**Design and Test of Lightweight Long-life Electric Mechanism without Controller**

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**Abstract.** The traditional airborne electric mechanism is mostly controlled by mechanical switch, which seriously restricts the life and reliability of the system. This paper introduces a design method of a lightweight electric mechanism without a controller. The electric mechanism drives the motor directly by receiving the instructions of the control system, acts directly on the switch of the pipeline valve through the decelerator, breaks down the lock after reaching the specified position, and feeds back the current position signal. It is a high reliability, long life, compact structure, and widely used EMA product, which can adapt to all kinds of extreme environments required by the airborne equipment. And it has good maintainability.

1. **Introduction**  
Under the special requirements of airborne equipment, the electric mechanism is controlled by the host command, and can respond quickly according to the requirements of the command. By driving the valve core by the drive mechanism, the output shaft is locked after reaching the specified position, the valve is switched on accurately and reliably, and the in-place signal is fed back to the host to participate in the whole flight control system.[1]

2. **Principle of the electric mechanism scheme**

2.1. **Principle of electric mechanism**  
The electric mechanism is driven by a brushless DC motor, and the output torque is connected to the output shaft by two-stage deceleration of the planetary decelerator and the gear decelerator.

   electric mechanism drives motor rotation by control instructions. When the electric mechanism receives the command of the specified position, the current position of the output axis, also the position of the valve switch, is determined according to the combination of different Hall sensor position signals.[2] The host compared with the given position to determine the direction of motor rotation. When the action is in place, the position signal is feedback through the Hall position sensor and the motor is disconnected. When the power is disconnected, the electromagnetic brake is driven by the diode in the driver to lock the output shaft and prevent accidental rotation.[3]

2.2. **The composition of the electric mechanism**  
The electric mechanism is connected to the valve core through the output shaft, which is perpendicular to the pipeline channel where the valve is located. The electric mechanism uses a drive circuit to drive...
the motor directly, feedback the in-place signal through the electromagnetic induction Hall zero position sensor, and there is no mechanical contact in the closed-loop position. This effectively improves the reliability and durability of the electric mechanism, and the position accuracy reaches 0.5°. The overall weight of the electric mechanism is less than 500g, which has the advantages of high control accuracy, good reliability, long life, light weight, small size and high integration.

3. Electric mechanism system design
The main components of the electric mechanism include: DC motor, electromagnetic brake, planetary reducer, gear reducer, Hall zero sensor, electromagnetic relay, filter, electrical connector, housing, tail cover, etc.

| No. | Part name  | Quantity | Installation location | Function profile                          |
|-----|------------|----------|----------------------|-------------------------------------------|
| 1   | Motor      | 1        | Case                 | Used to provide a source of power         |
| 2   | Reducer    | 1        | Case                 | Used to decelerate and output suitable torque |
| 3   | Hall sensor| 1        | Case                 | Used for position feedback and power-off  |
| 4   | Electromagnetic relay | 1 | Case                 | Used to change the direction of motor rotation |
| 5   | Filter     | 1        | Case                 | Used for filtering and suppressing interference |
| 6   | Brake      | 1        | Motor                | Used to lock the position of the shaft    |

![Electric mechanism structure diagram](image)

![Schematic diagram of the overall scheme](image)
3.1. Electrical design
The electrical principle of the electric mechanism is shown in Figure 3. When pin B (host on command signal) is connected to 28V power supply, the current passes through pin 9 of the Hall sensor to control the driver to drive the motor forward, and the output axis is driven forward through the decelerator. When turned to the "on" position, the magnetic steel is close to the induction point of the Hall zero position sensor, pin 9 is in high resistance state, and the motor is cut off. At the same time, pin 6 are powered on, brake lock shaft, pin 3 are connected, pin E output "on" position signal.

When the pin C (host shut-off command signal) is connected to 28V power supply, the situation is similar. The motor reverses and outputs "off" position signal.

3.2. Hall zero sensor design
The electromagnetic induction Hall zero position sensor is a key component of the electric mechanism. The position pointer is fixed on the output shaft of the motor rotor reducer, and the magnetic steel is embedded inside the position pointer. Hall position sensors are installed in the open and closed positions. When the pointer is in place Later, due to the Hall effect, the magnetic steel triggers the induction point in the sensor, outputs an position signal, and cuts off the power of the motor, and the brake locks the shaft.[4]

The sensor output form is open collector output. When the magnet does not trigger the sensor, the sensor outputs high level; when the magnet triggers the sensor, the sensor outputs low level. The following picture shows the Hall position in the open off state The high and low level of the sensor output.

3.3. Motor design
The motor is the basic executive part of the electric mechanism. The motor body is mainly composed of Hall, armature, stator, front cover, end cover components, bearings, baffles, adjustment washers, etc. The armature is slotted core, whose main function is to output electromagnetic torque. The stator is made of chassis and rare-earth magnet steel. Its main functions are mechanical support and magnetic circuit conduction. The end cover assembly is composed of Hall, bracket, lead wire, etc. Its main functions are mechanical support, positioning Hall chip and lead-out electrical interface.

3.4.Reducer design
The electric mechanism adopts the form of gear reduction plus planetary reduction two-pole reduction,
which can ensure the torque output while achieving the required reduction ratio.

The first stage adopts a gear reducer, the reduction ratio is 3.4, the second stage adopts a planetary reducer, the selection reduction ratio is 100, and the total reduction ratio is 340.

3.5. Brake design

The brake is composed of stator, rotor and so on. The stator is composed of winding, permeable ring, and permanent magnet. The stator winding is embedded and wound on the magnetic permeable ring according to the design requirements, and the electromagnetic field is generated by electricity.

The permanent magnet is pasted on the magnetic ring to provide a permanent magnetic field; the magnetic ring provides a path for the magnetic field. The rotor is composed of an armature, a spring, and a rotor hub. Among them, the spring generates a certain pulling force to lock the armature to the rotor hub.

The brake relies on three different states of the permanent magnetic force generated by the permanent magnet, the electromagnetic force generated by the energized coil and the spring tension generated by the spring to lock and unlock. The composition and functions of each part of the brake are shown in Table 2.

| Part and component name | Function |
|------------------------|----------|
| Stator Windings        | Electric current is applied to generate electromagnetic force |
| Permeable ring         | Support winding and permanent magnet, provide magnetic flux circuit, friction disc of friction pair, external connection |
| Permanent magnets      | Generate permanent magnet |
| Rotor Armature         | Brake disc with friction pair |
| Spring                 | Stretching produces spring tension |
| Rotor hub              | Support armature and spring, external connection |

1) Lock hold

When the coil is powered off, the permanent magnetic force generated by the permanent magnet overcomes the spring force of the rotor, and the stator and rotor pull in. The air gap between the armature and the stator core is 0.1mm, no reserved spring force. Simulation analysis shows that the magnetic force of the permanent magnet is F=3.6N, and the magnetic force of the permanent magnet can draw the armature back.

![Figure 4 The magnetic density distribution diagram of the electromagnetic lock in the power-off locked state](image)

2) Unlock hold

The electromagnetic force counteracts the permanent magnetic force, and the reserved spring force keeps the unlocked state. The current I=0.06A, the number of turns N=3000 turns, the residual

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magnetic force $F=0.006N$ obtained by the simulation analysis, and the magnetic force offset. Although there is no reserved spring force, the positive tension tolerance can maintain the unlocked state.

Figure 5 Magnetic density distribution diagram of the unlocked and held state of the electromagnetic lock

3.6. Filter design

If the electromagnetic compatibility effect is not good, the interference will cause interference to other easily interfering devices through the power line and space coupling and affect the normal operation of the product. Therefore, adding a power filter circuit to the power supply terminal is a way to solve the conduction and emission interference.

The three elements of electromagnetic compatibility (EMC) include interference sources, transmission channels, and sensitive equipment. To solve the problem of electromagnetic compatibility, we must start with the three elements of electromagnetic compatibility.

Electromagnetic interference propagated through power lines (or signal lines) is called conducted interference (CE), and electromagnetic interference propagated by electromagnetic waves through space is called radiated interference (RE). According to the principle of electromagnetic induction, changing electric and magnetic fields can be transformed into each other. Electromagnetic waves are formed, so conducted interference will also be converted into radiated interference. Therefore, radiated interference can be transmitted through space as well as through cables.[5]

1) Surge suppression

The schematic diagram of the surge suppressor is shown in Figure 6. When the input voltage is normal, the MOS tube is turned on normally, 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 MOS tube drive to make it in a linear working state to suppress the voltage surge. High-voltage and low-energy spikes are absorbed by capacitors and transient suppressors connected across the input.

Figure 6 Block diagram of surge suppressor

2) Suppress conducted interference

The electromagnetic interference generated by the motor needs to consider filtering from 100kHz to 1GHz. Because of the comprehensive consideration of the withstand voltage, inductance and
capacitance of the components, the filter circuit diagram is shown in Figure 7. The main components used are differential mode inductors, X and Y capacitors, and filtering is achieved 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, so high-frequency magnetic beads and grounding capacitors are used. This circuit can effectively suppress the electromagnetic coupling on the signal line. Interference to prevent excessive radiation emission.

![Figure 7 Filter circuit diagram](image)

3) Suppress radiated interference

Mainly suppress the radiation emission interference from the following aspects.

a) Structural design: The product shell is designed as a fully shielded metal shell, and all gaps and interfaces are shielded to prevent electromagnetic waves from radiating outward;

b) Grounding design: The product grounding is connected to the circuit board for single-point grounding to reduce the area surrounded by ground loops and reduce ground noise interference;

c) Reasonable wiring

In order to prevent electromagnetic crosstalk between the printed lines, the spacing between the printed lines should not be less than three times the width of the printed lines, and the ground wire should not form a closed loop when wiring, because the formed closed loop is easy to receive and transmit interference signals.

4. Simulation

The Simulink mathematical model of the electric mechanism is as follows.

![Figure 8 Electric mechanism model](image)
Enter a step instruction to the model, and the response curve of the system is as follows.

![Response curve](image)

The frequency characteristics of the system are simulated according to the mathematical model of the system, and its Bode diagram is shown in the following Figure 10. It can be seen from the diagram that the system has a bandwidth of about 5Hz when the amplitude-frequency is attenuated to -3dB.\[6\]

![Bode Diagram](image)

**Figure 10 Frequency characteristics of motor-drive mechanism**

5. Test verification

In order to verify the electromagnetic environment adaptability of the controller less motor-drive mechanism, RE102 and CE102 electromagnetic compatibility tests were carried out.

![RE102 10KHz～3GHz](image)

**Figure 11 RE102 10KHz～3GHz**
Vibration test lasts for 4 hours in each direction. Vibration magnitude according to the specific task requirements, power up during the vibration process and verify the functional integrity.

6. Conclusion
By optimizing the design of the circuit, the electrical principle is simple. By non-contact commutation, the power supply of the motor is cut off when it is in place, so that the motor and other components are on standby when they are not working, reducing the power-on time of the electrical components, reducing the work loss, thus improving the reliability of the electric mechanism for long-term operation.

The shell of electric mechanism is sealed externally, with good electromagnetic compatibility shielding, wide temperature environment, strong mechanical environment adaptability, compact structure and light weight, suitable for long-term operation, and coated with anti-corrosive coating. It can be used in the valve control system of aeronautics, ships and other fields. It can be used in the air, sky, sea, etc. Reliable work in different complex working environments on land.

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