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Test and Simulation Analysis on the Multidimensional Reduction

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Abstract: The vibration velocities of the seat platform and traditional mechanical reduction vibration device were measured through tests, which provided certain basis for proposing and design of the parallel mechanism with six degree of freedom in subsequent paragraphs. Adopting the parallel mechanism as the main part of the seat and the active joints with spring damping elements as the reduction vibration actuator, the reduction vibration seat model with the 3-PRPS parallel mechanism with six degree of freedom was established. With position and attitude of the mechanism as the premise, stability indexes of the reduction vibration seat in motion were put forward, and then getting the task space of moving platform by the inverse solution of the mechanism position. To achieve reduction vibration effectively, branched chain velocity matrix was built by vector method. Optimal parameter values were obtained by MATLAB numerical calculation to improve the reduction vibration space and flexibility. Finally, simulation analysis was carried out on the results. Meanwhile, comparison was carried out on the reduction vibration effects of the parallel mechanism with six degree of freedom and traditional mechanical reduction vibration device. The results show that this mechanism has a better vibration reduction performance, which provides a new thought for designing reduction vibration seat. Meanwhile, it also provides important reference for application and research of other parallel mechanisms.

Keywords: Traditional mechanical reduction vibration device, Parallel mechanism, Reduction vibration seat, Task space, Comparison on reduction vibration effects.

1. INTRODUCTION

There are some defects in traditional mechanical reduction vibration device of the seat. Therefore, multidimensional reduction vibration system based on parallel mechanism is proposed to improve the ride comfort. As the new idea and breakthrough in the field of reduction vibration, the multi-dimensional reduction vibration system based on parallel mechanism is of great applications and development value. Researches on the reduction vibration of parallel mechanism around the world concentrate on the followed aspects. Emdadul Hoque, Gexue R, Lvzhong M and Qizhi Y [1-4] replaced the traditional active vibration isolation system with the parallel mechanism and carried on the theoretical analysis and experimental verification. Thomas H, Lvzhong M and Wenjiang D [5-7] designed parameters of damping devices of the suspension system based on the parallel mechanism according to the sensitive frequency range of the human body and the natural frequency of the vehicle. Bing Li, Qizhi Y, Xiuxiang C and Peng Y [8-12] established the mechanism optimization design model with various constraints according to analyzing a kinematic performance indicator of the parallel mechanism. For the mechanism, size parameters largely relate to the motion performance, so the size optimization based on tasks in the multi-dimensional reduction vibration system of the parallel mechanism is of great significance, however, the size optimization of the reduction vibration of parallel mechanism by the task space has not been reported.

In this paper, compact, controllable and precise [13, 14] 3-PRPS parallel mechanism with six degree of freedom was the main mechanism of the multi-dimensional reduction vibration seat, and then the active joints were accompanied with elastic damping system to achieve energy absorption and dynamic self-adapting balance, thus reducing the physical and psychological harm to drivers due to strong vibrations of vehicles and improving driving and riding comfort. Meanwhile, stability index was figured out which limited the position and attitude of the mechanism's moving platform and the optimization in the task space of the parallel mechanism was more practical. Comparison was carried out on the reduction vibration effects of the optimized parallel mechanism with six degree of freedom and traditional mechanical reduction vibration device. The results show that this mechanism has a better vibration reduction performance, which provides a new thought for designing reduction vibration seat. Meanwhile, it also provides important reference for application and research of other parallel mechanisms.

2. TEST OF THE TRADITIONAL MECHANICAL REDUCTION VIBRATION DEVICE

In current stage, mechanical reduction vibration seats are universally used. The internal structure of the seat consists of parallel spring and damper, as shown in Fig. (**1**).

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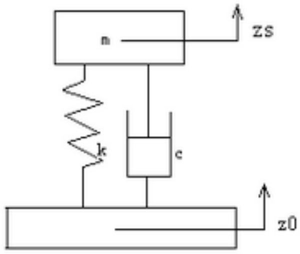


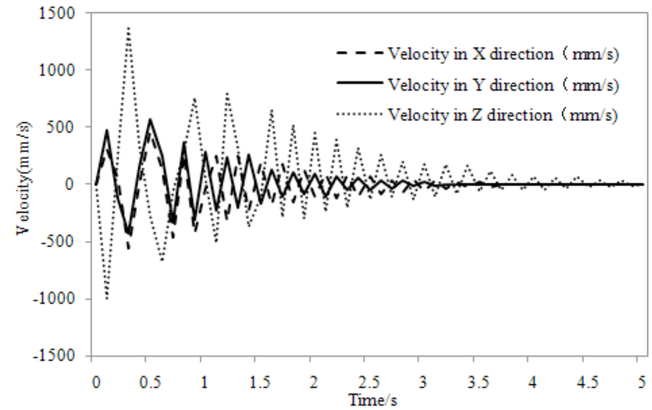
Fig. (1). Diagram of the reduction vibration mechanism inside the seat.

In Fig. (**1**), m is the sum of the mass of the reduction vibration seat and the passenger. K is the stiffness coefficient of the spring. c is the damping coefficient of the damper. zs indicates the displacement of the seat, and z0 indicates the displacement of the seat base-plate.

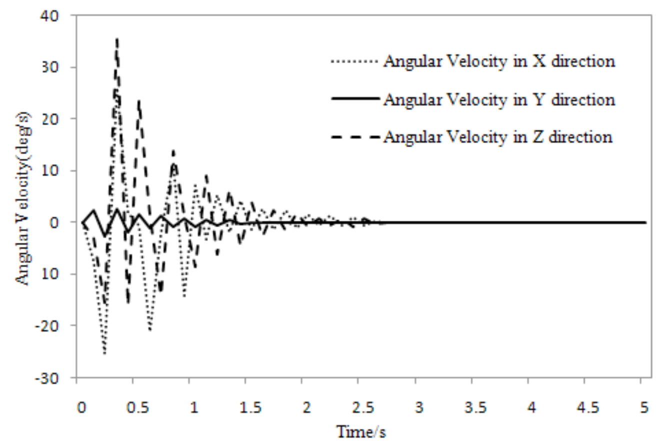
To research the performance of the mechanical reduction vibration seat system, a vibration test bench for researching the reduction vibration performance of the seat is built by MTS hydraulic servo system. The actuator of the hydraulic servo system is installed on the iron base-plate platform to enable its oil cylinder to move in the directions of the six degree of freedom, so as to simulate the actual moving conditions of the vehicle seat. An aluminum alloy platform is installed on the top of the actuator for dedicated use in seat test. The aluminum alloy platform which is light can reduce the added mass to the vibration system. Meanwhile, bolt holes with constant space are pre-processed for the platform to fix seats of various types.

In the test, the seat base-plate is fixed on the test bench, and a sandbag is used for simulating the mass of human body. The vibration test bench can realize the input of sine-swept vibration with variable amplitudes and equal strength, with the frequency range of the vibration ranging from 0.5Hz to 30Hz, which covers the vibration range sensitive to human body. In the test, velocity sensors are arranged on the vibration platform and the mechanical reduction vibration device. The signals are acquired by the data acquisition instrument. The velocity sensor is strain sensor because strain sensor is suitable for research on seat vibration as it has good low frequency characteristics and its frequency response range starts from zero. Data procession and analysis are carried out on the signals acquired by the signal sensor by exerting excitation signals on the system. The vibration velocities on the vibration platform and the mechanical reduction vibration device are obtained respectively, as shown in Figs. **2** and **3**.

In the directions of the six degree of freedom. On the one hand, the vibration velocity of the test bench platform can serve as the excitation for simulation analysis on the subsequent 3-PRPS structure. On the other hand, comparison in Figs. **2** and **3** shows that the vibration peak is obviously improved after attenuation through the mechanical reduction vibration device. In addition, the time for the vibration to attenuate to zero reduces to a great extent, which can improve the passenger's comfort. However, this process still needs at least 2.5s. The vibration signal is still strong during this period. Therefore, it's very necessary to improve the reduction vibration devices.



a) Vibration velocities in three directions of X, Y, Z



b) Vibration angular velocities in three directions of X, Y, Z

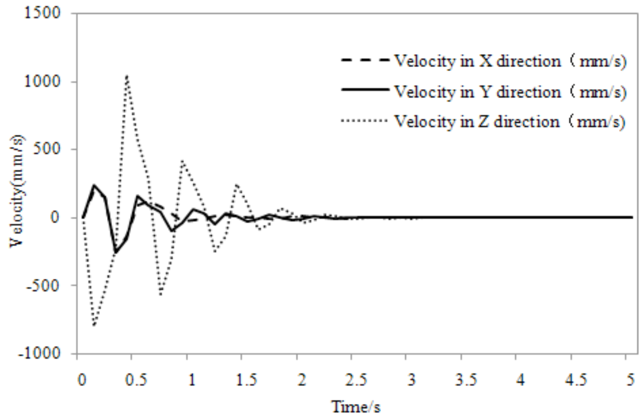
Fig. (2). Vibration velocities of the vibration platform in the directions of the six degree of freedom.

3. THE ESTABLISHMENT OF MECHANICAL MODEL AND SOLVING JACOBIAN MATRIX

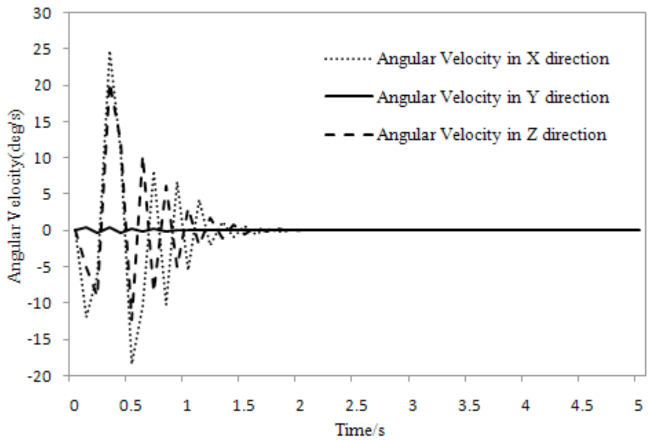
3.1. The Establishment of 3-PRPS Parallel Mechanism

As shown in Fig. **4**, the reduction vibration suspension of agricultural vehicles' seats adopted 3-PRPS parallel mechanism, which consisted of moving platform $B_1B_2B_3$, fixed platform $A_1A_2A_3$ and symmetrical branches connecting two platforms with three identical structure parameters, and each branch was composed of $(P - R - P - S)$. Both the moving platform and the fixed platform were equilateral triangles. The radius of the circum-circle for the moving platform was r and the radius of the inscribed circle for the fixed platform was R. According to the characteristics of 3-PRPS parallel mechanism, the fixed coordinate system $O - XYZ$ was established on the orthocenter of the fixed platform O and the moving coordinate system $p - xyz$ was established on the orthocenter of the moving platform p.

Springs and damping devices were established on the contact position P. Vertical rod length changes and horizontal movement of P could be realized through elastic support, so that to realize the reduction vibration in six-dimensional direction.



a) Vibration velocities in three directions of X, Y, Z



b) Vibration angular velocities in three directions of X, Y, Z

Fig. (3). Vibration velocities of the mechanical reduction vibration device.

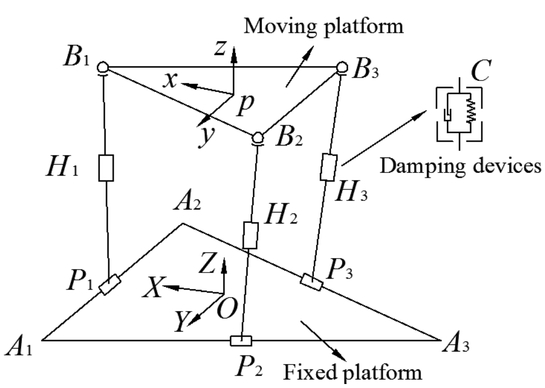
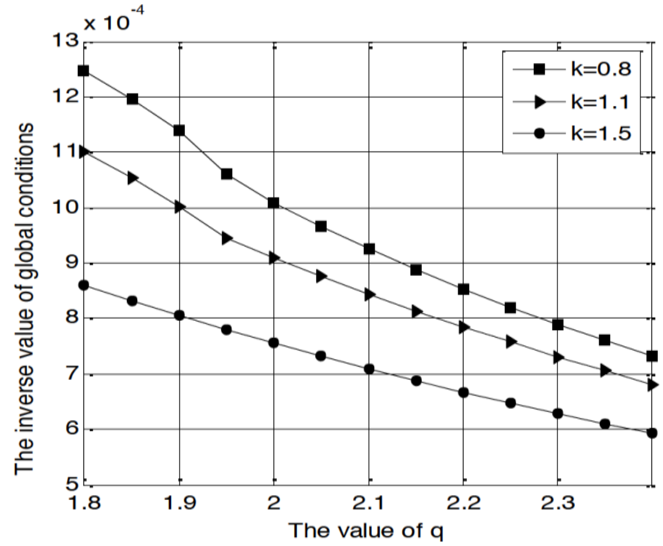


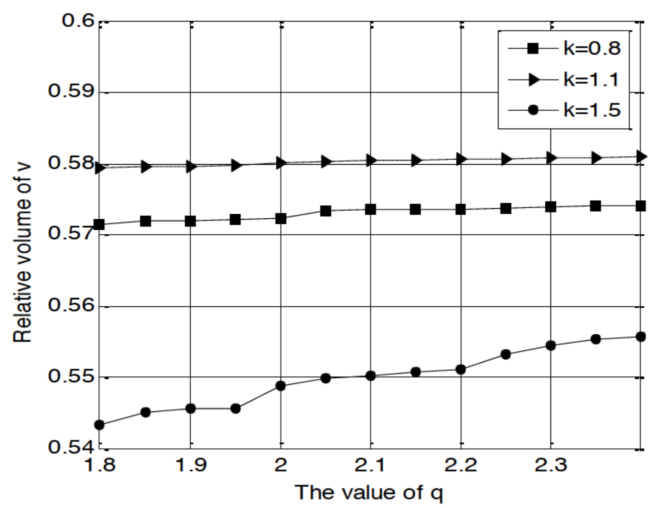
Fig. (4). Simple expression of 3-PRPS parallel mechanism.

4. SIMULATION OPTIMIZATION

The initial parameter of the mechanism was $r = 200\text{mm}$. When k=0.8, 1.1, 1.5 and $q \in (1.8, 2.4)$, numerical distribution curve of the workspace and flexibility are shown in Fig. **5**. When q=1.8, 2.1, 2.4 and $k \in (0.8, 1.5)$, numerical distribution curve of the workspace and flexibility are shown in (Fig. **6**).



a) The reciprocal of the mean of global condition number varied with the change of q



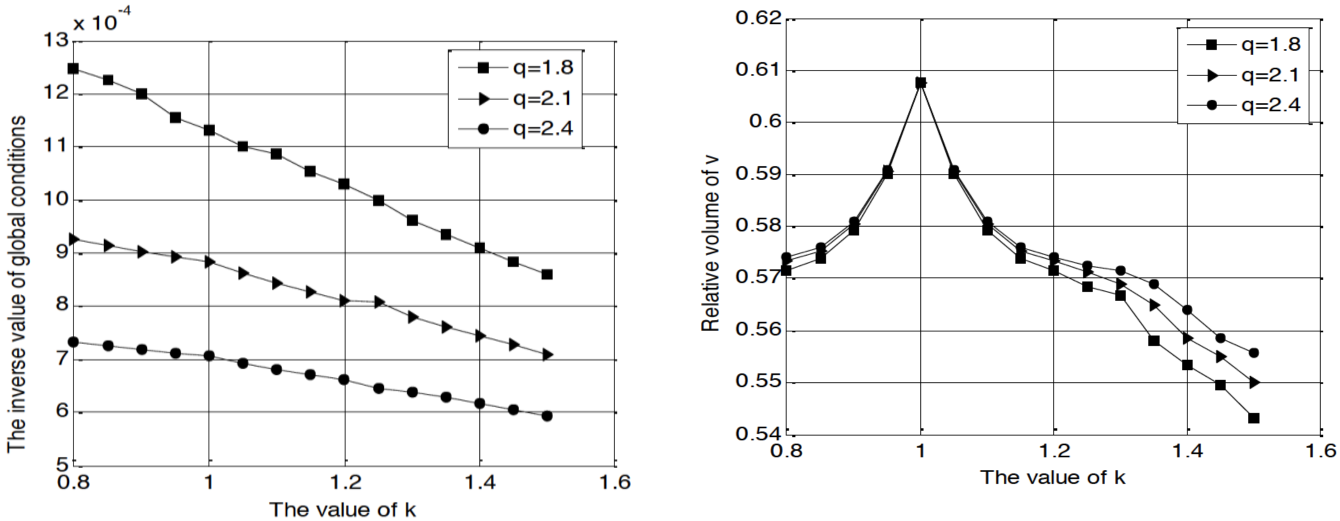
b) The relative volume varied with the change of q

Fig. (5). Optimization of target value with the q value change rule.

5. RESULTS AND CONCLUSION

As known from Figs. **5a** and **6a**, with the increase of q and k, the reciprocal of the mean of the condition number of the whole field reduced gradually, *i.e.*, the flexibility of the mechanism reduced. When q=1 and k=1, the reciprocal of the mean of global condition number decreased the most sharply and the flexibility change of the mechanism was the most prominent. As known from Fig. **5b** and **6b**, the volume of the mechanism in motion reached the maximum at k=1 and the fluctuation was the most obvious. When k=1, the deviation of the relative volume was symmetrical and had no obvious relation with the change of q.

Therefore, taking movement space and flexibility into consideration, we chose q = 1.9 and k = 1.



a) The reciprocal of the mean of global condition number varied with the change of k

b) The relative volume varied with the change of k

Fig. (6). Optimization of target value with the k value change rule.

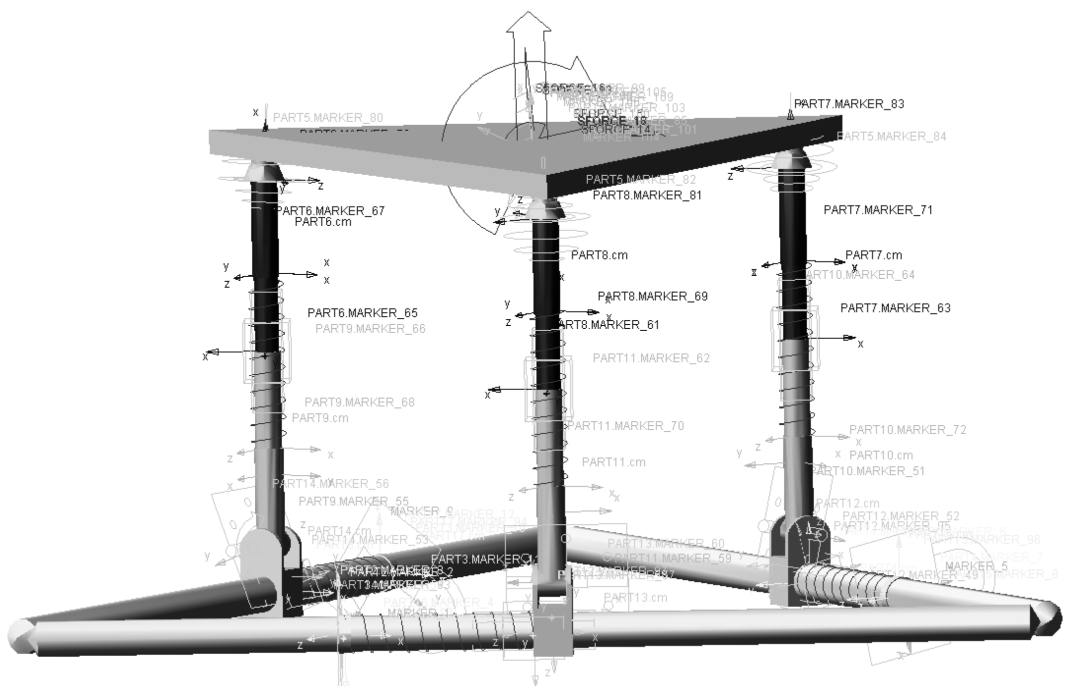


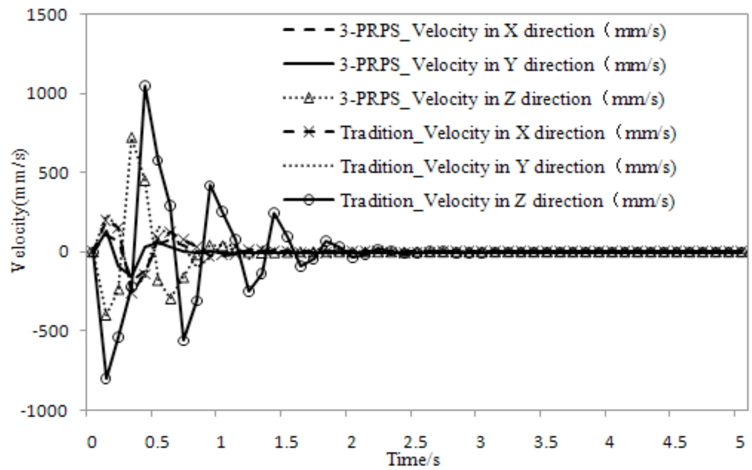
Fig. (7). The simulation model of reduction vibration seat of the mechanism.

5.1. Simulation Verification

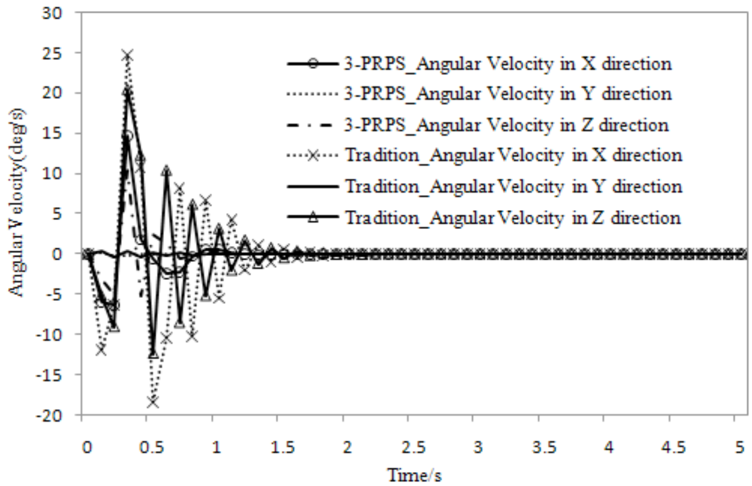
From the above, we selected parameters of the mechanism as r = 200mm, R = 200mm and h = 380mm. The model of the reduction vibration platform is shown in Fig. **7**.

To verify the reduction vibration effects, the mass of the moving platform is sum of the seat and the added mass. A damping spring with the stiffness coefficient of k=5.0N/mm and damping coefficient of c=0.5N.s/mm is added at the lateral movement pair. A damping spring with the stiffness coefficient of k=10.0N/mm and damping coefficient of c=10N.s/mm at the longitudinal movement pair. The vibration velocity measured in Fig. **2** is applied at the platform to serve as the excitation, and a dynamic simulation of End Time=10, steps=100 is carried out. The vibration velocity on the reduction vibration seat device in the directions of the six degree of freedom can be obtained. A comparison is carried out on that vibration velocity of the traditional mechanical reduction vibration device in Fig. **3**, as shown in Fig. **8**.

Vibration devices in the directions of the six degree of freedom. Fig. **8** shows that the reduction vibration effects of the 3-PRPS reduction vibration device for the vibration peak



a) Comparison on the vibration velocities of the two reduction vibration devices in three directions of X, Y, Z



b) Comparison on the vibration angular velocities of the two reduction vibration devices in three directions of X, Y, Z.

Fig. (8). Comparison on the vibration velocities of the two reduction.

in the directions of the six degree of freedom are all obviously superior to traditional mechanical reduction vibration device. Moreover, it can reduce the vibration to zero within a short time, which significantly improves the passenger's comfort. This provides a new thought for designing reduction vibration seat.

CONCLUSION

A: The vibration velocities of the seat platform and traditional mechanical reduction vibration device were measured through tests, which provided certain basis for proposing and design of the parallel mechanism with six degree of freedom in subsequent paragraphs.

B: The mechanism had less kinematic branches and compact structure and was easy to be controlled. The motion characteristics were of important significance and application prospects to researches on multi-dimensional reduction vibration.

C: Simulation analysis was carried out on the optimization results of the parallel mechanism with six degree of freedom by ADAMS software. Meanwhile, comparison was carried out on the reduction vibration effects of the parallel mechanism with six degree of freedom and traditional mechanical reduction vibration device. The results show that this mechanism has a better reduction vibration performance, which provides a new thought for designing reduction vibration seat. Meanwhile, it also provides important reference for application and research of other parallel mechanisms.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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