Optimization Design of Single Stage Cylinder Driven Rope Linkage Cantilever of Endoscope Device

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Abstract. Aiming at the problem of the detection of the inner wall surface of solid rocket motor, the design expansion of the existing endoscope detection device cantilever has reached 3.5m. In order to meet the measurement accuracy requirements, the static and modal analysis and optimization of the stepping motor, industrial camera and the whole cantilever are carried out based on the ANSYS software analysis platform. Ensure that the mechanical characteristics of the cantilever can meet the requirements, and ensure that the working frequency of the motor avoids the natural frequency of the cantilever, so that the shooting environment of the industrial camera is relatively stable, and the resonance will occur when it is detected. Therefore, optimize the design of the device, increase the damper to reduce the vibration of the device, so as to achieve the normal operation of the device.

1. Introduction
The interior of a ballistic missile fuel is hollow. Because it is a solid fuel rod, it is easy to crack the internal surface of the fuel rod when it is placed too long [1-3]. Therefore, a single-stage cylinder driven rope linked endoscope detection device is designed to meet the detection of the inner surface of the fuel rod. The detection device can extend 3.5 m, and complete the detection of the whole 7 m grain by extending the two ends separately [4].

There are stepping motors and industrial cameras in the front of the endoscope device. When it extends 3.5 m, it will produce a large moment, so it needs to carry out static analysis. According to the working steps, when the motor rotates at an angle, the industrial camera will take photos. For example, the frequency of the stepping motor is the same as the natural frequency of the cantilever, resulting in resonance, which will affect the shooting effect. Therefore, modal analysis is required.

2. Overall structure
The whole single-stage cylinder driven rope linkage endoscope device is mainly composed of single-stage cylinder, five-stage box, stepping motor, industrial camera, laser rangefinder, industrial control machine, electrical cabinet, manual control panel and air compressor. The electric control system includes manual control mode and automatic control mode. When the industrial computer receives the forward signal, it controls the forward of single-stage cylinder through the electromagnetic reversing valve, the single-stage cylinder drives the fourth stage box forward, and the five-stage box linkage of
the cantilever completes the expansion of the whole cantilever and the maximum extension of the cantilever.

Figure 1. Extension state of single-stage cylinder driven rope linked endoscope

Figure 2. Servo explosion-proof motor

The output is 3.5m. The expansion of the cantilever is fed back to the industrial computer by the laser rangefinder for real-time monitoring. When the cantilever is extended to a fixed position, the industrial computer controls the rotation of the motor through a servo driver, and the industrial camera takes photos and samples every 15° rotation of the motor. When the motor rotates for one turn, the cantilever extends to the next position, and the above actions are repeated. The working state of the cantilever is shown in Figure 1.

Because the tested device is a missile grain, it is necessary to avoid sparks. There are two alternative schemes. The first scheme is to directly select ex explosion-proof motor, which has a strong explosion-proof shell, can withstand internal explosion in special gas and dust environment without endangering the surrounding environment, which is very in line with the requirements of the experiment, but its disadvantage is high price and heavy weight, As shown in Figure 2. Due to the limited budget and considering the cost, we try the second plan.

In the second scheme, the ordinary stepping motor is selected, and the explosion-proof enclosure is added outside. The test is carried out under the protection of the explosion-proof enclosure. The results show that the design of the second scheme can also meet the explosion-proof requirements of the industrial site, but the disadvantage is that the angle accuracy of the motor is poor. Considering the low price and light weight of the scheme, it is only 1.5 kg, which basically meets the requirements of the experiment, so the scheme is selected Select the second scheme as the experimental scheme, as shown in Figure 3.
3. Static analysis

By applying different loads to the cantilever, the mechanical properties of the cantilever when the servo motor and the stepping motor are installed in the front of the cantilever are simulated, and then the influence of the two motors on the cantilever is analyzed. Suppose \( e \) is the elastic modulus of the fifth stage box, \( J \) is the moment of inertia of the fifth stage box to the neutral axis, \( W \) is the applied load, \( L \) is the length of the fifth stage box, \( \Delta \) is the deflection, and \( K_\Delta \) is the rigidity of the fifth stage box. Deflection of the fifth stage box: \( \Delta = \frac{WL^3}{3eJ} \); rigidity of the fifth stage box: \( k_\Delta = \frac{3eJ}{L^3} \).

3.1. Select servo motor

When the whole cantilever extends for 3.5m, the maximum deflection will be generated at the front end of the servo motor. When the servo motor is selected, since the mass of the servo motor is 4.5kg, a 45 N load will be applied, and the bottom of the lifting car is the fixed end. The results obtained through the analysis of ANSYS platform are shown in Figure 4.

As shown in Figure 4, it can be seen that the deflection of the cantilever is 9.08 mm when the servo motor is installed, and the maximum allowable deflection of the cantilever is 10 mm, which is within the allowable range.

3.2. Step motor selection

When the stepping motor is installed, the deflection of the cantilever is measured. Similarly, select the bottom of the lifting car as the fixed end, apply 15N load to simulate the gravity load of the stepping motor, and carry out ANSYS analysis. The results are shown in Figure 5.

As shown in Figure 5, it can be seen that the deflection of the cantilever is 4.13 mm when the servo motor is installed, which is better than 9.08 mm of the servo motor, and also within the maximum allowable deflection of the cantilever of 10 mm.

On the premise that both servo motor and step motor meet the requirements of shooting accuracy, step motor is smaller and lighter, the deflection of cantilever is smaller, and the cost is lower.

4. Modal analysis

In addition to the deflection of the cantilever, the factors that affect the shooting accuracy also include whether the cantilever is stable when the industrial camera is shooting. When the cantilever works, the cantilever extends into a certain hole depth and stops, the motor rotates 15°, and then the industrial camera takes photos. Because the time interval between the motor and the industrial camera is very short, if the rotation of the motor causes resonance of the whole cantilever, it will directly affect the shooting accuracy. Therefore, the modal analysis should be carried out to detect whether the natural frequency of the cantilever overlaps with the excitation frequency of the motor, thus causing resonance.

When the single-stage cylinder drives the rope linkage endoscope detection device to work, the sliding small wheel of the lifting car is in a fixed state. In the ANSYS platform, select the lifting car in
the X and Z direction as fixed state, carry out simulation operation, and the results are shown in Figure 6.

5. Optimization
In order to ensure that the device can operate without any problem, it is necessary to solve the problem of resonance. It is thought to add vibration suppression during the operation of the device.

5.1. Selection of damper
As a passive control method, energy dissipation and vibration reduction technology mainly provides certain additional stiffness or damping for the structure by adding dampers or energy dissipation components in some parts of the structure, and dissipates the energy input to the structure, so as to reduce the dynamic response of the structure and protect the safety of the main structure. Therefore, the selection of damping materials is the most critical part of the damping system, generally including oil damper, viscous damper, viscoelastic damper, metal damper, etc. To sum up, a kind of tuned elastic damper (TVD) is selected for vibration reduction, which is both an elastic element and a damping element. By adjusting the thickness of rubber and different types of rubber materials, the damping and stiffness of the damper are adjusted, and dynamic vibration absorption is used to achieve the effect of damper vibration reduction. The damper is mounted directly above the far end of the cantilever.

5.2. Modal analysis of damper
The damper is modeled based on the geometric dimension of the whole device. The damper is composed of rubber and mass block (tungsten copper alloy). The market share of tungsten copper alloy is large, high temperature resistance, wear resistance and viscosity resistance are good. The modal analysis is carried out by ANSYS, and the fixation method in the process of modal analysis is that the rubber of damper is fixed on the contact surface (upper surface of rubber sheet) of the device. Through the ANSYS analysis results, it can be seen that the first five vibration modes of the damper are the left and right swing or torsion of the mass, and the sixth vibration mode is the vibration of the mass in the direction of the vertical contact surface, so the sixth natural frequency of the damper is close to the device frequency, which plays the role of resonance energy absorption.

6. Conclusion
This paper analyzes and simulates the selection of the motor of the existing single-stage cylinder driven rope linked endoscope detection device. By comparing the two schemes of adding explosion-proof enclosure to the explosion-proof servo motor and the ordinary stepping motor, the ordinary stepping motor is selected to install explosion-proof enclosure based on the requirements of the lowest cost and smaller deflection when the cantilever deflection requirements are met. The modal analysis of the cantilever is carried out, and the working resonance frequency of the stepping motor is measured based on the LMS. According to the comparative data, when the stepping motor is working, it will cause the resonance of the whole cantilever, which can not guarantee the measurement accuracy. Therefore, the optimal design of the device increases the vibration reduction device to ensure the measurement accuracy.

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4
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