Structural Design and Simulation of Linear Motion Device

Xuefeng Sun1,a, ZheZhao2,b
1Kai Yue auto parts manufacturing (Zhangjiakou)co.,Ltd, Zhangjiakou, China
2School of Automation Science and Electrical Engineering, Beihang University, Beijing, China
asxfandlyn@sina.com
bzhezhao@buaa.edu.cn

Abstract: Linear motion device is widely used in various industries. In this paper, a linear motion device design method is proposed for the test system with large load mass, large impact velocity and short acceleration time.

According to this paper, the design of linear motion device is explicated, the structure of linear motion device is described, and the working principle is stated. Also, the three-dimensional model design of the components in linear moving device is carried out based on UG, and the sub-structure is illuminated. The finite element simulation analysis of each part in the catapult device is carried out based on Nastran. Conclusively, the structural deformation and stress of each part of the linear motion device are obtained, verifying the feasibility of linear motion device structure design.

1. Introduction
The linear motion device apply to simulate the load test of a missile system and is suitable for the test system with large load mass, large impact velocity and short acceleration time to simulate the missile launch canister within the motion[1]. Given a 100kg load of the linear motion device, the mechanism is able to move at high speed along the vertical direction through the measurement and control system to monitor the impact process, obtaining simulated loads of different structures, weights, motion status and process of the tested product[2]. The main performance indicators proposed in this project are: the load motion speed is not less than 45m/s[3], which ensures the completion of the motion travel and controls the relative position accuracy of the measured object and the simulated load.

2. WORKING PRINCIPLE OF LINEAR MOTION DEVICE
The linear motion device generally moves the tested component to the set position according to the requirements, which is mostly composed of the motion device, the release device and the motion frame. Among them, the motion frame mainly provides installation support for the linear motion device, and the motion device is mainly used for the component under test. The installation interface is provided to complete the vertical movement. The release device is used to complete the release of the load at the specified position. The basic principle is shown in Figure 1 by pulling the wire rope to move it along the guide column.
Analyzing the function and performance index of the linear motion device, the function of it is to move the measured part to the set position driven by the wire rope. The motion device is used to install the connecting piston and move with the piston. According to the structural design of the motion device, the diameter of the measured part shall not be greater than 200 mm. The motion device adopts the wheeled walking mechanism[5], among which the wheel diameter is 42 mm, the grease lubrication speed of the precision bearing can reach 36000r/min, and the maximum linear speed of the wheel can reach 79.13 m/s. For safety reasons[6], the maximum linear speed of the motion device and the tested part should not be higher than 70 m/s.

Linear motion device with the method of vertical movement. Measured component in any position must have a locking function, to prevent it from falling automatically due to the gravity. When the task starts, the locking device unlocks. Therefore, it must have good control logic to perform the unlocking of the ejection task. Besides, the unlocking time difference of the ejection task should be less than 1 ms, otherwise it will adversely affect the speed control.

3. STRUCTURAL DESIGN OF LINEAR MOTION DEVICE
The three-dimensional model of the linear motion device built based on UG software is shown in figure 2, which is mainly composed of motion device, motion frame and release device.

3.1. Motion Device
The motion device mainly drives the simulated load under the drag of the steel wire to achieve linear acceleration motion on the motion frame. As shown in Figure 3, the walking mechanism is mainly composed of a guide seat, wheels, frames and feet. The guide seat is installed in four directions 8 wheels, move linearly along the guide column. The wheels use nylon for better vibration damping effect. The bearings use NSK7201C, which can withstand a rated static load of 7900 N, a rated dynamic load of 3850 N and a grease-lubricated speed limit of 36000 r/min. The four guide seats are connected as
a whole through the frame to improve the mechanical characteristics. The two feet are used to contact the lifting mechanism to adjust the position of the linear motion device.

![Figure 3. Three-dimensional Model of Motion Device](image)

### 3.2. Movement framework
The motion frame mainly ensures the bracket moves along a straight line and plays a role of guidance. Since the contact distance between the simulated load and the buffer to test its performance is small while the movement distance and speed of the load are large, the performance test task may not be completed if it is not guided. As shown in Figure 4, the guide cylinder is machined with a steel cylinder with an inner diameter of 780mm, an outer diameter of 790mm and a length of 5100mm.

![Figure 4. Three-dimensional Model of Movement Framework](image)

### 3.3. Release Device
The release device is generally used to connect and separate the motion device and the simulated load. As shown in Figure 5, it mainly consists of base, supporting shaft, connecting rod and spring. The base and the moving device are connected by bolts to achieve linear walking. The four supporting shafts jack the bracket under the pre-pressure of the spring to ensure the linear movement of the load and movement device under the guidance. Since each supporting shaft is an elastic support, the linear movement of the bracket is also able to be automatically compensated.

![Figure 5. Three-dimensional Model of Release Device](image)
As shown in Figure 6, when the bracket reaches the specified position, the mechanical block on the guide barrel pushes the connecting rod to drive the supporting shaft to move backward, thus separating the supporting shaft from the load and realizing the separation of the load from the moving device.

![Figure 6. Release Status](image)

### 4. SIMULATION AND ANALYSIS

According to the working principle and motion characteristics of the ejection arresting simulation system, the motion device is divided into two processes in the whole ejection testing process: acceleration process and braking process. It is rather necessary to carry out finite element analysis on the moving devices in these two states respectively.

#### 4.1. Finite Element Analysis of Accelerator

According to the analysis of the working principle and operating characteristics of the moving device, it is necessary to provide 34g acceleration when the moving device accelerates to 45m/s. Firstly, the moving device is preprocessed (as shown in figure 7), the material characteristics and mesh division are set for each part of the structure. According to the force characteristics of the moving device, 35g gravity load is added, slider constraint is added at the wheeled walking position of the moving device and fixed constraint is added at the connecting hole of the wire rope. The finite element analysis is shown in Figure 8 where the maximum deformation is 1.82mm and the maximum stress is 92.2mpa, meeting the design requirements of mechanical properties of the product.

![Figure 7. Pretreatment of Motion Device](image)

a) Stress Distribution
4.2. **Finite Element Analysis of brake**

According to the analysis of the working principle and running characteristics of the motion device, when the motion device runs to 45m/s, it needs 101g acceleration to brake. Firstly, the moving device was pre-processed (as shown in Figure 9), and material characteristics and mesh division were set for each part. According to the force characteristics of the moving device, 101g of gravitational acceleration is added. Fixed constraints are added to the braking part of the moving device, and slider constraints were added to its wheeled walking position. The finite element analysis is shown in Figure 10, where the maximum deformation is 0.28mm and the maximum stress is 15.4Mpa, meeting the design requirements of mechanical properties of the product.

---

**Figure 8.** Results of Distribution

**Figure 9.** Pretreatment of Motion Device

**Figure 10.** Finite Element Analysis of brake
6

b) Strain Distribution

Figure 10. Results of Distribution

In terms of the finite element analysis results, it can be concluded that the structure design of the linear motion device is reasonable and its motion function can be achieved.

5. CONCLUSION

At present, the linear motion device has realized the test process of 45m/s speed with good control precision, and its stress and strain parameters are consistent with the simulation results. This paper provides a reference for linear motion device.

References

[1] Swett D W, Blanche IV J G. Flywheel Charging Module For Energy Storage Used In Electromagnetic Aircraft Launch System[C]. IEEE 2004 12th Symposium on Electromagnetic Launch Technology, pp. 551-554, May 2004.
[2] Stumberger G, Zarko D, Aydemir M T, Lipo T A. Design and Comparison of Linear Synchronous Motor and Linear Induction Motor for Electromagnetic Aircraft Launch System[C]. Proceedings of IEEE International Electric Machines and Drives Conference, IEMDC, 03, pp. 494-500, Wisconsin, USA, June 2003.
[3] Patterson D, Monti A, Brice C, Dougal R, Pettus R, Srinivas D, Dilipchandra K, Bertoncelli T. Design and simulation of an electromagnetic aircraft launch system[C]. Industry Applications Conference 2002. 37th IAS Annual Meeting.
[4] Araki K. Frequency response of a pneumatic valve controlled cylinder with an overlap four-way valve: Part I. theoretical analysis [J]. Journal Fluid Control, 1986, 7(1): 7-43.
[5] Merritt H E. Hydraulic control systems [M]. New York: John Wiley & Sons, 1967.
[6] Ruan J, Ukrainetz P, Burton R. Frequency domain modelling and identification of 2D digital servo valve [J]. International Journal of Fluid Power, 2000, 1(2): 76-85.
[7] Reichert M, Murrenhoff H. New Concepts and Design of High Response Hydraulic Valves Using Piezo-Technology[J]. Power transmission and motion. Bath: University of Bath, 2006. 401-414.
[8] Antonio G, Demonico L. Modelling and Simulation of A Hydraulic Breaker[J]. International Journal of Fluid Power, 2005, 6(2): 47-56.