Design of electric mechanism system based on Hall zero position sensor

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Abstract: Based on the electromagnetic induction Hall zero position sensor, a multi-stage reducer motor structure system with a brush DC motor is designed using an aviation fuel on–off valve. The output shaft of the motor structure can respond to deceleration, which are a harmonic reducer and a gear reducer. The electric mechanism is connected to the valve core through the output shaft, and the output shaft is perpendicular to the pipeline channel where the valve is located (see Table 1). The response of the motor mechanism is rapid and the on–off switching of the internal combustion oil valve can be realised within 1 s under rated conditions. The electric mechanism adopts the Hall zero position sensor of electromagnetic induction, without mechanical contact, which can greatly improve the reliability and service life of the electric mechanism. The angle feedback accuracy reaches 0.5°, the weight is not more than 600 g, with the advantages of high control accuracy, high reliability, long life, light weight, small volume, and high integration degree. The functional block diagram of the electric mechanism is shown in Fig. 1.

1 Introduction
Aviation fuel on–off valves are the key components of the aircraft engine control system. Their performance directly affects the performance of the engine and even the flight performance of the whole aircraft [1]. The aviation fuel on–off valve uses the electric mechanism to control the aviation fuel valve, further controlling the on–off of the pipeline fuel. In this way, it can realise the rapid and accurate control of the fuel circuit of the aircraft under special circumstances, and ensure the safety of the aircraft and pilot.

The traditional electric mechanism products rely on the mechanical contact micro-switch to control the start and stop of the motor. There is a situation that the contact cannot be triggered normally for a long time, which affects the reliable operation of the mechanism because the number of actions is limited. At the moment of switch triggering, there will be an electric pulse, which cannot meet the complex electromagnetic environmental requirements of the airborne electronic equipment.

Under the special flight requirements of the aircraft, by identifying the command of the host machine, the designed electric mechanism can respond quickly, reach the fixed position of the output shaft of the motor mechanism, and lock the shaft according to the command. At the same time, it drives the fuel ball valve body through the transmission mechanism to achieve the designated position, accurately and reliably realise the switch of the fuel on–off valve, further control the fuel distribution of the aircraft, and will be in place. The signal is fed back to the host to participate in the whole flight control system.

The design of the electric mechanism system adapts to the characteristics of high reliability, high safety, long flight time, light weight, and less maintenance of aviation products.

1.1 Scheme principle of electric mechanism
The electric mechanism is driven by a brush DC motor and the output torque is connected to the output shaft through two-stage deceleration, which are a harmonic reducer and a gear reducer.

Table 1 Composition of electric mechanism

| Part name               | Number | Product installation location | Product function profile          |
|------------------------|--------|-------------------------------|-----------------------------------|
| electric machinery     | 1      | case                          | used to provide power source      |
| retarder               | 1      | case                          | for deceleration and output of proper torque |
| Hall sensor            | 1      | case                          | for position feedback and power off in place |
| electromagnetic relay  | 1      | case                          | used to change the rotation direction of the motor |
| wave filter            | 1      | case                          | for filtering and interference suppression |
| brake                  | 1      | electric machinery            | used to lock the shaft position   |

By changing the sequence of power on the electromagnetic relay, the direction of the motor can be changed. When the motor mechanism receives the specified position command, according to the position signal combination of different Hall zero position sensors, it can judge the current position of the output shaft lock shaft, it can also judge the current switch position of the valve body by comparing with the given positioning device, and then it can judge the rotation direction of the motor, which is composed of metal-oxide-semiconductor (MOS) tube integrated into the Hall zero position sensor. After the action is in place, the position signal is fed back by the Hall zero position sensor and the motor is powered off. At the same time, the diode integrated into the Hall zero position sensor drives the electromagnetic brake to act to fix its locking shaft and prevent it from starting accidentally.

1.2 Composition of electric mechanism
The electric mechanism is connected to the valve core through the output shaft, and the output shaft is perpendicular to the pipeline channel where the valve is located (see Table 1). The response of the motor mechanism is rapid and the on–off switching of the internal combustion oil valve can be realised within 1 s under rated conditions. The electric mechanism adopts the Hall zero position sensor of electromagnetic induction, without mechanical contact, which can greatly improve the reliability and service life of the electric mechanism. The angle feedback accuracy reaches 0.5°, the weight is not more than 600 g, with the advantages of high control accuracy, high reliability, long life, light weight, small volume, and high integration degree. The functional block diagram of the electric mechanism is shown in Fig. 1.

2 Methodology
The components include a brush DC motor, an electromagnetic brake, a harmonic reducer, a gear reducer, a Hall zero position sensor (including magnets), an electromagnetic relay, a filter, an electrical connector, a shell, a tail cover, and so on.
2.1 Electrical design

The electrical principle of the electric mechanism is shown in Fig. 2. When pin a (host on command signal) is connected to 28 V power supply, and the current flows through pin 9 of Hall sensor, and the electromagnetic relay is in reset state, and the motor is driven to rotate forward, then the output shaft of the product is driven to rotate forward through the reducer. When it is turned to the ‘on’ position, the magnetic steel is close to the induction point of Hall zero position sensor, pin 9 is in high resistance state, and the motor is powered off, the same as when the six-pin is powered on, the brake lock shaft and three-pin are connected, and the e-pin and c-pin output the ‘on’ position signal.

When pin b (host off command signal) is connected to 28 V power supply, current flows through five pins of Hall sensor, and the electromagnetic relay is in reversing state, driving motor to reverse, driving output shaft of product to reverse through reducer, when turning to ‘off’ position, magnetic steel is close to another sensing point of Hall zero position sensor, five pins are in high resistance state, the motor is powered off, seven pins are powered on, and brake lock shaft, two-pin on, d-pin and c-pin output ‘off’ position signal.

2.2 Design of Hall zero position sensor

The electromagnetic induction Hall zero position sensor is the key component of the electric mechanism. The output shaft of the motor rotor reducer has a fixed position pointer. The position pointer is embedded inside the magnet. The Hall position sensor is installed at the opening and closing positions, respectively. When the pointer is in place, the magnetic steel triggers the induction point in the sensor, outputs the in-place signal, and cuts off the power supply of the motor. The actuator locks the shaft.

The output form of the sensor is open collector output. When the magnet does not trigger the sensor, the sensor outputs a high level. When the magnet triggers the sensor, the sensor outputs a low level. As shown in Fig. 3, the Hall sensor realises the power-off of the motor in place and sends out the switch signal.

When the magnet reaches 0°, the V1 impedance is infinite. It can be considered that the out1 is open circuit; the motor is powered off and locked. At the same time, the V2 impedance is close to 0, the V2 output is in high level. When the magnet leaves 0°, the V1 impedance is close to 0, the brake is open, and the motor is powered on and started. On the other hand, the V2 impedance is infinite, and the position signal is in high level.

When the magnet is turned to 90°, and so on, the motor can be cut off and locked after the electric mechanism reaches the open position or the closed position, and the corresponding low level in place signal can be output to the host, to achieve the purpose of precise and reliable control of fuel valve on-off without a controller.

2.3 Design of motor (including brake)

The motor is the basic executive part of the electric mechanism, which consists of an electromagnetic brake and a brush DC motor.

The motor body is mainly composed of armature, stator, front cover, end cover assembly, brush, bearing, retaining ring, adjusting washer etc. The armature is a slotted iron core, whose main function is to output electromagnetic torque; the stator is composed of shell and rare earth magnet, whose main function is mechanical support and magnetic circuit conduction; the end cover assembly is composed of brush carrier ring assembly, brush, outgoing line etc., whose main function is mechanical support, positioning brush, and outgoing electrical interface [2].

The motor stator uses a rare earth magnet to generate an excitation magnetic field, and the armature core is slotted to be embedded in the armature winding. When voltage is applied to the armature winding of the motor, armature current will be generated in the winding. The current interacts with the stator excitation magnetic field to generate rotation torque so that the motor drives the load at a certain speed and torque. The circuit diagram is shown in Fig. 4.

The motor body and brake share the same power supply. The brake is the power-off kind. When the motor body is powered on and working, the brake unlocks and loses the braking effect, making the motor works normally. When the motor body is powered off, the motor stops working and the brake locks, making the motor body lock and not work, and the action of the motor and brake can be reasonably set dead through the delay relay. Zone time avoids motor stalling (Fig. 5).
2.4 Two-stage deceleration design

The electric mechanism adopts the form of gear speed reduction plus harmonic speed reduction with two poles to achieve the required speed reduction ratio and ensure the torque output. The harmonic reducer drives the rigid wheel through the elastic deformation of the flexible wheel, which is a planetary transmission with less tooth difference. Two of the three parts are active and the third one is driven.

As shown in Fig. 6, in the harmonic drive, the elliptical wave generator squeezes the flexible wheel to make the long shaft and short shaft of harmonic reducer in the state of alternating change, continuous tooth engagement, and continuous disengagement of each state change to produce staggered tooth movement, to realise the movement transmission of active wave generator and flexible wheel [3].

(i) Reduction ratio design of reducer: The first stage adopts a gear reducer with a reduction ratio of \((66/19) = 3.4\); the second stage adopts a harmonic reducer with a selected reduction ratio of 80 and the total reduction ratio of \(3.4 \times 80 = 272\).

(ii) Performance check: The output torque calculated according to the rated output of the motor is

\[
T_S = T_N \times i_Z \times \eta = 0.023 \times 272 \times 45\% = 2.8 \text{ Nm}
\]

where \(T_N\) is the rated torque of motor, \(\eta\) is the transmission efficiency of reducer, 45\%, and \(i_Z\) is the reduction ratio of reducer.

Calculate the rated output speed as

\[
V_S = \frac{n_{th}}{i_Z} = \frac{6600}{272} \times \frac{360\degree}{60} = 145\degree/s
\]

2.5 Filter design

If the electromagnetic compatibility effect is not good, the interference will occur in equipment through the power line and space coupling, and then affect the normal operation of the product (see Fig. 7). Therefore, adding a power filter circuit to the power end is the solution to conduct emission interference [4].

(i) Surge suppression: The schematic diagram of a surge suppressor is shown in Fig. 8. When the input voltage is normal, the MOS transistor is normally open, and the output voltage is equal to the input voltage. When there is a voltage surge in the input, the feedback voltage control circuit controls the drive of the MOS transistor to make it in a linear working state and suppresses the voltage surge. High-voltage and low-energy spikes are absorbed by capacitors and transient suppressors across the input.

(ii) Suppression of conducted interference: The electromagnetic interference generated by the motor shall be filtered from 100 kHz to 1 GHz. Owing to the comprehensive consideration of the withstand voltage, inductance, capacitance, and other factors of components, the filter circuit diagram is shown in Fig. 9. The main components are differential mode inductors, X and Y capacitors. The function of the filter is realised through the combination of components. For signal filtering, because the signal line is affected by power line coupling and space radiation, the main interference is high-order harmonic coupling etc., so using high-frequency magnetic beads and grounding capacitance, the circuit can effectively suppress the electromagnetic interference coupled on the signal line and prevent the radiation emission from exceeding the standard.

(iii) Radiation interference suppression: Mainly from the following aspects to suppress radiation emission interference.

(A) Structural design: the product shell is designed as a fully shielded metal shell, with all gaps and interfaces designed by shielding treatment to prevent an electromagnetic wave from radiating outwards.

(B) Grounding design: the product grounding is connected to the circuit board through an electrical connection for single-point grounding to reduce the area surrounded by the ground loop and reduce ground noise interference.

(C) Reasonable wiring: To prevent electromagnetic crosstalk between printed lines, the spacing between printed lines shall be more than three times the width of printed lines, and the ground wire shall not form a closed loop when wiring because the formed closed loop is easy to receive and transmit interference signals.
Results

The electric mechanism of the aviation fuel on–off valve works in a complex electromagnetic environment and harsh natural environment, which requires it to have strong electromagnetic compatibility characteristics, climate environment adaptability, and mechanical environment adaptability.

According to the above requirements, the electromagnetic compatibility characteristics, high- and low-temperature load performance test, low air pressure test, temperature shock, damp heat alternation, temperature humidity height test, noise, vibration, functional shock, acceleration etc. are tested and verified in the electric mechanism. The test Atlases are shown in Figs. 10–18.

Through the above tests and assessments, the electric mechanism can work normally without the performance affected. It has good electromagnetic compatibility, climate, and mechanical environment adaptability. It is proved to meet the working requirements of the aviation fuel on–off valve.

Fig. 10 Installation photo and Atlas of functional vibration test of electric mechanism

Fig. 11 Installation photo and Atlas of durable vibration test of motor structure

Fig. 12 Installation photo and Atlas of electric mechanism impact test

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4 Conclusion

In this paper, the electric mechanism system for a fuel on–off valve is designed based on a Hall zero position sensor. It can respond quickly to the special flight needs of the aircraft, accurately and reliably realise the on–off of fuel valve, further control the on–off situation of pipeline fuel, and ensure the safety of the aircraft and flight mission. It is of great significance for the development of light and intelligent fuel system and can be used for other researches and developments of fuel valve control systems and aircraft engines.

Fig. 13 Installation photo and Atlas of constant acceleration test of motor structure

Fig. 14 Installation photo and Atlas of temperature impact test of electric mechanism

Fig. 15 Temperature test and installation photos of electric mechanism and photos after hot and humid

Fig. 16 Temperature test Atlas of electric mechanism
### References

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**Fig. 17** CE102 test Atlas of motor structure with different voltage and load

**Fig. 18** Test Atlas of rc102 under different voltage and load of motor structure