Design of High-Power Dual-Redundancy Electro-Mechanical Actuator for Scout and Strike UAV

Tao Yang*, Shuaibing Wang and Jinpeng Yang
China Academy of Aerospace Aerodynamics, Beijing, China

Abstract. As the technology advance of UAV (Unmanned Aerial Vehicle), the large UAV is a prevalent trend, which is widely used for scout and strike in modern military battlefield. The flight safety is rather important because of the cost increase of UAV with various airborne devices equipped. EMA (Electromechanical Actuator) is one of the key components in UAV system. Whether its performance is reliable or not determines the flight safety. In this paper, in order to design high-power EMA for scout and strike UAV with fast response and high stability to ensure UAV safety, dual-redundancy technology is adopted. There are two communication interfaces between the actuator and the flight mission computer. The control circuit and the drive circuit are in the form of dual redundancy, while there are two sets of windings in the motor. The controller and actuator design are introduced in details one by one. Also, the paper presents the dual-redundancy design scheme. Several ground tests simulating the real flight conditions are conducted, proving that the EMA design is feasible and its performance is satisfactory. The UAV flight tests are needed later in the future to verify EMA performance in practice.

Keywords: UAV; dual-redundancy; EMA.

1. Introduction

Ever since the first UAV (Unmanned Aerial Vehicle) developed successfully in UK in 1917, UAV’s historical process began in synchronism with the development of the manned aircraft. By the middle and late 1980s, hundreds of UAVs were manufactured and produced by various countries, which were used as target aircraft, reconnaissance aircraft, electronic jammer aircraft and decoy aircraft. In recent years, UAV is applied more and more widely. And there is urgent need for large UAV which attracts more and more attention of researchers and users all over the world than small UAV. Besides the traditional applications in the modern battlefield, its application scenario extends to integration of scout and strike. UAV flight safety is the top priority, especially when all kinds of complex airborne devices are equipped in UAV assisting in completing flight tasks, for the airborne devices are expensive leading to the high cost of UAV, if the UAV crashes not for military reasons, it suffers from big economic losses. EMA (Electromechanical Actuator) is a key unit of the large UAV as its actuator system. To a large extent, desirable EMA performance ensures the flight safety.

Methods such as improved quality level of the components, enhanced component protection and even upgraded design can increase the system reliability. However, these improvements are far from perfect and not proportional to the cost. As a result, current researches focus on combination of redundancy technology and fault-tolerant technology, an effective measure to improve reliability without increasing requirement of components [1]. In this paper, a high-power dual-redundancy EMA is designed for scout and strike UAV [2]. As shown in Figure 1, the EMA communicates with the flight mission computer via two RS422 interfaces for dual-redundancy. The controller is in the form of dual redundancy, namely, there are the main control circuit and the backup control circuit in the control...
module while the drive module includes the main drive circuit and the backup circuit [3-4]. According to different commands, the motor with two sets of motor windings rotates the control surface via the transmission mechanism [5]. For real-time indication of actuator position, the linear transducer serves as the feedback component.

![Figure 1. Actuator system function diagram.](image)

**2. Controller Design of the EMA**

As shown in Figure 2, the controller receives the command signal from the flight mission computer and then drives the actuator to rotate [6-7].

![Figure 2. Block diagram of the controller.](image)

In this section, the controller design is introduced in details as three parts, namely, the control module (main and backup control circuit), the drive module (main and backup circuit) and the power circuit. The control module exerts control algorithm, communicates with the flight mission computer, monitors the actuator system status, conducts the redundancy control, and acquires the position feedback. The drive module consists of high-power components. As the control command changes, corresponding drive signal generates to drive the actuator towards different position. The power supply circuit offers power supply for the control circuit and the drive circuit respectively.

**2.1. Control module**

As shown in Figure 3, there are the main control circuit and the backup control circuit which adopt same hardware scheme for dual redundancy in the control module.

![Figure 3. Control circuit.](image)

They have separate peripheral circuit and power supply circuit. The control circuit selects DSP (Digital Signal Processor) as its control core, thus conducting algorithm and generating the corresponding or analog PWM (Pulse Width Modulation) signals. It communicates with the flight mission computer via two different RS422 interfaces. As for the internal communication, the CAN (Controller Area Network) transceiver does that job. Other parts of the control circuit consist of the feedback circuit, the redundancy switch circuit and the data storage circuit. The feedback circuit acquires and processes LVDT (Linear Variable Differential Transformer) signal, and it transforms into the digital signal via AD (Analog Digital) converter. The redundancy switch circuit serves to switch the control circuit, choosing the appropriate circuit to perform digital control function. The data storage circuit records the system status and error information when needed.
The main and backup control circuit is able to accomplish control tasks independently. The functions are summarized as follows: receive and analyze the RS422 command; acquire the position feedback from LVDT signal; send the control and enable signal to the main and backup drive circuit; receive the feedback information from the main and backup drive circuit; conduct redundancy switch function in case of unavailability of one control circuit or drive circuit; report back the system and error status to the flight mission computer; communicate with the other control circuit; record system information in EEPROM (Electrically Erasable Programmable Read - Only Memory).

2.2. Drive module
The dual-redundancy drive module includes drive circuits with different structures. The main drive circuit uses the integrated drive module with high-power endurance as the drive component, while the backup drive circuit uses the motor driver, the 3-phase MOSFET (Metal Oxide Semiconductor Field Effect Transistor) bridge as the drive solution. Thanks to the intelligent drive module, the main drive circuit is relatively easy, for the simple reason that the drive module incorporates the 3-phase bridge and realizes the motor control via analog command. The backup drive circuit conducts the motor commutation and monitors function error. The motor driver controls the 3-phase bridge made up of MOSFETs with \( V_{DS} \) up to +600V for device safety when the spike voltage is invoked under the condition of +270V power supply. The auxiliary power of the main drive circuit and the backup circuit is independent and there are separate enable and disable bits. In this way, functions of different drive circuits are performed independently. The main and backup drive circuit cannot work at the same time, namely, one circuit is at work while the other one is disabled.

The drive module can conduct the following functions: conduct motor commutation; receive the drive command from the control circuit; rotate the motor; perform error detection, diagnosis and isolation; report back the error information to the control circuit.

2.3. Power circuit
As shown in Figure 4, there are two power supplies in the actuator system, +28V and +270V. +28V DC (Direct Current) mainly serves the control module and offers part of the power supply for the drive module, while +270V is the source of the power drive.

For better EMI (Electro Magnetic Interference) performance, +28V passes an EMI filter first and then sends to different parts of the control circuit. After that, there are DC-DC converters which transform +28V into +5V for the digital control part in the control module. The main control circuit and the backup control circuit are powered separately, thus two converters are needed. The power source of the control core is +3.3V tolerant. Therefore, low dropout regulators exist to transform +5V into +3.3V. As for the feedback circuit, another DC-DC converter works to transform +27V into ±15V. In the drive module, ±15V is needed in the main drive circuit, which is obtained from +28V via a DC-DC converter. At the same time, the step-down voltage regulator transforms +28V into +15V for the 3-phase bridge driver in the backup drive circuit. +270V directly powers up the high-power component in the drive module.

3. Actuator Design of the EMA
Traditionally, there are two output modes for the EMA, resulting in the linear actuator and the rotatory actuator. As for the large scout and strike UAV, in order to meet the requirement of high speed, fast
response and high torque, the high-power actuator is needed, which usually is the linear actuator. The actuator designed in this paper is linear actuator and the output force can reach up to 30000N. The linear actuator consists of the motor, the transmission mechanism and the linear transducer. The motor selected is of dual redundancy. The motor can work in the cold standby mode. When one redundancy works, the other is waiting as a substitute. Each redundancy has its own Hall sensor and motor winding. And one redundancy can work independently to yield nominal power output without help of the other one. As shown in Figure 5, the transmission mechanism adopts a scheme that the motor rotates the gear mounted coaxially and the gear pair rotates the ballscrew [8].

![Figure 5. Actuator transmission mechanism.](image)

According to requirement of high reliability and small size, the ball screw is a perfect choice as the main actuating mechanism. There are advantages such as low rotational inertia, high transmission efficiency and great precision for this transmission scheme. The linear transducer in this design is LVDT, which features zero friction measurement, infinite mechanical life, infinite definition and excellent environmental adaptability. Undoubtedly, it is the best choice for the high-power EMA used for UAV. After detailed design, the digital model of the actuator is shown in Figure 6.

![Figure 6. Digital model of the actuator.](image)

4. Dual-Redundancy Design

In the high-power dual-redundancy actuator system, key parts of the controller and the actuator adopts dual-redundancy design. There are the main and backup control circuit in the control module, as well as the main and backup drive circuit in the drive module. At the same time, the motor used in the actuator is in the form of duplex winding with cold standby.

4.1. Redundancy scheme

In the control module, both of the main and backup control circuit are capable to communicate with the flight mission computer and conduct actuator control. When the main control circuit is working, the backup control circuit monitors the status of the main control circuit via internal communication interface. If the communication data received by the backup control circuit is missing or indicative of abnormal status of the main control circuit, the backup control circuit cuts off the link between the main control circuit and the drive module as well as the flight mission computer, and then takes over the communication and control task.

As for the drive module, it works in the cold standby mode. The backup drive circuit can work as well as the main drive circuit. The backup drive circuit can work as well as the main drive circuit. At first, the main drive circuit drives the actuator, while the backup drive circuit is disabled. Once error is detected in the main drive circuit, the control module switches the drive redundancy from the main drive circuit into the backup drive circuit. The backup drive circuit stands out to drive the actuator. In the meanwhile, the main drive circuit is invalid in the drive mode.

4.2. Redundancy switch

The main control and drive circuit collaborates when the actuator system is powered on in the beginning. In case of emergency, the redundancy is switched. To summarize, there are mainly the
following conditions triggering redundancy switch, that is the control module error, the drive module error and the mission unfinished in time. The control module error occurs when the main control circuit fails to work properly and the backup control circuit takes over digital control. The drive module error occurs when the main drive circuit cannot drive the actuator as expected and then the drive task is assigned to the backup drive circuit. Normally, the actuator can finish the task within a certain period of time as the command tells. However, accidents sometimes happen. If the flight task is unsuccessful, the flight mission computer has the right to decide whether to switch the actuator redundancy or not.

5. Experimental Test
In order to verify the feasibility of actuator design in this paper, the high-power dual-redundancy electro-mechanical actuator is tested as shown in Figure 7.

![Figure 7. Experimental test.](image)

In order to validate performance of the actuator system, several experiments are conducted to test its performance one by one. The results are shown in Table 1. The nominal force is 1200N, the maximum force is 2700N, the nominal speed is 135 mm/s, the no load speed is 175 mm/s, the control accuracy is ±0.1mm, and the bandwidth is 12Hz. The real performances of the actuator system satisfy what are required and they are even better than required.

| No. | Item              | Required performance | Real performance |
|-----|-------------------|----------------------|------------------|
| 1   | Nominal force     | ≥1200N               | 1200N            |
| 2   | Maximum force     | ≥2500N               | 2700N            |
| 3   | Nominal speed     | 127mm/s              | 135mm/s          |
| 4   | No load speed     | 160mm/s              | 175mm/s          |
| 5   | Control accuracy  | ±0.2mm               | 0.2mm            |
| 6   | Bandwidth         | ≥5Hz                 | 12Hz             |

6. Conclusion
This paper introduces the design of high-power EMA with dual redundancy which is used in UAV. The controller and actuator design are introduced in details. The control module and the drive module are designed with dual redundancy in the form of the main circuit and the backup circuit cooperating in the way that each one can realize the whole function of the controller. And also, there are two sets of windings in the motor, and they work in cold standby mode. Compared with the traditional EMA, the EMA in this paper ensures safety of more and more expensive UAV for scout and strike. The EMA can communicate with the fight mission computer efficiently and its control accuracy is high with rapid response and high torque output. Several ground tests simulating the real flight conditions are conducted to verify its performance and results show that it can complete the control task remarkably. It will be equipped in a UAV later to further test its actual performance in practice.

References
[1] Shao Qing and Cang Song, “Research and Design of Dual-redundancy Digital Servo Actuator System,” in Micromotors, vol. 46, pp. 37–39, 2008.
[2] Deng Xiaoqun and Xia Yanhong. “Study on Structure Design of Integrated High Power Electrical Servo Mechanism,” in Navigation Positioning and Timing, vol. 6, pp. 68-74, 2019.

[3] Li Rong, Liu Weiguo, Ma Ruiqing and Hu Yashan, “Research on Current Balance in Dual-redundancy BLDCM Servo System,” in Transactions of China Electrotechnical Society, vol. 20, pp. 77–81, 2005.

[4] Wang HuiJuan and Wang Dabao, “Design on a Kind of Dual-redundancy Electric Mini-Actuator for UAV,” in Micromotors, vol. 43, pp. 24–27, 2010.

[5] Li Shengkun and Li Xinnan, “Servo Control Circuit Design Based on Miniature Projectile,” in Computer Measurement and Control, vol. 19, pp. 839–841, 2011.

[6] Xie Yanwu. “Integrated Guidance-Control System for Winged Missile,” in Ordnance Industry Automation, vol. 11, pp. 38-40, 2012.

[7] Wang Qian and Li Xuedong, “Multi-channel Robot Actuator Controller Design based on FPGA,” in Science Technology and Engineering, vol. 9, pp. 3083–3085, 2009.

[8] Di Bin, Zhou Rui and Ding Quanxin, “Distributed Coordinated Heterogeneous Task Allocation for Unmanned Aerial Vehicles,” in Control and Decision, vol. 2, pp. 274-278, 2013.