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Research on the Optimization of the Vibration Reduction Seat Based on Genetic Algorithm

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Abstract: Adopting the parallel mechanism as the main body of the seat and the active joints with spring damping elements as the vibration actuator, we established the damping seat model with the parallel mechanism of six degrees of freedom 3-PRPS. To achieve good damping effect, the damping space and flexibility of the mechanism were improved by affecting the velocity matrix with branched speed built by vectors. Optimal parameter values were obtained by genetic algorithm. Finally, results were synthesized and verified to provide an important theoretical basis for the practical application of the mechanism.

Keywords: Damping seat, simulation and verification, parallel mechanism, task space, genetic algorithm.

1. INTRODUCTION

As the new idea and breakthrough in the field of vibration, the multi-dimensional damping system based on parallel mechanism is of great applications and development value. Researches on the vibration of parallel mechanism around the world focused on the following 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 after analyzing a kinematic performance indicator of the parallel mechanism. To the mechanism, size parameters largely relate to the motion performance. The size optimization based on tasks in the multi-dimensional damping system of the parallel mechanism is of great significance. However, the size optimization of the damping of parallel mechanism in the task space has not been reported.

In this paper, compact, controllable and precise [13, 14] parallel mechanism with six degrees of freedom 3-PRPS was the main body of the multi-dimensional vibration seat. The active joints were accompanied with spring damping elements to achieve energy absorption and dynamic adaptive balance, thus reducing the physical and psychological harm to drivers due to strong vibrations of agricultural vehicles and improving driving and riding comfort. Meanwhile, it was figured out that stability index limited the position and orientation of the mechanism's moving platform and that the optimization in the task space of the parallel mechanism was more practical, which provided significance in the engineering application of the mechanism.

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2. THE MECHANICAL MODEL ESTABLISHMENT AND THE SOLUTION OF JACOBIAN MATRIX

2.1. The Establishment of 3-PRPS Parallel Mechanism

As shown in Fig. (**1**), the damping 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 of the 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 circumcircle radius of the moving platform was r and the inscribed circle radius of the fixed platform was R. According to the characteristics of 3-PRPS parallel mechanism, fixed coordinate system ***O-XYZ*** was established on the orthocenter of the fixed platform O and moving coordinate system ***p-xyz*** was established on the orthocenter of the moving platform p.

We installed spring and damping devices on the longitudinal moving pair of branch H and the contact position P between branched chain and the fixed platform. With elastic support, vertical rod length changes and horizontal movement of P could be realized, so that to realize the damping seat with six-dimensional direction.

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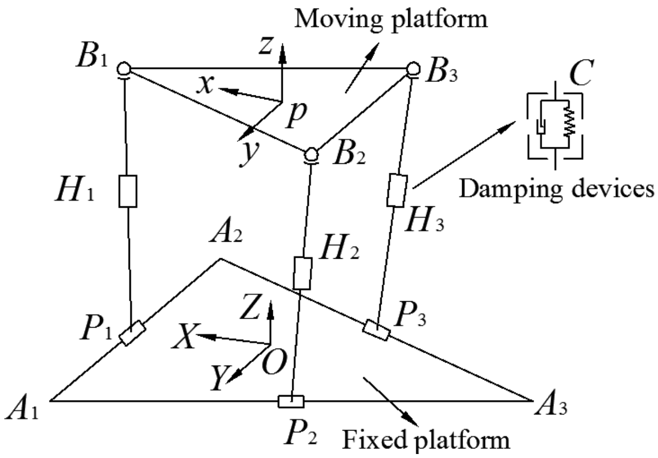


Fig. (1). Simple expression of 3-PRPS parallel mechanism.

2.2. The Solution of Speed and Acceleration of the Mechanism

According to the symmetry of 3-PRPS parallel mechanism, we studied a loop of the mechanism and established the single chain vector diagram of the mechanism as shown in Fig. (**2**).

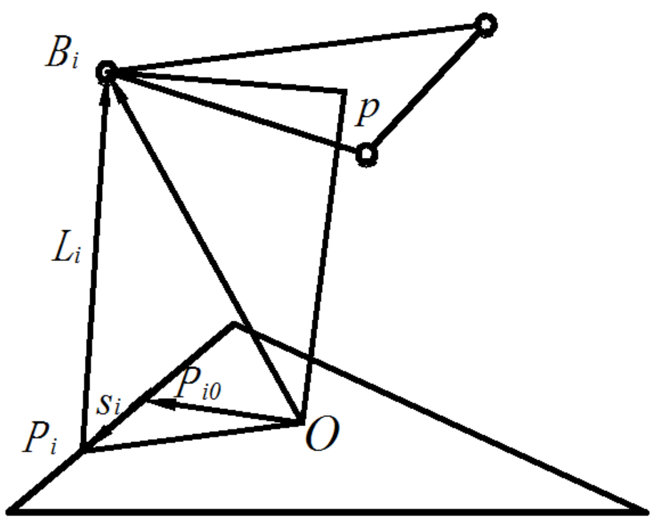


Fig. (2). Single chain vector diagram of the mechanism.

We can see:

$$\boldsymbol{OB}_i = \boldsymbol{OP}_{i0} + \boldsymbol{P}_{i0}\boldsymbol{P}_i + \boldsymbol{P}_i\boldsymbol{B}_i \tag{1}$$

(1) shows that:

$$\boldsymbol{P}_{i0}\boldsymbol{P}_i = \boldsymbol{OB}_i - \boldsymbol{P}_i\boldsymbol{B}_i - \boldsymbol{OP}_{i0} \tag{2}$$

$$\boldsymbol{P}_i\boldsymbol{B}_i = \boldsymbol{OB}_i - \boldsymbol{OP}_{i0} - \boldsymbol{P}_{i0}\boldsymbol{P}_i \tag{3}$$

Substitute $\boldsymbol{P}_{i0}\boldsymbol{P}_i = \boldsymbol{S}_i$, $\boldsymbol{P}_i\boldsymbol{B}_i = \boldsymbol{L}_i$ into (2) (3) and derivative of the time to obtain:

$$\dot{\boldsymbol{S}}_i = \boldsymbol{v}_{B_i} - \dot{\boldsymbol{L}}_i \tag{4}$$

$$\dot{\boldsymbol{L}}_i = \boldsymbol{v}_{B_i} - \dot{\boldsymbol{S}}_i \tag{5}$$

And because:

$$s_i^2 = \boldsymbol{S}_i \bullet \boldsymbol{S}_i \quad l_i^2 = \boldsymbol{L}_i \bullet \boldsymbol{L}_i \tag{6}$$

Wherein s_i , l_i are respectively the displacement of horizontal slider at the chain I and the length of longitudinal connecting rod

Derive the time of (6) and make (4) and (5) simultaneously to obtain:

$$s_i \dot{s}_i = \boldsymbol{S}_i \bullet \dot{\boldsymbol{S}}_i = \boldsymbol{S}_i \bullet \boldsymbol{v}_{B_i} \tag{7}$$

$$l_i \dot{l}_i = \boldsymbol{L}_i \bullet \dot{\boldsymbol{L}}_i = \boldsymbol{L}_i \bullet \boldsymbol{v}_{B_i} \tag{8}$$

Further derive the time to obtain:

$$s_i \ddot{s}_i + \dot{s}_i \bullet \dot{s}_i = \dot{\boldsymbol{S}}_i \bullet \boldsymbol{v}_{B_i} + \boldsymbol{S}_i \boldsymbol{a}_{B_i} \tag{9}$$

$$l_i \ddot{l}_i + \dot{l}_i \bullet \dot{l}_i = \dot{\boldsymbol{L}}_i \bullet \boldsymbol{v}_{B_i} + \boldsymbol{L}_i \boldsymbol{a}_{B_i} \tag{10}$$

Make $\boldsymbol{s}_i$, $\boldsymbol{l}_i$ the unit vector of the sliding along the directions of $\boldsymbol{S}_i$ and $\boldsymbol{L}_i$, then:

$$\boldsymbol{S}_i = s_i \boldsymbol{s}_i \quad \boldsymbol{L}_i = l_i \boldsymbol{l}_i \tag{11}$$

In addition, the speed of $\boldsymbol{B}_i$ can be expressed as:

$$\boldsymbol{v}_{B_i} = \boldsymbol{v}_p + \omega_p \times \boldsymbol{r}_{pBi} \tag{12}$$

Wherein $\boldsymbol{v}_p$, ω_p are respectively the linear and angular velocities of P in the moving platform.

$$\boldsymbol{a}_{B_i} = \boldsymbol{a}_p + \varepsilon_p \times \boldsymbol{r}_{pBi} + \omega_p \times (\omega_p \times \boldsymbol{r}_{pBi}) \tag{13}$$

Make $\boldsymbol{V}$, $\boldsymbol{A}$ the velocity and acceleration of the position and orientation of the moving platform, then:

$$\boldsymbol{V} = [\omega_p \ \boldsymbol{v}_p]^{\mathrm{T}}_{6\times1} \quad \boldsymbol{A} = [\boldsymbol{\varepsilon}_p \ \ \boldsymbol{a}_p]^{\mathrm{T}}_{6\times1} \tag{14}$$

In matrix form:

$$\boldsymbol{V}_{Bi} = \boldsymbol{G}_p^{Bi} \boldsymbol{V} \tag{15}$$

$$\boldsymbol{A}_{Bi} = \boldsymbol{G}_p^{Bi} \boldsymbol{A} + \boldsymbol{V}^T \boldsymbol{H}_p^{Bi} \boldsymbol{V} \tag{16}$$

where:

$$\boldsymbol{G}_p^{Bi} = [\boldsymbol{i} \times \boldsymbol{r}_{pBi} \ \boldsymbol{j} \times \boldsymbol{r}_{pBi} \ \boldsymbol{k} \times \boldsymbol{r}_{pBi} \ \boldsymbol{i} \ \boldsymbol{j} \ \boldsymbol{k}]_{3\times6}$$

$$\boldsymbol{H}_p^{Bi} = \begin{bmatrix} \boldsymbol{i}\times(\boldsymbol{i}\times\boldsymbol{r}_{pBi}) & \boldsymbol{j}\times(\boldsymbol{i}\times\boldsymbol{r}_{pBi}) & \boldsymbol{k}\times(\boldsymbol{i}\times\boldsymbol{r}_{pBi}) & \\ \boldsymbol{i}\times(\boldsymbol{j}\times\boldsymbol{r}_{pBi}) & \boldsymbol{j}\times(\boldsymbol{j}\times\boldsymbol{r}_{pBi}) & \boldsymbol{k}\times(\boldsymbol{j}\times\boldsymbol{r}_{pBi}) & [0]_{3\times3\times3} \\ \vdots & \vdots & \vdots & \\ & [0]_{3\times3\times3} & & [0]_{3\times3\times3} \end{bmatrix}_{3\times6\times6}$$

Make (7) - (10) simultaneously to obtain:

$$\boldsymbol{P} = \boldsymbol{GV} \tag{17}$$

$$\dot{\boldsymbol{P}} = \boldsymbol{GA} + \boldsymbol{V}^{\mathrm{T}} \boldsymbol{HV} \tag{18}$$

where:

$$\boldsymbol{P} = \begin{pmatrix} \dot{s}_1 & \dot{s}_2 & \dot{s}_3 & \dot{l}_1 & \dot{l}_2 & \dot{l}_3 \end{pmatrix}^{\mathrm{T}}$$

$$\boldsymbol{V} = [\omega_x \ \omega_y \ \omega_z \ v_x \ v_y \ v_z]^{\mathrm{T}}_{6\times1}$$

They are respectively the input and output speed matrices of the mechanism. $\boldsymbol{G}$, $\boldsymbol{H}$ are respectively the first-order influence coefficient matrix and first-order and second-order influence coefficient matrix of input speed to moving platform velocity.

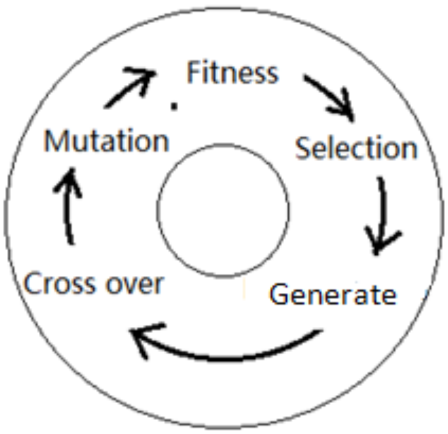


Fig. (3). Genetic algorithm.

3. OPTIMIZATION DESIGN OF PARALLEL MECHANISM BASED ON GA

3.1. Optimization Model Establishment

Constraints of the intersection angle of the revolute pair Limit the vice rotation angle by defining the angle ϕ between the longitudinal connecting rod L_i and the initial position L_i^0. The maximum was $\phi_{\max}$ and minimum was $\phi_{\min}$. ϕ_i should meet $\phi_{\min} \le \phi_i \le \phi_{\max}$. Constraints of parameters of the mechanism:

The constraints were shown as follows:

$$\begin{cases} 0.8 \le k \le 1.5 \\ 1.8 \le q \le 2.4 \\ -30^\circ \le \phi \le 30^\circ \end{cases} \tag{19}$$

3.2. Optimization Algorithm Selection

Genetic algorithm is a kind of machine learning technique, which relies on evolutionary theory. Unlike traditional optimization methods, genetic algorithm is a colony optimization technique. In the algorithm, individuals are often decoded by binary system. Individuals need to be decoded during fitness calculation. Fitness is an index for evaluating the advantage and disadvantage of a solution. According to Darwin's evolutionary theory, individuals with high fitness are more likely to be selected to generate the next generation.

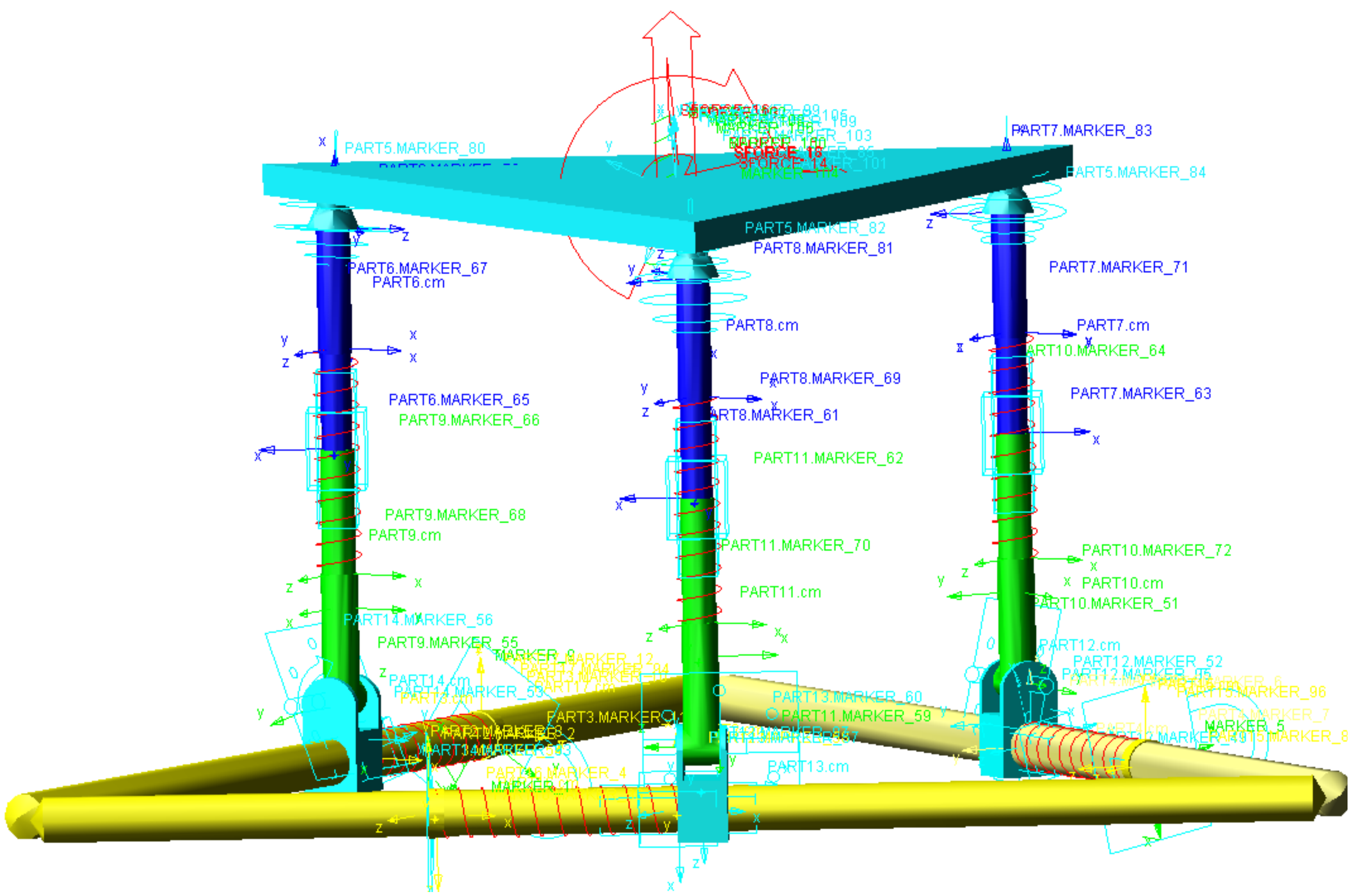


Fig. (4). Suspension seat simulation model of the mechanism.

Based on the selected individuals, the next generation is generated by genetic operators. Each of the individual conducts cross over and mutation with another selected individual according to certain probability. The generated individuals become the candidate solutions for the next generation. This process is repeated for many generations to enable the population to evolve constantly, thus acquiring the solution of the optimization problem, as shown in Fig. (**3**). The genetic algorithm is characterized by: 1). Preserving a small number of elites in the population to the next generation. 2). Automatically determining the size of the population according to the defined optimization problem. 3). Providing 3 categories of cross over operations, i.e., single-point cross over, two-points cross over and uniform cross over. 4). Mutating the individuals according to certain probability.

And the parameter configuration of GA was as follows:

Scale of sub-population: 20

Scale of total group：300

Total evolving algebra: 150

Crossover rate：0.7

Mutation probability: 0.01

Elite individual: 1

4. RESULTS AND CONCLUSION

We chose q = 1.9 and k = 1 taking movement space and flexibility into account after optimization.

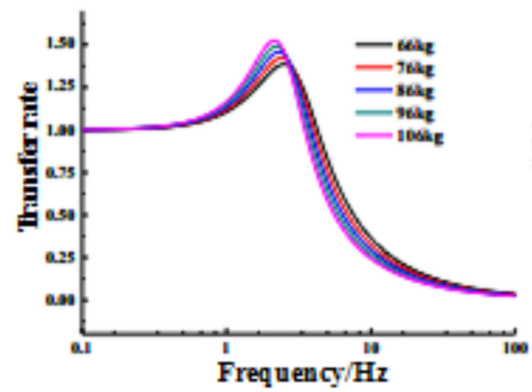
4.1. Simulation

From the above, we selected the mechanism parameter as $r = 200\text{mm}$, $R = 200\text{mm}$ and $h = 380\text{mm}$. The model of the damping platform is shown in Fig. (**4**).

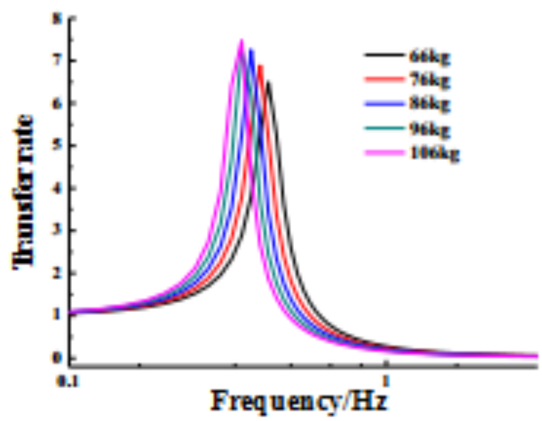
In order to verify the damping effect, we took the quality of the moving platform as 66,76,86,96,106kg respectively, added damping spring with stiffness coefficient $k = 5.0\ \text{N/mm}$ and damping coefficient $c = 0.5\ \text{N}\cdot\text{s/mm}$ to the lateral movement joints and added damping spring with stiffness coefficient $k = 10.0\text{N/mm}$ and damping coefficient $c = 1.0\ \text{N}\cdot\text{s/mm}$ to the longitudinal connecting rod movement joints. Then we exerted pulse force F and pulse torque M from x , y , z to the center of moving platform. The amplitude of the force was 600N . Torque amplitude was $600\text{N}\cdot\text{mm}$. The total time of the pulse was 0.4 seconds. The pulse function was STEP (time,0,0, 0.1,600)+STEP (time,0.1,600,0.3,-600) +STEP (time,0.3,-600,0.4,0). After the dynamics simulation at End Time=10 and steps=100. Through above parameters and in combination with a multi-body dynamic model, we could obtain acceleration transfer characteristics in 3 perpendicular axial directions under different bearing qualities, as shown in Fig. (**5**).

It is shown in Fig. (**5**) that, with gradually increased bearing quality, resonance frequency and maximum transfer rate of acceleration in each axial direction changed very little. The general smooth and steady trend reflects that bearing quality of system does not exert large impacts on dynamic performances of a damping device, indicating that the multi-dimensional damping device proposed in the paper can be adapted to vibration damping demands of members with different weights.

a) Vertical Direction Z



b) Horizontal Direction X



c) Horizontal Direction Y

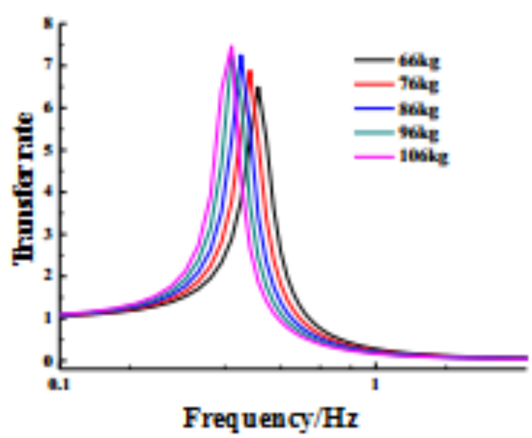


Fig. (5). Acceleration transfer characteristics of system in each Axial direction under different bearing qualities.

CONCLUSION

(1) Based on the multi-directional vibration of agricultural vehicle seat and combining with multi-dimensional movement of the parallel mechanism, a

new seat suspension of the parallel mechanism with six degree of freedom was designed.

(2) The mechanism had less 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 damping.

(3) Taking the improvement of workspace and flexibility as the purpose, the seat may achieve good damping effect, which provides an important theoretical basis for the application of the mechanism.

(4) Optimization results were analyzed emulationally by ADAMS software. Results showed that the mechanism had great damping properties, which not only laid a solid foundation for the application of the mechanism in terms of damping seat but also provided important reference for the application of the other parallel mechanism.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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