch chain is:

$$F_1 = \frac{1}{3}F \tag{1}$$

The moving pair welded with the upper platform applies force to the parallelogram, as shown in Figure 5. The length of the parallelogram rod is L = 300mm

Therefore:

$$M_a = \frac{1}{6}F * \frac{1}{2}L \tag{2}$$

For the same reason:

$$M_b = \frac{1}{6}F * \frac{1}{2}L \tag{3}$$

$$M_{c-e} = \frac{\sqrt{3}}{9} F * \frac{\sqrt{3}}{4} L \tag{4}$$

$$M_{d-e} = \frac{\sqrt{3}}{9} F * \frac{\sqrt{3}}{4} L \tag{5}$$

So that:

$$\sum M_e = M_{c-e} + M_{d-e} = \frac{1}{6} FL \tag{6}$$

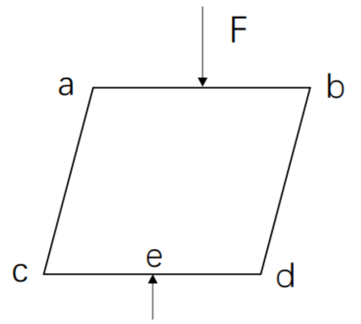

Figure 5: Stress analysis diagram of parallelogram

In order to make the overall structure invariable, its parallelogram will move, and four identical members will weaken the vertical force, so that the first buffer branch can achieve the effect of vibration reduction. At this time, the MR damper connected in series with the parallelogram begins to play a role as the second buffer branch and absorbs the influence of the residual vertical force through its own internal MR fluid, so as to realize the reverse drive adaptive system of the multi-dimensional damping platform.

When a force F= 400N in any direction is applied to the upper platform (static platform), only the first buffer branch can't meet the action effect of the force in different directions. Because the second buffer branch is equipped with the link mode of spherical joint, the action effect of couple in this direction is realized through the vibration reduction of magnetorheological damper and the rotation of spherical joint. To realize the multi degree of freedom motion of multi-dimensional damping platform.

4.2. Damping Principle

The new multi-dimensional damping platform is composed of upper platform (static platform), first buffer branch, second buffer branch, spherical joint and lower platform (dynamic platform). It attenuates the force brought by the upper platform (static platform) through the first buffer branch, and then through the second buffer branch, that is, the interaction between magnetorheological damper and lower platform (dynamic platform), The purpose of reducing the vibration of the lower platform (moving platform) is achieved.

Applied range: precision instrument damping experiment, micro vibration damping instrument, fragile and explosive object transportation.

5. Conclusions

(1) A multi-dimensional damping platform with reference to Stewart mechanism is proposed, which can realize multi degrees of freedom, high bearing capacity and provide damping effect in turn.

(2) The theoretical mechanical analysis of the first buffer branch of the multi-dimensional damping platform is carried out. The theoretical analysis results are reasonable, and the force can be weakened under the static action. Then, the residual force is eliminated through the action of the magnetorheological damper of the second buffer branch, and the spherical joint is used to deal with the effect of the force in any direction, so as to realize vibration reduction.

Acknowledgements

This work was supported in part by the College Student Research Training Program of Jiaxing University (SRT) (Grant number: CD8517203211), the National Innovation and Entrepreneurship Training Program for College Students (Grant number: 202110354055).

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