A Typical Failure Mode and Effects Analysis for EMA Used for UAV and Guided Missile

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Abstract. Scout and strike UAV (Unmanned Aerial Vehicle) is one of the important products of latest UAV technology, which is becoming prevalent in modern war. The scout and strike UAV can complete scout tasks efficiently and hit the target with the guided missile accurately. And also the military use of scout and strike UAV brings low casualty. It attracts more and more attention. EMA is the actuator of the UAV and the guided missile. It controls the control surface, rotation of which determines the flight attitude, exerting heavy influence on the flight safety. Failure mode and effects analysis is an important tool for EMA (Electronic Mechanical Actuator) design, for the simple reason that it helps to assess EMA reliability, maintainability and safety. In this paper, a typical failure mode and effects analysis is conducted with EMA as the research object. EMA system definition and FMEA (Failure Mode and Effects Analysis) basic principle are presented. And then the detailed analysis is given based on some certain rules and the FMEA table illustrates the analysis. To summarize, the failure mode and effects analysis offers reference for EMA design. With it, the weak part in the design can be found and some potential risks can be eliminated in early stages of EMA design.

Keywords: FMEA; EMA; UAV; Guided Missile.

1. Introduction

With the development of the UAV technology, UAV is becoming more and more popular in different domains, with application scenario from to single and simple to diverse and complex [1]. The scout and strike UAV is one important branch of UAV, which is relatively large and able to carry several guided missiles, featuring newest technology and military use. As the modern advances toward the direction of intellectualization and low casualty, the military requirement evolves with it. And the stronger capability of rapidity, accuracy and efficiency and is demanded for the scout and strike UAV [2].

Currently, the scout and strike UAV works mainly in two ways [3]. One way is to when it is exposed. The other way is to hit the target in close range with the operation and intervention by the manipulator. Apparently the first way saves man power and doesn’t need manipulator at all. No matter in which way the scout and strike UAV works, it is more efficient and rapid in target hitting than the manned vehicle. Also compared with the manned vehicle, the UAV is relatively small and agile. There is no casualty in wars and it can perish together with the enemy when needed. To summarize the scout and strike UAV loaded with the guide missile is a star equipment in modern war and attracting more and more attention.

As the key component of the UAV and the guided missile, EMA decides performance of the UAV and guided missile, for the flight attitude is severely influenced by the EMA. In order to reduce risk and improve EMA quality, the EMA design should be taken seriously. Several typical design scheme exists and also the experience can be accumulated with more and more EMA designed and produced.
However, that is not enough. Sometimes, the failure mode and effects analysis must be conducted carefully and precisely, thus paving the way to a successful EMA design. Through FMEA, the influences imposed on the reliability, maintainability and safety of EMA can be analyzed and assessed. In this way, the reason why the EMA suffers from failure or fault is able to be found, locating to some certain components. FMEA helps to improve EMA design and ensure quality. In this paper, a typical FMEA method is presented in the context of EMA used for UAV and guided missile. The system definition of EMA and basic principle of FMEA are introduced. And then the detailed failure mode and effects analysis is conducted following some certain rules. In the end of this paper, the conclusion is given. It is not hard to see that with the FMEA method proposed in this paper. The EMA design gets more reliable and effective.

2. System Definition of EMA

2.1. System Composition

The EMA used for UAV and the guided missile consists of the controller and the actuator [4]. In details, the controller and the actuator can be divided into several submodules. The EMA submodules are shown in figure 1. Typically, the controller is made up of the power converting circuit, the digital control circuit, the analog signal processing circuit, the isolation circuit, the motor drive circuit and the monitoring circuit. The actuator comprises the DC (Direct Current) motor, the harmonic reducer and the potentiometer.

![Figure 1. System composition and indenture of the EMA controller](image)

As for the controller, the power converting circuit converts the external power supply into various power sources by DC-DC converters or low dropout regulator for the analog part, the digital part and the power drive part. The digital control circuit mainly consists of the control core and its peripheral circuit as well as the digital communication circuit. DSP (Digital Signal Processor), STM32 or C51 MCU (Micro Control Unit) is selected as the control core according to different application requirement. The analog signal processing circuit usually process the potentiometer feedback, the drive current feedback and the analog command. The isolation circuit serves as the link between the digital part and the power drive part, which is in the form of optoelectronic isolation and is able to isolate the digital signal and the power drive signal effectively. The motor drive circuit serves to generate the corresponding motor drive signal rotating the motor, thus leading the actuator to a certain position. The monitoring circuit in the controller monitors the system status and offers reference for fault judgment. As for the actuator, the DC motor is the drive element of the actuator. Because of its advantages such as high motion precision, little backlash, smooth motion, small noise, strong bearing capacity and accurate transmission ratio in a wide range, the harmonic reducer is commonly used in the actuator as the part which reduces speed and increases torque. The potentiometer is mounted in the actuator output mechanism to indicate the real position of the control surface.

2.2. Working Principles and Functions

The working principle of the EMA is shown in figure 2. After equipped in the UAV or guided missile, once reset, how the EMA works and functions of each components are as follows. The EMA
controller receives the control command from the control computer or the mission computer via certain communication interface. Usually, the control command is in the form of analog voltage or the digital communication such as RS422 (Recommend Standard 232) or CAN (Controller Area Network). As for the analog voltage, it is acquisition by an external ADC (Analog to Digital Converter), while the responding transceiver is needed for the digital communication. The control command is calculated with some certain conversion relation and the command position is obtained. At the same time, the potentiometer output is also acquired by the external ADC, thus obtaining the feedback position.

![Diagram](image)

**Figure 2. Working Principle of EMA**

In the control core, based on the command position and the feedback position, the control algorithm is conducted and the PWM (Pulse-Width Modulation) signals are generated as a result. Passed by the signal isolation circuit, the PWM signals with certain frequency and duty cycle turned into the exclusive drive signals for the motor drive circuit, whose output rotates the DC motor. The torque is increased and the speed is decreased by the harmonic reducer, transforming to the output mechanism. In this way, the control surface is manipulated. In the meanwhile, the system feedback has to be sent back to the control computer or the mission computer typically in two ways. One is the analog feedback and the other is the digital feedback. Usually only one way of system feedback exists in the EMA for simplicity and low cost. The monitoring circuit cannot be neglected. It serves as the unsung hero, monitoring the system status in the backstage. From the contents above, it is not hard to see that the EMA is a typical close-loop servo system [5].

3. Basic Principle of FMEA

Failure mode and effects analysis is a method for reliability analysis, which can evaluate and analyze the potential risks, thus eliminating the risks or reducing the risks to an acceptable level. Not only is
the FMEA method able to be used as the preventive analysis in advance, but also it can improve and optimize the current design target according to history data [6, 7].

For EMA used for UAV and guided missile, there are two ways to conduct FMEA, namely, the hardware method and the functional method [8]. The hardware method is applied in the EMA detailed design phase when the EMA design is confirmed. At that time, the hardware components can be listed which paves the way for classification and analysis of all the possible and potential failure modes. Generally speaking, the hardware method is usually used in the component-level analysis from bottom up to the system-level analysis. The functional method is applied in the EMA preliminary design phase when the EMA design is not finished and the detailed component list cannot obtained. At this time, the functional method is the realization of FMEA. Based on the functions each component conducts, the failure mode is analyzed. If there is quantitative data of failure mode, the criticality analysis can be conducted further [9]. The typical failure mode and effects analysis for EMA used for UAV and guided missile in this paper combines the hardware method and the functional method together.

4. FMEA of the EMA

EMA is the system which helps UAV or the guided missile to control the flying attitude. Undoubtedly, it plays a significant role in deciding the flight performance and ensuring the flight safety. This paper adopts combination of the hardware analysis and the functional analysis to conduct FMEA for the typical EMA used in the UAV system or in the guided missile. The EMA composition and functions of each components are classified scientifically and reasonably [10]. The failure mode and effects are analyzed. The influences of component fault or failure are imposed on the EMA are decided as ordinary or important [11, 12]. Thereby, the design requirement of EMA and matters needing attention can be summarized. To summarize FMEA is an important tool in EMA design.

4.1. Analysis Premise

As for FMEA in this paper, the premise should be made as follows:

- Failure mode and effects analysis is conducted based on the EMA introduction above.
- When conducting analysis of one certain failure mode, it is assumed that there are no other faults in the EMA.
- Based on the historical experiences and statistics, the printed circuit board, the control box of the EMA controller, the electrical connector, the interconnecting cable, the actuator shell and the mounting screws are quite durable and hardly prone to failure. As a result, they can be regarded as one hundred percent sound and safe. In this paper, they are eliminated from the failure mode analysis.
- The EMA failure mode information in the FEMA table comes from three sources. The first one is the statistics of the failure modes occurring during using process. The second one is the failure modes encountered in experimental tests such as the environmental tests, the electromagnetic compatibility tests and the reliability tests. The third one is the potential failure modes predicted by principle analysis according to the system composition.

4.2. Indenture Level

In order to be more general and instructive, there are three indenture levels for failure mode and effects analysis for EMA typically used for UAV and guided missile in this paper. Also as shown in figure 1, the initial indenture level is defined as EMA. The second indenture level is defined as the controller and the actuator. And then the third level is defined as the power converting circuit, the digital control circuit, the analog signal processing circuit, the isolation circuit, the motor drive circuit, the monitoring circuit, the DC motor, the harmonic reducer and the potentiometer.

Different parts in each indenture level is encoded with different codes as shown in figure 1. There are several failure modes for each part [13]. For distinction of different faults in one certain part, the fault has to be encoded as well. Define codes of the failure mode in the same part as the part code+F00X [14]. X stands for the nth failure mode. For instance, the first failure mode for the power converting circuit can be encoded as 011F001.
4.3. Fault Judgment and Probability
According to the design and maintenance experience of EMA used in different kinds of UAV and guided missiles, the fault in the failure mode can be summarized and judged as follows:

- In the specified time and under specified conditions, EMA cannot accomplish the specified function.
- In the specified time and under specified conditions, although the EMA functions well, EMA performance cannot meet the desired requirement and cannot accomplish the specified function either.

The probability of EMA failure mode is declared in table 1. The probability for each level is the proportion of the failure modes in that level calculated according to all failure modes in total [15].

**Table 1. Failure mode probability**

| No. | Level | Degree  | Probability  |
|-----|-------|---------|--------------|
| 1   | A     | Frequent| >20%         |
| 2   | B     | Possible| 10%~20%      |
| 3   | C     | Accidental| 1%~10%     |
| 4   | D     | Unlikely| 0.1%~1%      |
| 5   | E     | Rare    | <0.1%        |

4.4. FMEA Table
Based on the contents above, FMEA is conducted and there are 29 failure modes. The corresponding FMEA table is given in table 2.

**Table 2. FMEA Table**

| Code | Item             | Failure Mode Code | Performance | Influences | Probability |
|------|------------------|-------------------|-------------|------------|-------------|
| 011  | Power Converting Circuit | 011F001 | No output | The controller loses power and all the functions shut down. | E |
|      |                   | 011F002 | Output is too large | Some parts of the controller will burn out and all the functions shut down. | E |
|      |                   | 011F003 | Output is too low | The actuator cannot be controlled as desired. | E |
|      |                   | 011F004 | Output Drift | Functions are abnormal. Incorrect motor drive signals and abnormal. Controller functions are abnormal. | D |
|      |                   | 012F001 | PWM Malfunction | Incorrect monitoring information. Controller functions are abnormal. Incorrect analog command and potentiometer feedback. Controller functions are abnormal. | E |
| 012  | Digital Control Circuit | 012F002 | ADC Malfunction | Incorrect working parameters. Controller functions are abnormal. Incorrect actuator control. Controller functions are abnormal. | E |
|      |                   | 012F003 | SPI Malfunction | No analog command and potentiometer feedback. Actuator loses control. | E |
|      |                   | 012F004 | IIC Malfunction | Fixed analog command and potentiometer feedback. Controller functions are abnormal. Incorrect analog command and potentiometer feedback. Controller functions are abnormal. | E |
|      |                   | 012F005 | TIMER Malfunction | | D |
| 013  | Analog Signal Processing Circuit | 013F001 | No output | | E |
|      |                   | 013F002 | Fixed output | | E |
|      |                   | 013F003 | Output Drift | | D |
In table 2, no output means there is no output from certain modules. Output drift means the output is random without any certain rules to follow. Fixed output means the output is a certain value which cannot be changed. Output too large means the output is beyond the output ability of the module while output too low means the output is below the output ability. Malfunction means the module cannot function properly.

In the light of probability, there are no failure modes rated as A, B and C, while there are 7 failure modes rated as D and there are 22 failure modes rated as E. Take all the potential factors into consideration, failure modes with the codes of 011F001, 021F001, 022F001 and 022F003 are the key failure modes. That is to say that the quality and function of the power converting circuit, DC motor and harmonic reducer decides whether the EMA suffers from the key failure modes or not.

5. Conclusion
The scout and strike UAV is a non-negligible force in modern way for military use, because of its advantages such as low causality, high maneuverability and great flexibility. EMA plays a key role in deciding the attitude of the scout and strike UAV, severely imposing influence on flight safety of UAV as well as the guided missile loaded in it. For better EMA performances, influencing factors should be considered as soon as possible in early design stages, thus saving trouble in late design stages. Failure mode and effects analysis serves as a useful tool to find the weak points in EMA design according to previous statistics, design experience and theory analysis. With FMEA, the quality and the reliability of EMA can be improved a lot. EMA design is becoming relatively easy and regular. Engineers should take the FMEA seriously when conducting new EMA design.

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