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Research on Missile PHM Design based on FMECA

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The failure analysis focused on failure mode effect and criticality analysis (FMECA) is one of the main tasks of PHM design. This article analyzes the defects of the current augmented FMECA (aFMECA) method and puts forward the application of functional FMECA in the conceptual design phase of missile design. The table of functional FMECA and hardware (software) FMECA are improved. Through the correspondence of function detection demands and failure detection methods, the detection data connection between the conceptual design phase and detailed design phase is established. According to the analysis result of FMECA, the failure diagnosis methods and failure forecast methods are preliminary set, and the configuration of related test points and sensors are arranged. By giving the example of a missile control system, this article demonstrates the missile PHM design method based on aFMECA, the result of which proves the feasibility of this method.

1. Introduction

Based on all kinds of intelligent reasoning algorithms (physical models, neural network, data fusion, fuzzy logic, expert systems), PHM (Prognostic and Health Management) is a kind of technology that can assess the health condition of the system, forecast system failures before they really happen, and finally provide series of maintenance and support measures by taking advantage of all available resource information to guarantee the on-condition maintenance of the system. (Hess and Fila, 2002)

With the combination of PHM design and the conventional missile design process, the missile PHM system could be constructed, based on which the current status of missiles can be monitored and the probable failures can be forecasted, thus realizing the health management of missiles, reducing the possibility of disastrous maintenance failures and cutting down maintenance and support costs. (Hu et al.2010)

The diagnosis and forecast of failures are the main concerns in the design of PHM. So failure analysis focused on FMECA is one of the important jobs that should be paid special attention to in PHM design. Tian and Zhao (2006) interpret some basic analytical content on aFMECA. Kurtoglu et al. (2008) introduce a systematic design methodology, namely the Functional Fault Analysis (FFA), developed with the goal of integrating SHM into early design of aerospace systems. Kacprznski (2002) provide an update on the developments associated with a Prognostics and Health Management (PHM) system design tool that integrates a model-based FMECA methodology with state-of-the-art system simulation directly linked to downstream Life Cycle Costs (LCC). Shi and Ji (2011) describe the importance of the enhanced FMECA in PHM design, modify the meaning of the enhanced FMECA and make some complement on application methods of aFMECA.

However, there are some defects in the FMECA methods provided by the current literatures when they are applied in PHM design, which are as follows:

1) The augmented FMECA is done at the detailed design phase only, when the design of PHM is about the selection (configuration) of sensors (test points) and the methods for failure forecast according to the preliminary prototype. In this case, the hardware and software have been basically defined, therefore, the selection of test points and the configuration of sensors are quite limited, or much amendment is required on the designed hardware and software.

2) The correspondence of the testability between the conceptual design phase and the detailed design phase is ignored.

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3) There has been a lacking in the researches on the application of disposable equipments like the missiles.
This article puts forward the way to improve the functional FMECA in the conceptual design phase, taking the requirement of failure detection into account. Research the correspondence between functional FMECA and the hardware (software) FMECA, making a data transmission from function detection requirement to the layout of sensors and test points, the failure diagnosis and prognostics and so on. Finally, it gives some examples to test the effectiveness of the methods.

2. PHM design with the application of FMECA

2.1 Design philosophy

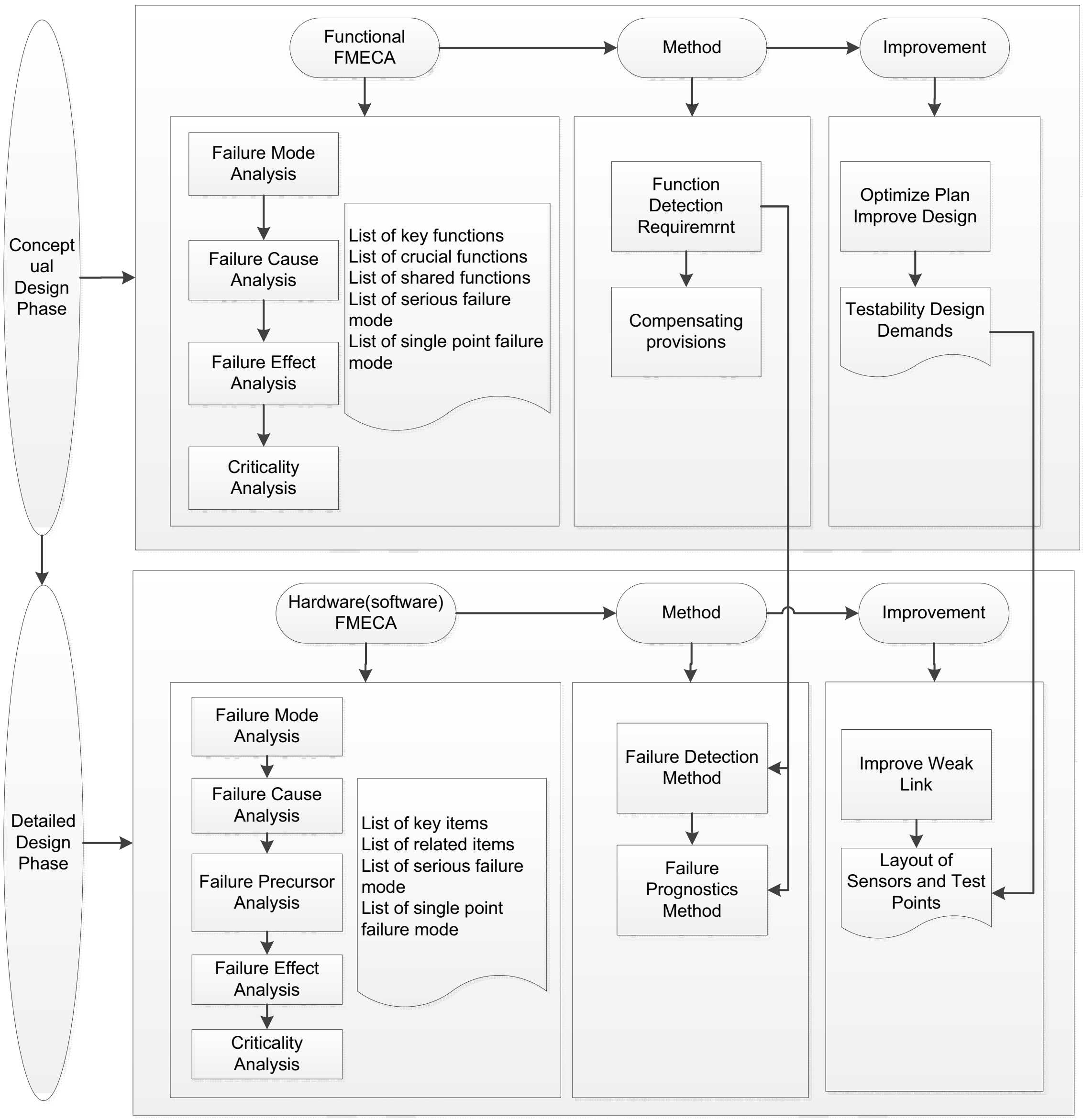

Figure 1 Missile PHM design flow chart

FMECA is a reliability design and analysis method that has been widely used. Conventional FMECA analyzes all the failure modes that may occur in a product in the static way, finds the reason for these failure modes and their possible consequences, and then figures out methods for the detection of the failure modes, finally presenting reasonable measures to avoid or reduce these failure modes. While the PHM system focuses on the dynamic way, in which failures will be caught, analyzed and confirmed by real-time monitoring before they really happen, then through certain reasoning mechanism, the possible mode and position of the failures will be confirmed. Conventional FMECA methods cannot adapt to the PHM system perfectly, because failures have to be forecasted before they really happen, and the changing state parameters should be taken into consideration. Besides, its analysis is far from enough for the application of PHM.

To solve this problem, there should be some adjustments in the conceptual design phase and the definition phase. In the conceptual design phase, first of all, the modes, causes, consequences and harmfulness of failures should be analyzed according to the improved functional FMECA. Then, key functions, crucial functions, shared functions and functions correspondent to serious failure mode and single point failure mode should be figured out, so as to make function detection demands and improvement measures. Along with the overall optimization of the design, the function detection demands should be extracted as the testability design demands. Through the design of hardware and software, some of the function detection demands will be met, while the rest demands will be transferred to the next phase of FMECA. When it comes to the detailed design phase, first, the modes, symptoms, consequences and criticality of failures should be analyzed by means of augmented hardware FMECA. Then, the key products, related products and products correspondent to serious failure modes and single point failure mode should be figured out. Finally, considering the unmet function detection demands in the previous phase, some failure detection methods and failure forecast methods should be raised. Besides, the configuration of sensors and test points should also be arranged, so as to facilitate the monitoring of parameters.

2.2 The improvement on the table of functional FMECA

The improvement of functional FMECA lies on the analytical method featured by in-depth analysis of the influence on related functions, based on which the function detection demands and design improvement measures will be made.

In the conceptual design phase, designers are to comb the product functions layer by layer, and then build the product function diagram and the function layer diagram. As for products that have sequential relationships, the function flow diagram or time reference map should be built. Finally, the reliability diagram will be completed, based on which the functional FMECA analysis will be done. The *failure detection methods* in conventional FMECA are not adaptable in this phase, so they should be replaced by function detection demands, which require that designers raise demands on the detection of functions according to the influence of failures. The failure modes of key functions, crucial functions and shared functions, serious failure modes and single point failure modes should be paid special attention to. Table 1 shows the modified functional FMECA table.

Table 1 modified functional FMECA

Code	Function	Failure modes	Failure causes	Mission phase/operational mode	Failure effect			Function detection requirement	Severity class	Failure precursor
					Local effects	Next higher level	End effects			

2.3 The improvement on the table of hardware (software) FMECA

According to the demand of condition monitoring and analysis, augmented hardware FMECA conducts analysis on correlative information like sensor settings, monitoring parameters and failure symptoms. Four aspects are newly added.

1) Failure symptom is the perceptual knowledge people acquire from failure by observation and measurement. It indicates the existence of one or more failures with certain probability. The purpose for the analysis of failure symptom is to provide the basis for the determination of failure detection methods.

2) Failure indication is the external expression of failure observed in the early phase of its mode transformation. The purpose for the analysis of failure indication is to provide the basis for the determination of failure forecast methods.

3) Based on the result of analysis on failure symptom and failure indication, the configuration of sensors and test points for detection can be determined. As for electronic systems, failure symptom and failure indication are usually expressed by electrical signals like voltage, current and resistor, so first the positions of their correspondent test signals (test points) must be figured out. While for non-electronic systems where failure symptom and failure indication cannot be expressed by electrical signals, sensors are always needed. So what sensors to use for test and where they shall be placed should be determined first.

4) When setting the failure forecast methods, internal forecast can be realized by statistical methods, while external forecast can be realized by both statistical methods and machine learning methods. When analyzing the failure forecast methods, to determine the specific forecast method, the arrangement of sensors (test points), the type of test parameters and the settings of forecast methods should be considered.
Table 2 shows the augmented hardware FMECA table.

Table 2 augmented hardware FMECA

Code	Item	Function	Failure modes	Severity class	Failure probability	Failure precursor	Types of sensors and test points	Layout of sensors and test points	Failure detection method	Failure forecast method

2.4 Data transmission

In the data transmission phase, the function detection demands raised in the analysis of functional FMECA are transmitted to the design of hardware and software. Failure diagnosis and failure forecast are taken into consideration in the design process. At the same time, the detection demands that have not been met in the design of hardware and software are transferred to the next phase of design, during which the failure detection methods and failure forecast methods will be determined and the configuration of sensors and test points will be arranged. The correspondence between failure indication and failure mode (influence), between sensor settings and gathered signals, and between failure indication and test parameters should be implemented on every part.

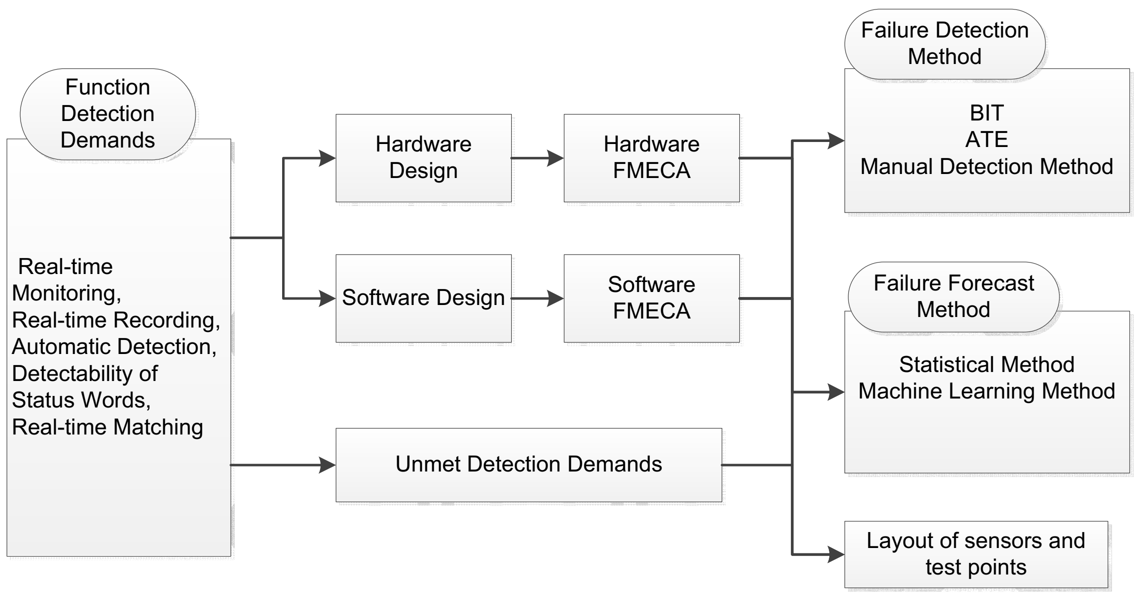

Figure 2 diagram of data transmission

The function detection demands raised in the conceptual design phase of missile design mainly consists of the following items: real-time monitoring, real-time recording, automatic detection, detectability of status words and real-time matching.

Table 3 shows the methods that are usually used in the failure diagnosis of missiles. In the configuration of diagnosis, the BIT methods are often used in internal diagnosis, while external diagnosis can be realized by manual or automatic detection methods. In the analysis of failure diagnosis methods, the specific diagnosis method should be determined according to the settings of sensors (test points), the types of test parameters, and the configuration demands of diagnosis mode.

Table 3 failure diagnosis method

Category of diagnosis method	Implication	Examples
Built-in test	To conduct global or partial diagnosis on system/equipment automatically with detection hardware and software designed inside the system/equipment	Voltage summation BIT; loop BIT; Boundary scan BIT
Automatic test	To conduct local or remote diagnosis on system/equipment automatically with ATE,ATS or automatic diagnosis system	ATE test; Relay automatic test; Remote automatic test
Manual test	to conduct local diagnosis on system/equipment with maintenance personnel operations as the focus	Visual test; non-destructive detection; test point test

3. The application

Here is an example of some units in a missile control system. (Jackson, 2010) *Figure 3* shows the main functions of the control system in the ground test phase. The power supply of the system lies on the forepart of the function diagram. The following functions will be directly affected if failure occurs in this part. *Table 4* shows how the functional FMECA works based on the analysis of the power supply function. The hardware needed for this function include: the power source module, resistors, capacitances, filters and connectors. *Table 5* shows how the hardware FMECA works based on the analysis of the power source module.

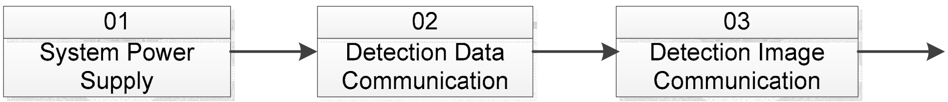

Figure 3 Function flow chart of ground test phase

Table 4 Functional FMECA case form (part)

Code	Function	Failure modes	Failure causes	Mission phase/operational mode	Failure effect			Function detection requirement	Severity class	Failure precursor
					Local effects	Next higher level	End effects			
01	System power supply	System power supply failure	Power failure	Ground test	System power supply failure	Control system can't start	Failure of ground test	detectability of power supply status words	□	E
		System power-on reset	Circuit unstable	Ground test	System power supply failure	Control system can't start	Failure of ground test	Real-time monitoring	□	E
		System power supply unstable	Power failure	Ground test	System power supply unstable	Control system operation unstable	Instability of ground test	Real-time monitoring	IV	E

Table 5 Hardware FMECA case form (part)

Code	Item	Function	Failure modes	Severity class	Failure probability	Failure precursor	Types of sensors and test points	Layout of sensors and test points	Failure detection method	Failure forecast method
H1	Power module	Provide power for missile	degeneration; leak; open circuit	□	D	Control channel output voltage abnormal	Voltage test	Control channel output end	External test	--

The example of the power source module shows that failure detection can be realized by setting electric sensors at the output end of the control channel. The design of other parts can also refer to the column “sensor configuration/ test points” in Table 5. The signal or data of sensors and test points will be transmitted to the state monitoring device, in which calculation and evaluation related to the system condition will be done, and failure warnings will be activated if the result is beyond the default parameter limit/threshold. At last, the health assessment module will assess the system by the combination of historical and present data.

4. Conclusions

The conceptual phase of functional FMECA plays an important role in completion of the overall design. Through the improvement of functional FMECA, the correspondence between it and the hardware (software) FMECA is realized. The tables and methods used in it also serve as the guidance in the design of missile PHM. This method can deal with the majority of failures that occur in the design phase, those which remain unknown should be obtained and dealt with through reliability experiments. With the help of aFMECA, the failure diagnosis methods and failure forecast methods could be configured and analyzed preliminarily, based on which health assessment and prognostic modeling on the system level are also needed to indeed realize the management of health.

References

Dong Hu, Jinsong Xie, Weimin Lei, 2010, Applications of PHM Technology in Missile Weapon Systems, Missiles and Space Vehicles, 4, 24-30.

Hess A., Fila L, 2002, The joint strike fighter (JSF) PHM concept: potential impact on aging aircraft problems, In: IEEE Aerospace Conference Proceedings, March9-16, Montana, US, 6, 3021-3026.

Kacprznski G.J., Roemer M.J., Hess A.J., 2002, Health management system design: development, simulation and cost/benefit optimization. In: IEEE Aerospace Conference Proceedings, March9-16, Montana, US, 6, 3065-3072.

Kurtoglu T., Johnson S.B., Barszcz E., 2008, Integrating system health management into the early design of aerospace systems using functional fault analysis. In: International Conference on Prognostics and Health Management. Denver, CO, 1-11.

Jackson P. B., 2010, Overview of Missile Flight Control Systems, The Johns Hopkins APL Technical Digest, 1, 9-24.

Jin Tian, Tingdi Zhao, 2006, Research for Augmented FMEA Method Applying to Prognostics & Health Management System, Engineering&Technology, 4, 34-37.

Junyou Shi, Chao Ji, 2011, Study on Enhanced FMECA Method Application, Measurement & Control Technology, 5,110-114.