Fault Detection and Isolation of the Electro-Mechanical Actuator Based on BIT

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Abstract. Large UAV (Unmanned Aerial Vehicle) for scout and strike is a new trend in modern battlefield because of economy in use, high attendance and low casualty, whose safety is of top concern. EMA (Electromechanical Actuator), as the key component, impacts on UAV a lot. Its performance decides whether the flight is safe or not. In this paper, BIT (Built-In Test) function is designed according to characteristics of EMA with dual-redundancy used for scout and strike UAV. Based on the BIT analysis and BIT design principle, the BIT test methods are brought up. Thanks to the BIT design, the corresponding fault detection and fault isolation of EMA are available which are presented in details. The paper tells the faults that can be detected and then describe how to isolate them. In order to verify the validity of BIT design and the effectiveness of fault detection as well as fault isolation, the corresponding experimental platform is built and several experiments are conducted. The results show that the rates of fault detection, fault isolation and false alarm is desirable. The methods in this paper is feasible and effective.

Keywords: EMA; fault detection; fault isolation; BIT.

1. Introduction
With the rapid advance of science and technology, the military equipment is more and more complex. The maintainability and testability play a more and more important role in combat capability, survival ability and maintenance of military equipment. Traditionally, external ATE (Automatic Test Equipment) tests the military equipment offline. However, it is hard to meet the constantly updated requirements of equipment testability. Maintainability improvement calls for internal fault detection and fault isolation of military equipment, thus shortening the maintenance time [1]. As a result, BIT (Built-In Test) technology emerges. According to the definition of U.S. military standard MIL-STD-1309C, BIT is the auto-testing capability that a system possesses which detects and isolates the fault internally [2]. The equipment with the ability to conduct BIT function is the so-called BITE (Built-In Test Equipment). In order to judge whether the complex military equipment is in normal operation or not by fault detection, the BIT technology becomes an irreplaceable choice [3]. There is no denying the fact that the wide application of BIT technology greatly improves the maintainability and testability, as well as maintenance efficiency [4]. In this way, the battle effectiveness of military is highly enhanced.

Large UAV for scout and strike is a new military equipment in the modern battlefield for its advantages such as economy in use, great time efficiency, high attendance rate and low casualty, which makes battlefield more transparent, scout more real-time and strike more efficient. EMA (Electro-Mechanical Actuator) is the key component of UAV. Its maintainability and testability are quite important. Recently, researches on how to improve EMA testability based on BIT becomes the hotspot. The ultimate purpose of BIT is to find the weakness and error of the EMA system and grid rid of the fault detected to ensure EMA performance, thus ensuring safety of UAV [5]. In this paper, one
certain EMA with dual-redundancy is taken as the object for study. At first, the rationale of EMA is introduced. And then the BIT design and fault detection as well as fault isolation are presented. Right after the EMA begins work, BIT module starts to monitor the system status. Once there is fault detected and confirmed by certain methods, the main redundancy switches to the backup redundancy when needed, thus realizing fault detection, fault isolation and system reconfiguration. The design of BIT technology, fault detection and fault isolation this paper can improve the testability and stability, which offers reference for other EMA design.

2. Rationale of EMA

Usually, EMA is made up of the controller, the motor, the transmission mechanism and the feedback transducer. It is a typical servo system, which transforms the electrical signal into mechanical movement, in order to control the control surface [6]. The control object of EMA is the DC motor and the controlled variable is the output position of actuator. It works in the following process. The control signal is processed and amplified to generate the motor drive signal to rotate the motor. And then after torque amplification, the transmission mechanism drives control surface. At the same time, the actual position indicated by the linear or rotatory transducer is sent back to the EMA controller as feedback. Thus, the closed-loop control is conducted to make the actuator to stay in the demanded position or operate as the command instructs to [7].

![Actuator system function diagram.](image)

As shown in Figure 1, the EMA in this paper is different from the traditional EMA for there is the dual-redundancy controller and motor with double windings. The control part and the drive part of the controller is in the form of main circuit and backup circuit, whose power supplies are independent. And there are two sets of windings in the motor, both of which can work to yield maximum power required. The EMA is specially designed for scout and strike UAV. Although the cost is a little higher than the traditional EMA, the advantages such as improved stability and enhanced safety it brings are worthy of the cost, for the simple reason that dual-redundancy EMA is convenient for fault detection and fault isolation based on BIT design.

3. BIT Design of EMA

In order to realize BIT design, the testability must be considered thoroughly and systematically. At first, The EMA is an intelligent device which can process all kinds of tasks on its own, providing the prerequisite of BIT design. Based on the exclusive detection circuit and self-test software in the controller, EMA can monitor the system status and detect the fault.

3.1. BIT analysis

For the BIT design, first analyze whether there is the application platform in the system or not. If the EMA is a digital one, the BIT is available thanks to its internal intelligent chip and corresponding software. However, if the EMA is an analog one, the BIT is hard to realize. The digital EMA for scout and strike UAV is qualified for the BIT design which is one of the important methods to monitor the system status for fault detection and isolation. BIT runs through the whole process of flight task. Before the UAV takes off, EMA has to be tested to decide whether it works normally or not. Once the UAV powers up, BIT starts to work. Normally, the BIT completes the following functions, namely, monitor the key parameters of the system, inspect the system to find the fault, and isolate the fault detected to the board level. The application of BIT and existence of BITE are required not to make a difference to the system performance and reduce its safety and reliability. In EMA system, the hardware and software cooperate to realize BIT. The components that BIT mainly works on are the transmission mechanism, the motor winding, the feedback transducer, secondary power, the control circuit, the drive circuit and so on. Unless any part of EMA works well, the BIT can tell EMA is in normal operation. When BIT results show that the performance deteriorates to the extent that cannot be accepted or detects some errors, BIT also indicates the corresponding status and sends back to the
flight mission computer. The effectiveness of BIT design can be evaluated by the rate of fault detection, fault isolation and false alarm.

3.2. Principle of BIT design
Basically, BIT design in the EMA requires the hardware design and the software design together. EMA adds the detection circuit in the controller to realize BIT, and the BITE is digital circuit. The software design is made up of two parts, namely, the fault detection and fault isolation. BIT during the working process of EMA is mainly used to monitor the system status and test its performance, thus getting informed of the working status of different parts of EMA. The BIT design should be fast and accurate in the form of centralized control and distributed detection. The rate of fault detection is expected more than 90% and the rate of fault isolation is more than 85% [8]. The fault should be isolated to the LRU(line replaceable unit) immediately after it is detected. According to the characteristics of EMA in the scout and strike UAV, the BIT design includes the power up BIT and Period BIT. Power up BIT is the initial test when the system powers up and it conducts detailed tests of the whole system to detect whether the EMA works well or not. Period BIT is the periodic test which detects certain testpoints to detect the corresponding system status in operation. The schematic diagram of BIT design in EMA is shown in Figure 2.

3.3. BIT realization
Thanks to the help of the relevant hardware and software design, BIT is realized. The hardware design needs the detection circuit, while the software design can refer to the flow in Figure 2. Power up BIT is available, for some modules in the EMA system needs preheating to work and there is enough time to conduct power up BIT. At the same time, power up BIT is essential. In order to ensure EMA function and performance in normal operation, it is demanded to test the whole EMA system to check the week points in the system and then detect fault if there is any, for fault isolation and system maintenance. Power up BIT is conducted automatically once the system starts to work with the transmission mechanism, the motor winding, the feedback transducer, secondary power, the control circuit and the drive circuit as its detection items. The detection results are sent back to the flight mission computer and then methods to deal with faults is taken. After EMA passes the power up BIT and enters normal operation status, the period BIT is on the way to check whether the whole system performance and the main functions are normal or not, in order to ensure flight safety and detect the faults in time.

![Figure 2. BIT design.](image-url)
Fault Detection and Isolation

Right after the system is power on, EMA starts to work. There are two status, namely, the normal status and fault status. The normal status means EMA works all right, whereas the fault status indicates there is fault in the system. The EMA faults can be divided into two groups, with one group the non-fatal faults and the fatal faults [9]. The non-fatal impacts on the flight security in certain degrees, while the fatal faults can lead to serious results such as the flight failure and property loss. No matter what kind the fault is, once detected, it had better be dealt with for fault isolation.

4.1. Fatal faults in EMA

The typical faults in EMA are jamming of the transmission mechanism, open or short circuit of the motor winding, misfunctioning of the feedback transducer, open or short circuit of secondary power, failure of the control circuit and failure of the drive circuit. As mentioned above, the EMA in this paper is in the form of dual-redundancy with the main and backup control/drive circuits powered by each own power source in the controller. Meanwhile, the motor is equipped with two separate windings. Due to the dual-redundancy design, most parts can operate normally without ruining flight safety, even if one redundancy is not available. The fatal faults arise from the weak parts of EMA system. It is not hard to find that the fatal faults in EMA are jamming of the transmission mechanism and misfunctioning of the feedback transducer. As for jamming of the transmission mechanism, the chief culprits are abrasion of the long-time operation, changes of actuator load, or variations of ambient conditions. If there is jamming, the control surface is stuck in a fixed position. The UAV is unable to rotate the control surface and generate torque as desired, thus the flight safety is highly threatened and the UAV is prone to crash. As for the feedback transducer, there is a potentiometer in the EMA system. When the potentiometer suffers from harsh vibration or heavy impact, poor contact between carbon brush and basement membrane may result in severe disturbances of the output signal. The feedback position becomes random and it cannot offer the feedback for the controller correctly. The actuator control is not likely to control the control surface accurately and steadily. Instability of UAV is apparent and UAV accident is a big probability.

4.2. Fault detection and isolation

Based on BIT design and dual-redundancy design, the controller in the EMA system detects the faults internally and then resort to isolation methods through power up BIT and period BIT. Faults that can be detected and the corresponding isolation methods is shown in Table 1.

Table 1. Fault detection and isolation.

| No. | Fault                                | Isolation Strategy                        |
|-----|--------------------------------------|-------------------------------------------|
| 1   | Jamming of transmission mechanism    | Report back to the flight mission computer |
| 2   | Open circuit of motor winding        | Switch to backup winding                   |
| 3   | Short circuit of motor winding       | Switch to backup winding                   |
| 4   | Misfunctioning of transducer         | Report back to the flight mission computer |
| 5   | Open circuit of secondary power      | Switch to backup power source              |
| 6   | Short circuit of secondary power     | Switch to backup power source              |
| 7   | Failure of control circuit           | Switch to backup control circuit           |
| 8   | Failure of drive circuit             | Switch to backup drive circuit             |
5. Experimental Test
In order to verify the BIT design as well as fault detection and isolation, the experimental platform is constructed in Figure 4. It is made up of the ATE (Automatic Test Equipment), the upper computer and EMA.

![Figure 4. Experimental platform.](image)

The upper computer imitates the role of the flight mission computer and it sends command to EMA via ATE. And then ATE communicates with EMA via RS422 interface and transform the instructions from upper come into certain format, thus making EMA to work as the upper computer tells to. After EMA starts to work, BIT is running and fault detection and isolation is conducted. With the help of the experimental platform, inject the faults listed above artificially into the EMA and then record the times of fault detection and fault isolation. The result is shown in Table 2.

**Table 2. Experimental results.**

| No. | Item                                      | Inject Times | Detect Times | Isolate times |
|-----|-------------------------------------------|--------------|--------------|--------------|
| 1   | Jamming of transmission mechanism         | 100          | 92           | 88           |
| 2   | Open circuit of motor winding             | 100          | 93           | 88           |
| 3   | Short circuit of motor winding            | 100          | 93           | 89           |
| 4   | Misfunctioning of transducer              | 100          | 91           | 90           |
| 5   | Open circuit of secondary power           | 100          | 95           | 92           |
| 6   | Short circuit of secondary power          | 100          | 96           | 92           |
| 7   | Failure of control circuit                | 100          | 96           | 93           |
| 8   | Failure of drive circuit                  | 100          | 96           | 91           |

When there is no fault, record the system status to check whether there is false alarm or not. The system works 100 times, and then indicates No.1 fault 2 times, No.2 fault 0 times, No.3 fault 3 times, No.4 fault 1 time, No.5 fault 2 times, No.6 fault 2 times, No.7 fault 4 times and No.8 fault 1 time. Calculate the rate of fault detection, fault isolation and false alarm, and then get the result in Table 3. The detection rates for different faults are between 92% and 96%, the isolation rates for different faults are between 88% and 93%, and the false alarm rates are between 0 and 4%.

**Table 3. Rate calculation.**

| No. | Item                                      | Detection Rate | Isolation Rate | False Alarm Rate |
|-----|-------------------------------------------|----------------|----------------|-----------------|
| 1   | Jamming of transmission mechanism         | 92%            | 88%            | 2%              |
| 2   | Open circuit of motor winding             | 93%            | 88%            | 0               |
| 3   | Short circuit of motor winding            | 93%            | 89%            | 3%              |
6. Conclusion

In the context of EMA with dual-redundancy controller and double winding motor for scout and strike UAV, this paper introduces the fault detection and fault isolation based on BIT. This paper presents the BIT design in details and then tells how to realize. With the help of BIT, fault detection and fault isolation are easy to realize, and the paper tells how to do that. In order to verify the BIT design and evaluate fault detection as well as fault isolation, several tests are conducted in the experimental platform. Results show that the rate of fault detection is more than 91%, the rate of fault isolation is more than 88% and the rate of false alarm is less than 4%, which are quite desirable. The methods of fault detection and fault isolation of EMA based on BIT are proved to be feasible and effective, which can be widely applied in EMA in large UAV for scout and strike.

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