Design and Verification of a 2 Dimension Mechanism used in Cryogenic Vacuum Environment

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Abstract. In order to monitor the state of the test product during the thermal test, a two-dimensional mechanism installed the infrared thermal imager used in cryogenic vacuum environment was designed. The two-dimensional mechanism is placed on the opposite of the specimen. According to the actual needs, it drives the infrared thermal imager to move to the designated area. The transmission mechanism is using the ball screw. The whole system includes transmission mechanism, stepping motor, supporting mechanism and control system. For environmental requirements of vacuum 10^-4pa and 100K, some special design enables the two-dimensional mechanism to overcome the failure of the low temperature, and realize the vacuum environment lubrication and cryogenic vacuum environment stepping motor overheat. The two-dimensional mechanism has been designed and verified, and it is able to satisfy the cryogenic vacuum environmental requires.

1. Introduction
During the thermal test, the product is placed in a sealed container. The status of the product such as its surface temperature cannot be easily gotten. In order to monitor the state of the test product during the thermal test, it needs a mechanism to move the camera and detect the product during the thermal test. The two-dimensional mechanism is used in cryogenic vacuum environment. There are two moving directions of the mechanism, horizontal and vertical. The horizontal movement range is 2000mm, the vertical movement range is 1000mm.

This paper analyzed and designed the two-dimensional mechanism used in the cryogenic vacuum environment, including mechanism design, thermal design and control system development. It solving the failure of the low temperature, vacuum environment lubrication and cryogenic vacuum environment stepping motor overheat. After test and verification, it can satisfy the requirement of the cryogenic vacuum environmental [1-2].

2. Scheme implementation
The development process of the two-dimensional mechanism includes mechanism design, product manufacture, product assembly, thermal design, thermal control implementation, control system development, control cabinet design, electrical design, system integration and testing, as it is shown in the Figure 1.
2.1 Mechanism Design
There are two moving directions of the mechanism, horizontal and vertical. To ensure the motion accuracy and prevent camera on the vertical direction from sliding automatically. The transmission mechanism is using the ball screw. The stepping motor connect to the screw and realize the mechanism moving, selecting the Phytron vacuum stepping motor. Its maximum torque is 4.3Nm, it can work in the vacuum environment. To avoid the motor temperature rise too fast when the motor is not working in the vacuum environment, a delay is installed in the motor circuit and the controller calculate the motor stop time and monitor the motor temperature. If the motor stops for more than a certain time or the motor temperature is too high then control the relay cuts the circuit, it can be controlled by engineer either \[3-4\].

Lubrication and sealing should also be considered in the vacuum environment. The common lubrication oil will fall in the cryogenic environment, in the vacuum environment it will evaporate and cause pollution. So the vacuum lubricating grease is required in the cryogenic vacuum environment. It also needs to ensure that there is no airtight space in the mechanism during the thermal vacuum test. In case that the vacuum is not qualified due to the degassing of the mechanism, it can be realized by punching holes in the mechanism shell. To prevent the cables from dragging and wearing, the cable drag chain was designed to protect the cables \[5-6\].

The maximum torque is required in the horizontal direction when the mechanism is accelerating or decelerating, so the horizontal direction was taken as an example for calculation and analysis. Firstly, the inertia of the load is calculated, the Function(1) is as fellows \[7\]:

\[
J_l = W \times \left(\frac{\pi \times 15}{2 \times 10} \right)^2 
\]

In this function, the \(J_l\) is the load inertia, \(W\) is the load weight, \(V\) is the motor linear velocity, \(N\) is the rotate speed. After calculating the inertia is 3.5kg·cm\(^3\). Then the maximum torque is calculated, the Function(2) is as fellows \[7\]:

\[
T = \frac{(T_1+T_m) \times N}{t \times 9.55 \times 10^4} 
\]

In this function, the \(J_l\) is the load inertia, \(J_m\) is the motor inertia, \(N\) is the rotate speed, \(t\) is the accelerating or decelerating time, the torque is 1.03N·m, it is smaller than the motor torque, the schematic diagram of the mechanism is in the Figure 2.
2.2 Thermal Design

During the thermal test, the background environment is a cryogenic vacuum environment. In such environment, there is only radiation heat transfer. In order to prevent the lead screw deformation causing the device cannot work, the cable become brittle and the stepping motor is too cold to start in this environment. The thermal control design is needed. In this study, the heating plates was attached on the guide rail and the motor casing to provide heating power and avoid the mechanism temperature being too low. Installing the multilayer heat insulation assembly on the surface of the device, due to its high thermal resistance and low surface emissivity, it can keep the mechanism at constant temperature.

To ensure the reliability of thermal control design, the Thermal Desktop software was used for simulation. Thermal Desktop can be quickly combine with the AutoCAD software. During the simulation, the material of the mechanism is stainless steel, the thermal conductivity is 12.6W/m·K and the specific heat capacity is 490J/kg·K. The surface optical material is multilayer heat insulation assembly, the emissivity is 0.1, the heat sink temperature is 100K, the total heat power is 30W. The simulation result are shown in the figure3.

As it is shown in the Figure 3, under the condition that the motor is not working, the motor temperature is about 265 K, the motor can work normally at this temperature. The guide temperature is between 267K to 276K, the deformation of the lead screw is very small, the mechanism can work smoothly.

2.3 Control System

The control system includes control cabinet design, motion control and temperature control, they are integrated in a web server. Engineers can operate the motion control system and the temperature control system on a workstation access the web server.
The control cabinet is shown in the Figure 4, the size of the control cabinet is 1000mm×1000mm×300mm. It includes the motor drivers, moving control card, web server, temperature controller and power supply.

![Figure 4 Control cabinet](image)

The motion control system is using the motion control card as the controller. It control the motor driver and sends pulse signals to the stepping motor, then realize the purpose of controlling motor acceleration, deceleration and changing its rotation direction, the schematic diagram of motion control is as follows:

![Figure 5 Motion control schematic diagram](image)

The MR13 temperature controller was used for the temperature control. PT100 was used as the input sensor, it measuring the temperature of the mechanism. The heating plates was used heat the mechanism. The output of the temperature controller connect to solid state relay then it connect to the heating plates, At the same time the heating plates circuit is connected to the power supply, the schematic diagram of temperature control is as follows:
2.4 Human machine interface (HMI)

The HMI design is after the mechanism design and electrical design. Engineers control the two-dimensional mechanism by setting parameters on the interface. Temperature control and motion control are on the main page, the temperature control zone is on the left side of the page and the motion control zone is on the right side of the page. In the process of temperature control, the engineer sets the target temperature and alarm threshold in the temperature parameter setting page, the target temperature and real-time temperature of the measuring point can be fed back on the page and the temperature curve can be drawn. Motion control includes moving control, zero point control, and program control. The function of moving control is to control the two motors when motion speed and distance are set respectively. The zero point control is control the mechanism moves to the origin position. The programming control is to set the motion parameters by the engineer so that the two motors move simultaneously according to the conditions of the engineer. The feedbacks such as motion speed, target position and current position are on the main page too. The main page is shown in Figure 7.

3. Verification and Conclusion

After the design of the 2-dimensional mechanism, in order to verify its mechanical performance in the cryogenic vacuum environment, the 2-dimensional mechanism, is put into the environment simulator for test. The test environment includes atmospheric pressure test, vacuum test and cryogenic test. In these three environment, the motion of the 2-dimensional mechanism were tested in different speed and acceleration and the temperature control effect was verified. The flowchart of the test process is shown in the Figure 8 and the test conditions set are shown in the Table 1.


During the test, the mechanism was put into an environmental simulator. Firstly, it was tested at normal temperature and pressure. In this environment, the moving control, program control and emergency stop control of the mechanism are tested. Then the simulator was sealed and tested the machine in the vacuum environment, the moving conditions are similar to the atmospheric environment test. At last, test the machine on the cryogenic vacuum environment, the moving conditions are similar too.

The transmission mechanism adopts the ball screw, with its advantage of high transmission efficiency, high precision and good rigidity. In the circuit and program design, some measures are taken to cut the motor circuit, effectively prevent the motor over heating when it works in the vacuum environment.

Table 1. Test condition setting.

| Test Environment | Work conditions | Moving direction | Speed mm/s | Acceleration mm/s² | Distant mm |
|------------------|-----------------|------------------|------------|--------------------|------------|
| Atmospheric pressure test | Conditions 1 | horizontal | 6 | 20 | 200 |
| | vertical | 6 | 20 | 100 |
| | Conditions 2 | horizontal | 10 | 25 | 2000 |
| | vertical | 10 | 25 | 1000 |
| | Conditions 3 | Stop | | | |
| Vacuum test | Conditions 1 | horizontal | 5 | 15 | 100 |
| | vertical | 5 | 15 | 200 |
| | Conditions 2 | horizontal | 10 | 25 | 2000 |
| | vertical | 10 | 25 | 1000 |
| | Conditions 3 | Stop | | | |
| Cryogenic test | Conditions 1 | horizontal | 3 | 10 | 100 |
| | vertical | 3 | 10 | 100 |
| | Conditions 2 | horizontal | 10 | 25 | 2000 |
| | vertical | 10 | 25 | 1000 |
| | Conditions 3 | Stop | | | |

Figure 8 The process of the two dimensional mechanism
environment. The motor and guide rail were adopted the thermal control measures, solving the problem that the mechanism deformation and environment temperature is too low to start the motor.

The 2 dimensional mechanism can moving smoothly in the atmospheric pressure, vacuum and cryogenic environment. In the cryogenic environment the transmission mechanism didn't stuck, and can move normally in the automatic and manual mode according to the working conditions. The temperature control of the motor and guide rail is also controlled within the appropriate range, guaranteeing a good working performance. It fulfill the requirement of design of a 2 dimension mechanism used in cryogenic vacuum environment, it embodies the engineering value in the vacuum cryogenic environment.

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