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DESIGN OF A MULTIPLE EXPERIMENTAL SYSTEM WITH 3-AXIAL ACCELERATION AND TEMPERATURE

Qian Liu(*), Yang Min
Institute of System Engineering, China Academy of Engineering Physics,
Mianyang Sichuan, China
(*)*Email:* liuqian_hj@163.com

ABSTRACT

Advanced aerospace systems will experience the axial acceleration, the tangential acceleration, the normal acceleration and varying temperature environment during flight scenarios, which have seriously threatened flight reliability. In order to evaluate and qualify aerospace systems, it is necessary to carry out acceleration and temperature environment tests on the ground. A new technique for testing in a combined 3-axial acceleration and temperature experiment has been developed. It is able to provide a combined three axial accelerations and temperature environment. The configuration and working principle are described in detail in this paper. Besides, the system supplies a new method for the experiment testing of similar products.

Keywords: 3-axial acceleration, centrifuge, system design.

INTRODUCTION

In recent years, with the development of aeronautics and astronautics, high-speed and high-flexibility aerospace systems raise the demand for the high performance and reliability. The high cost of flight testing and the high consequence of system failure during an actual mission make ground-based testing essential for the aerospace system. However, one shortcoming of ground based testing is that different aspects of the flight environment are tested separately instead of concurrently. For example, the aerospace system will experience acceleration loading and temperature loading simultaneously during launch, but the environments will typically be simulated with separate traditional centrifuge and temperature box tests. The traditional centrifuge can only provide a single axial acceleration environment for testing. Any potential synergistic interactions among the multiple environments will not be captured with the conventional testing approach. Because of this uncertainty, it is desirable to test the environments simultaneously. This paper focuses on recent work performed at China Academy of Engineering Physics to combine three axial acceleration and temperature environments in a single test.

In order to overcome these limitations for future testing, a new technique termed a 3-axial acceleration and temperature multiple experimental system has been recently developed for aerospace system testing in a combined three axial accelerations and temperature environment. The structure of this experimental system is shown in Fig.1.

In this paper, the new technique is proposed in detail. The 3-axia acceleration and temperature multiple experimental system uses a traditional centrifuge as its motion base, and also has a long steel arm, which can turn around on an axis by a motor. Located at the terminal end of the arm of this traditional centrifuge is a two gimbals support system providing two degree of freedom rotation; a continuous 360 degrees of rotation about the yaw (backwards and forward rotation) axis and roll (left and right rotation) axis. The yaw axis is mounted vertically on the terminal end of the arm of the system. The roll gimbals and its driver motor situate inside the yaw gimbals. The roll and yaw gimbals are rotated by means of motors. Then the heating system is added to the two gimbals support system. Therefore, the multiple environments of the three axial accelerations and the temperature can be simulated synchronously.

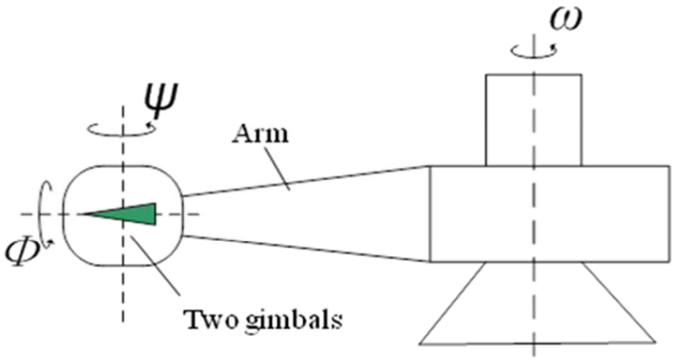

Fig. 1 - Structure of the 3-axia acceleration and temperature multiple experimental system

CONTROL SYSTEM DESIGN

The structure of control system is shown in Fig.2.

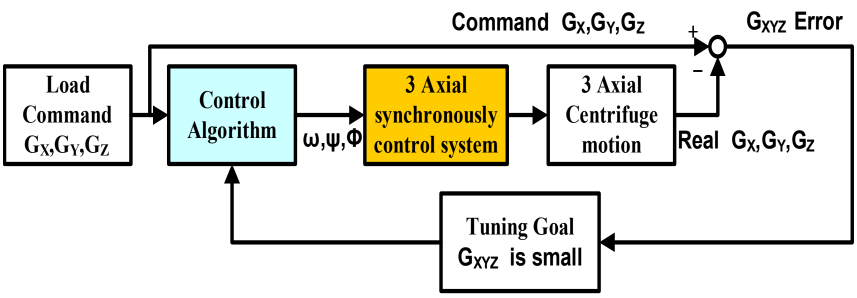

Fig. 2 - Structure of control system

There are three steps to this transformation:

1. Load the command of the time history curve of the three axial acceleration vector (Gx, Gy, Gz) to the computer, and the computer uses the optimized control algorithm to wash out the three motion vector time history: the rotational speed of the centrifuge arm (ω), the yaw angle (ψ) and the roll angle (Φ).
2. Add the three motion vector time histories to the three axial synchronization control system, which synchronously controls the main motor for arm, the motor for yaw gimbals and the motor for roll gimbals. The synchronization control system must be real-time and accurate.
3. The centrifuge arm accelerates to generate a mapped G magnitude, and the gimbals permit the missile to be continuously positioned with respect to the resultant of radial, tangential and vertical components of acceleration. The error between the real acceleration vector and the command acceleration vector can be reduced by turning some compensation factor.

DESIGN OF MECHANICAL SYSTEM

A. Design of a 3.5m centrifuge

As shown in Fig.3, the mechanical system of the 3-Axia acceleration and temperature multiple experimental system is composed of two main components that are a 3.5m centrifuge and a pod system. The 3.5m centrifuge is mainly composed of a motor, a transmission shaft and an arm. The motor is mounted on the base and directly drives the arm rotating through the transmission shaft which is supported by a pair of bearings. The main purpose of the 3.5m centrifuge is to generate accelerations at the place of the pod system. The arm is mounted on the transmission shaft through an expanding sleeve. In addition, the arm is the mounting plate of the pod system.

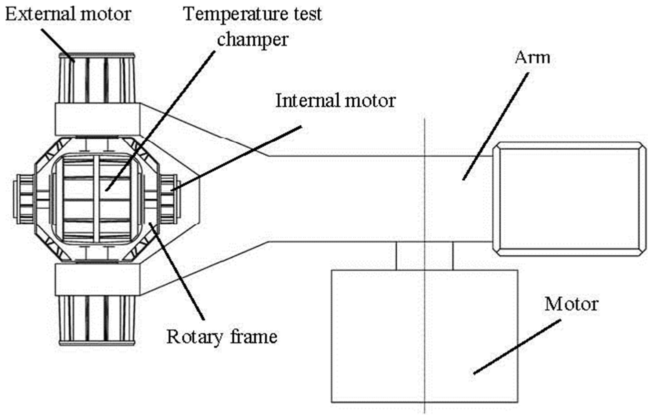

Fig. 3 - Structure of mechanical system

B. Design of a pod system

The pod system is a mechanical system with double crossing axis. As shown in Fig.3, it is composed of an external transmission system, an internal transmission system, a rotary frame and a temperature test champer. The rotary frame is mounted on the external transmission system and is also rotated by the external transmission system. The rotary frame is also the mounting plate of the internal transmission system. The temperature test champer is connected with the internal transmission system. In addition, the temperature test champer is both the mounting plate and the temperature load device of test items.

There are two main driving ways for transmission system that are a directly driving way and an indirectly driving way. The indirectly driving way is such a transmission system which is composed of servo motor and reduction box. Traditional reduction gear box includes gear box and harmonic gear. The directly driving way is driving directly by motor. The transmission system based on the indirectly driving way is so much long in the axis direction that the transmission system cannot meet the requirement of transmission accuracy. In addition, the mass of the transmission system based on the indirectly driving way is much greater than that of the transmission system based on the directly driving way. Therefore, the directly driving way is adopted about the pod system.

C. Design of an external transmission system

The external transmission system is composed of an external motor and an external transmission axis. As shown in Fig.3, the external motor is mounted vertically on the centrifuge arm and drives the rotary frame rotating though the transmission axis.

Output torque of the motor includes acceleration gradient torque, inertia torque, eccentric torque and friction torque. The acceleration generated by the 3.5m centrifuge is different in the radial direction.

When the rotary frame rotates, acceleration gradient torque is generated because acceleration value of each mass point is different. The acceleration gradient torque can be got according to (1). The variable can be shown in Fig.4.

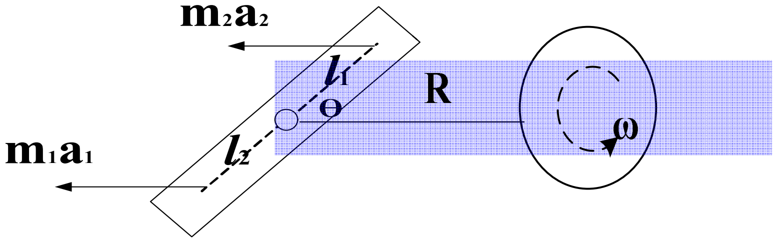

Fig. 4 - Acceleration gradient torque

The inertia torque aims to the torque that is generated by moment of inertia of the pod system. The inertia torque is shown in (2). J is the moment of inertia of the rotary part. ε is the angle acceleration. The eccentric torque aims to the torque that is generated by the eccentricity of the rotary part of the pod system in the acceleration environment.

The eccentric torque is shown in (3). m is the mass of the rotary part. a is the acceleration. e is the eccentric displacement. The friction torque aims to the torque that is generated by friction of bearings. The friction torque is shown in (4). f is friction coefficient. N is the normal stress of the bearings. According to the torque listed above, the external motor is able to be designed.

$$T_1=m_1a_1l_1\sin\theta - m_2a_2l_2\sin\theta \quad (1)$$

$$T_2=J\varepsilon \quad (2)$$

$$T_3=mae \quad (3)$$

$$T_4=fN \quad (4)$$

The external motor is shown in Fig.5. The external motor is mainly composed of a stator, a shell, a rotor, a shaft, a pair of bearings, an encoder and a collecting ring. The shell is mounted on the centrifuge arm. The stator is mounted on the internal surface of the shell. The rotor is mounted on the surface of the shaft by the means of sticking. The shaft is supported by a pair of bearings.

The shaft is connected with the external transmission axis by double flat keys which can avoid tangential force caused by single flat key. The encoder and the collect ring are mounted on the end of the motor. The material of the shaft is mild steel in order to satisfy the need of magneto conductivity. And the other parts of the motor are made of high strength steel.

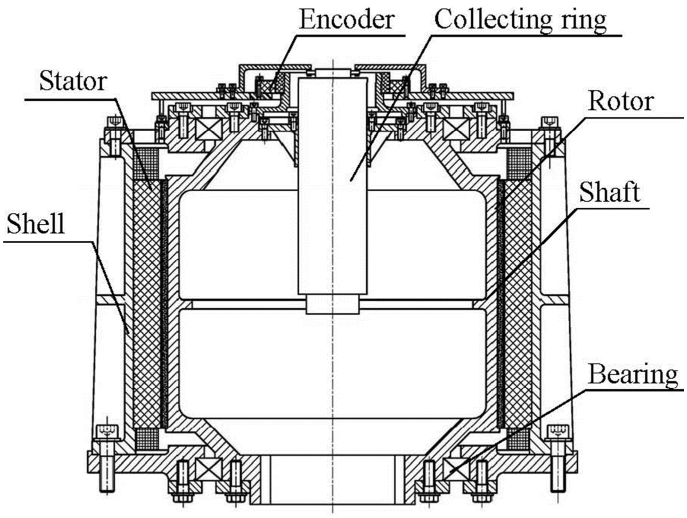

Fig. 5 - External motor

The external transmission axis is shown in Fig.6. Its function is to transfer torque and to support the rotary frame. In order to decrease mass and pass cable, there is a big hole in the center of the transmission axis. The rotary shaft is supported by a bearing. The direction of the acceleration is always perpendicular to the axis of the external transmission system. Then, a kind of double row deep groove ball bearings is adopted to support the combined load mainly consisting of radial load. And the rotary shaft is connected with the rotary frame by an expanding sleeve. Therefore, the external motor can drive the rotary frame rotating.

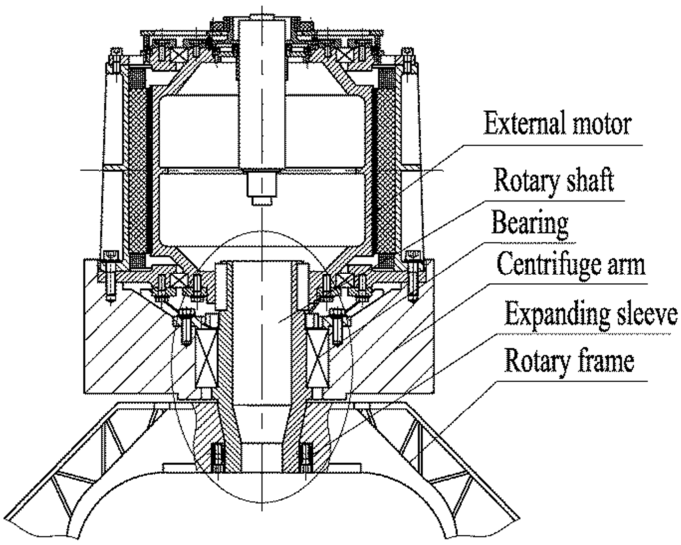

Fig. 6 - External transmission axis

D. Design of an internal transmission system

The internal transmission system is composed of internal motor axis and internal transmission axis. As shown in Fig.3, the internal motor is mounted vertically on the rotary frame and drives the temperature test champer rotating around the internal transmission axis.

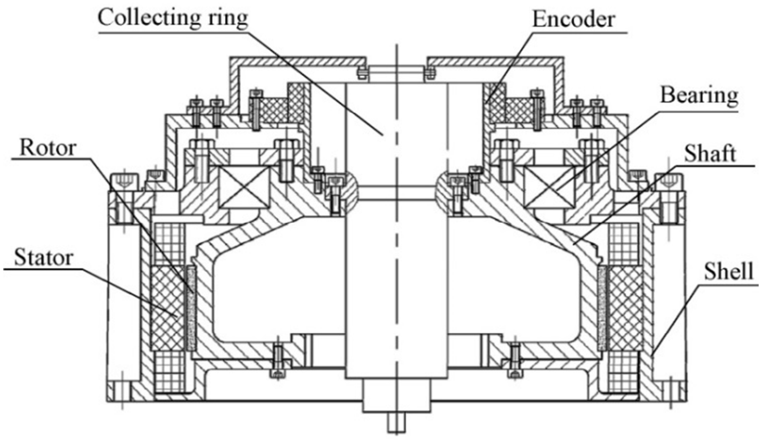

Fig. 7 - Internal motor

Output torque of the internal motor is similar to the external motor. Structure of the internal motor is shown in Fig.7. Its function is to drive the temperature test champer rotating. Composing of the internal motor is similar to the external motor. The main difference is that there is just only one bearing inside the internal motor to support the shaft, because the shaft is also supported by the internal transmission axis which is connected with the shaft. Then, mass and height of the internal motor can be decreased.

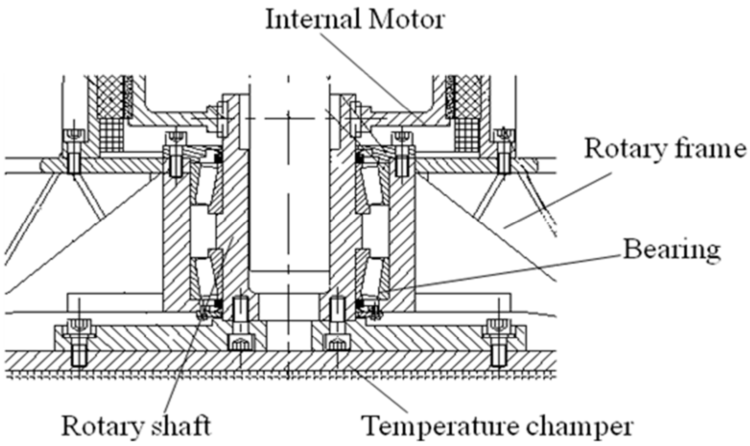

Fig. 8 - Internal transmission axis

The internal transmission axis is shown in Fig.8. Its function is to transfer torque and support the temperature champer. Similar to the external transmission axis, it is hollow in the center of the transmission axis to decrease mass and pass cable. Rotary shaft is supported by a pair of tapered roller bearings. The rotary shaft is connected with the temperature champer by bolts.

In order to validate the reliability and stability of the internal motor and the external motor in the acceleration environment, a prototype of the motor is made. As shown in Fig.9, the prototype has been tested in the 3-axial acceleration environment. It is validated that the sample of the motor works well.

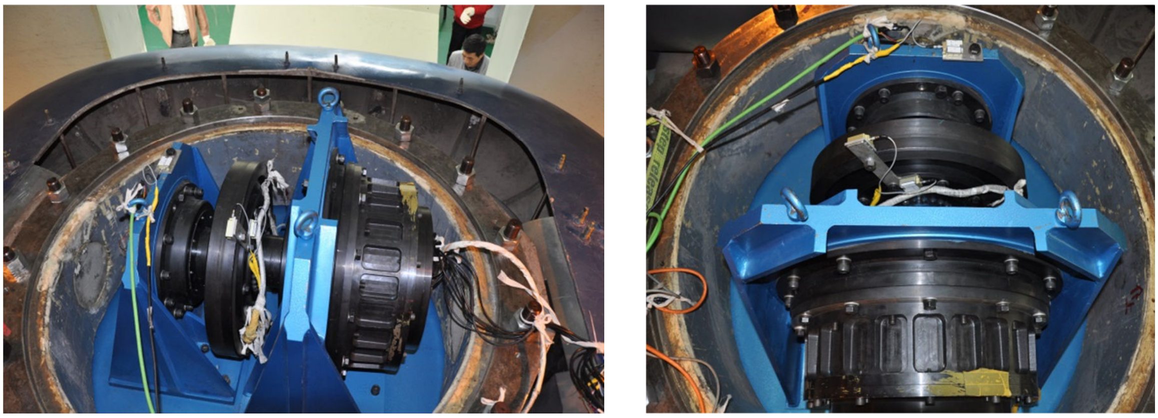

Fig. 9 - Acceleration test of the motor

E. Design of a rotary frame

In order to reduce moment of inertia of the 3-Axia acceleration and temperature multiple experimental system, it is necessary to minimize the mass of the rotary frame. Therefore, the rotary frame is designed with topology optimization based on variable density method.

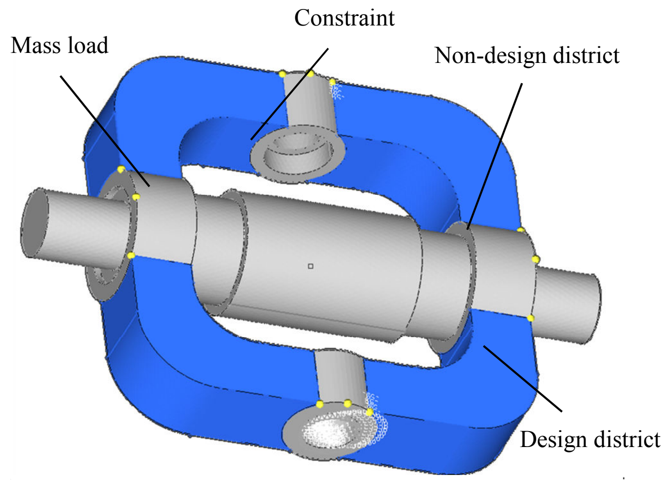

Fig. 10 - Topology model

Based on the software of Hyperwoks/Optistruct, topology model of the rotary frame is shown in Fig.10. The part of the rotary axis is non-design district whose color is white in Fig.10. And the rest part is design district whose color is blue in Fig.10. Mass load simulates the internal transmission system, the mass of the test item and the temperature test champer. The constraint is also set to the topology model. In addition, the topology design of the rotary frame is set in the 3-axial acceleration environment.

After the topology optimization based on the variable density method, the material with intermediate density can be obtained. This is not consistent with the actual design that the density of the material must be 0 or 1. As a result, threshold value of the intermediate density has to be set to remove the material with intermediate density. In order to get density nephogram with clear structure and continuous material, the threshold value is usually set to the values between 0.1 and 0.3. In this paper, the threshold value is set as 0.13.

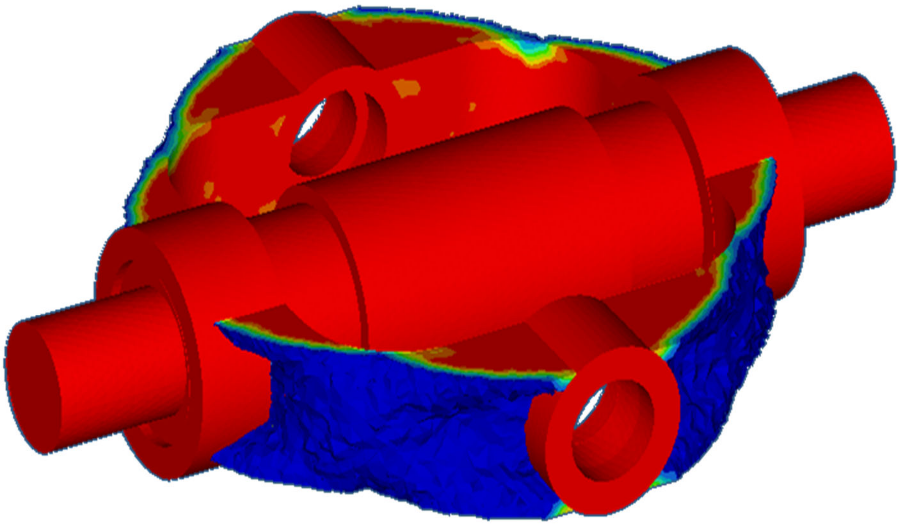

Fig. 11 - Topology result

The result of topology optimization is shown in Fig.11. According to the result, there are chamfers in four corners of the rotary frame. Therefore, the final design model can be get as shown in Fig.12. The rotary frame is made by the means of jointing with steel plates.

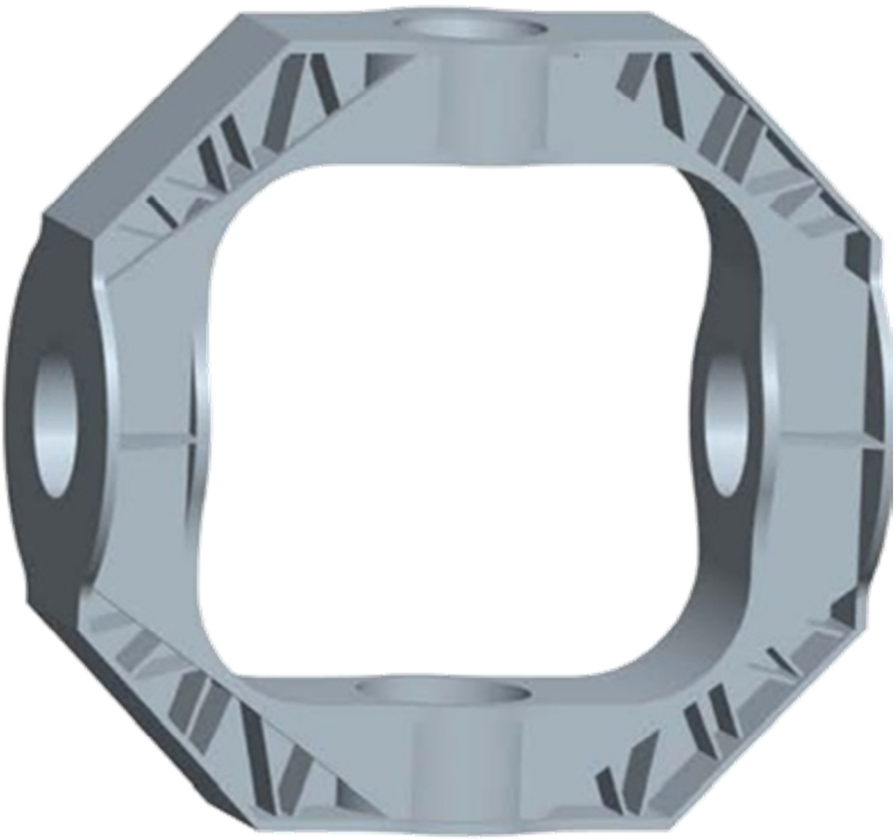

Fig. 12 - Final model

F. Design of a temperature test champer

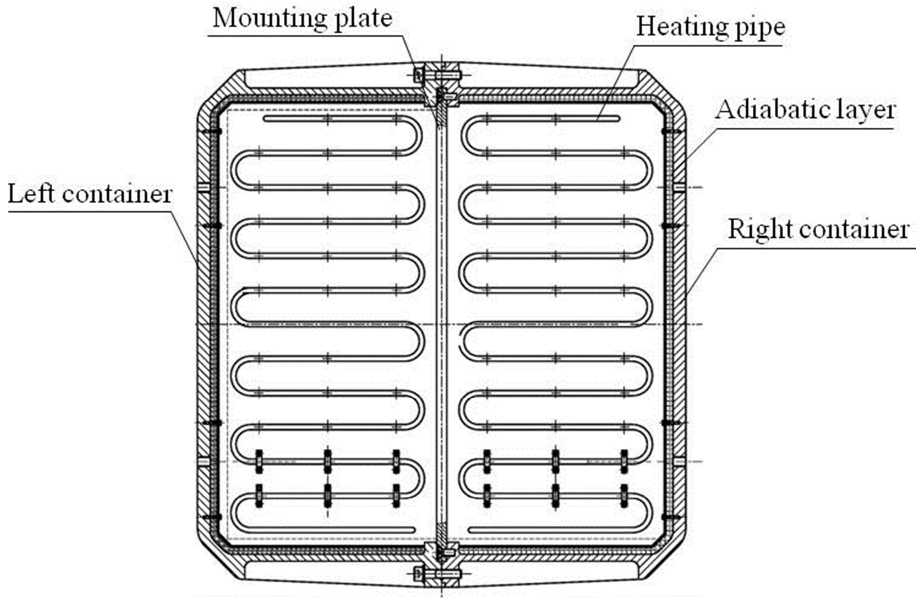

Fig. 13 - Structure of the temperature test champer

The temperature test champer is not only a temperature load device, but also a mounting plate of the test item. It is composed of a left container, a mounting plate, a heating pipe, an adiabatic layer and a right container. As shown in Fig.13, the left container, the right container and the mounting plate are connected with each other by bolts. The test item can be mounted on the mounting plate. The left container and the right container are respectively connected with the internal motors. Both of the containers are made of aluminum metal for lightweight design. The adiabatic layer is mounted on the internal surface of the containers by a layer of steel board. In addition, the heating pipe which aims to heat the test item is mounted on the steel board.

CONCLUSION

A novel approach to generate a combined three axial accelerations and temperature environment is introduced in this paper. Design of such a 3-axial acceleration and temperature multiple experimental system is much more challenging than that of a traditional centrifuge. But careful analysis and fixture design can be applied to meet the required specifications. The system can provide a way to analyze the effects of the three axial accelerations on the structure and performance of aerospace systems. This system can also provide a reference for similar environmental system designers.

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