Research and design of scanning servo device for airborne microwave radiometer

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Abstract. The Microwave Radiometer can obtain various characteristics of the measured target. The remote sensing aircraft has several outstanding advantages such as stronger mobility and larger capacity, which makes the Airborne Microwave Radiometer become the most important part of Microwave Remote Sensing technology. The mechanical structure was designed in this paper, which included airborne microwave radiometer scanning servo device structure and servo control system according to the requirements of the project. The statics and dynamics simulation of the scanning servo device were analyzed, the maximum value is 46.48MPa at the connection between the left support pedestal and the left drive shaft in the statics analysis and the first-order natural frequency of the scanning servo device is 50.516Hz in the modal analysis. The results showed that the mechanical structure meets the requirements of airborne working environment. The current - speed double closed loop control system was used to achieve the high precision speed control. The current - speed double closed loop control system was used to meet the requirements of high precision airborne microwave remote sensing technology.

1. Introduction
Microwave remote sensing technology was a high-end detection technology related to national economy and people's livelihood. Microwave radiometer was an important instrument which can obtain various characteristic information of the target in microwave remote sensing technology. It had the advantages of small size, low power consumption, light weight, high work stability and low manufacturing cost. In the 1980s, some scholars had pointed out that it was an inevitable development trend that the remote sensing instruments were installed on remote sensing aircraft[1-2]. In the working process, the microwave radiometer needed to scan the microwave radiation signal and complete the calibration of the instrument. Because airborne microwave radiometer was carried on the aircraft, its working environment was worse than ground-based microwave radiometer and satellite-borne microwave radiometer[3-4]. Therefore, the scanning servo is a key component that affects the accuracy of microwave detection. The research work was carried out on the scanning servo device of airborne microwave radiometer which included the structural design of the device, the static
and dynamic performance simulation of the structure, the analysis and design of the servo control system, and the simulation study of the servo control system in this paper.

2. Structural design of scanning servo

2.1 Design guidelines and working principles

According to the working environment requirements of the airborne equipment and the working characteristics of the microwave radiometer, the structure of airborne microwave radiometer scanning servo device was designed that followed the principle of simple structure, high strength, avoiding resonance, small size and easy maintenance[5]. The microwave radiometer receives the microwave radiation signal released by the target to be measured through the antenna. The radiated signal was processed by the receiver, converted into an electrical signal, and then inverted into the electrical signal. The physical parameters of the target can be obtained.

2.2 Scanning servo layout design

The airborne microwave radiometer scanning servo device was designed which included microwave radiation, calibration source, temperature control unit, motion control unit and data communication unit in this paper. The microwave signals were emitted by the normal temperature calibration source, thermal calibration source and the measured target were transmitted to the microwave radiometer through the reflection of the mirror[6]; Microwave signal would be converted into electrical signal by microwave radiometer and sent to upper computer. The servo motor was controlled by the upper computer to drive the rotation of the microwave radiometer and the mirror, change the direction of the mirror, and complete the calibration and acquisition of the measured target signal. The temperature of the thermal calibration source was controlled within the specified range through the temperature of the normal temperature calibration source and the thermal calibration source that were gathered by the upper computer[7]. The overall structure of the scanning servo was designed using 3D modeling software (CATIA), which included a mounting plate, a support base, a drive shaft, a microwave radiometer box, a radiometer antenna, a DC motor, a conductive slip ring, a drive plate, a normal temperature calibration source, a heat calibration source, a microwave mirror, and a photoelectric encoder., as shown in Figure 1.

3. Statics and Dynamics Analysis of Scanning Servo Devices

3.1 Static analysis of scanning servo
The load on the scanning servo was mainly from gravity load and acceleration load in static analysis. The acceleration load was analyzed emphatically in this paper because the acceleration load had the greatest influence on equipment performance. The acceleration load was divided into two types of acceleration and deceleration. The acceleration and deceleration processes were divided into two modes: acceleration and deceleration in horizontal and acceleration and deceleration in horizontal-vertical. Therefore, the acceleration load analysis should be considered in four cases. According to the design parameters, the maximum acceleration of the aircraft during flight was 6g. In order to ensure the structural strength requirements, the acceleration load was analyzed with 6g in the analysis of the four working conditions, as shown in Figure 2–5.

In conclusion, it can be seen that the maximum stress borne by the scanning servo device was 18.73MPa and 24.217MPa in the horizontal direction in Figure 2 and Figure 3. It can be seen that the maximum stress borne by the scanning servo device was 44.123MPa and 46.48MPa in the horizontal and vertical direction in Figure 4 and figure 5. When the plane decelerated horizontally and vertically, the scanning servo device bore the greatest stress which occurred at the connection between the left support seat and the left drive shaft. Since the maximum stress was much smaller than the allowable stress of the material, it indicated that the structural strength of the device met the design requirements.

3.2 Modal analysis of scanning servo
In the practical work of airborne microwave radiometer, the scanning servo device was fixed to the mounting frame in the aircraft payload bay by bolts, so the mounting plate was fixed. According to the vibration frequency range of the airborne equipment, the modes of the first four modes were solved by ANSYS workbench, as shown in Figure 6–9:
From Figure 6, it can be seen that the first-order natural frequency of the scanning servo device was 50.516 Hz from the modal analysis diagram, which was higher than the resonant frequency range of 15-20 Hz required by the airborne load. It shows that the dynamic characteristics of the device designed were matched with the airborne environment and no resonance occurs during the working process.

4. Analysis and design of servo control system

4.1 Establishment of double closed loop speed control system
Servo control system needed high precision[8]. Current - speed double closed loop control was often used in high precision speed control system that can achieve a good control effect. The scanning servo speed control system can be obtained by the different characteristics of current loop and speed loop[9].

4.2 Performance test of double closed loop speed control system

4.2.1 Simulation test of motor starting process
According to the designed parameters of the current regulator and the speed regulator[10], the starting performance of the double closed loop speed control system was simulated and tested. The current and speed change curves of the motor energization moment were made in the MATLAB software, as shown in Figure 10. It can be seen that the current value rapidly increased to the maximum value when the motor is energized. At this time, the motor speed increased at a constant speed. When the speed approached the set value, the current value began to decrease and the speed of the speed rose gradually. Until the speed and current reached a steady state, the entire start-up acceleration process of the motor took only 0.3s. The simulation results showed that the current overload capability of the motor was fully utilized and the starting speed was accelerated during the starting process of the motor.
4.2.2 Anti-interference performance test
In order to test the anti-jamming, the load of the servo control system was suddenly increased by 50% when the aircraft was in stable flight posture. The change curve of rotation speed was drawn by MATLAB in Figure 11. It can be seen that the load increased by 50% at t=5s, and the speed decreased rapidly as the load increased. The speed started to rise until the original horizontal current value returned to the steady state.

![Figure 10. Current-speed change when the motor starts](image1)

![Figure 11. Current-speed change diagram when load changes](image2)

5. Conclusions
According to the project requirements, the design criteria and working principle were introduced about airborne microwave radiometer scanning servo device. The overall layout of the scanning servo device was designed, which combined with the practical working environment of airborne microwave radiometer. Statics and dynamics analysis were carried out on the scanning servo device. When the plane decelerated horizontally and vertically, the scanning servo device bore the greatest stress and occurred at the connection between the left support seat and the left drive shaft. The maximum stress value was 46.48MPA in statics. From the modal analysis diagram, the first-order natural frequency of the scanning servo device was 50.516 Hz, which was higher than the resonant frequency range of 15-20 Hz required by the airborne load. Therefore, the strength of the structure meet the requirements and the structure would not produce resonance phenomenon. In order to ensure the high precision of servo control system, the current speed double closed loop control system was adopted. The anti-jamming performance of the motor starting process and the speed control system was simulated by MATLAB software. The analysis results show that the double closed loop speed control system had good working performance.

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