Application mode and efficiency discussion of PHM technology in missile weapon system integrated logistic support domain

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***Abstract*—Missile is a long-term stockpile and single-use purpose exclusive weapon system which varies from aircraft, warship or radar and other weapon systems in terms of operating mode and usage frequency. In order to improve the missile weapon system integrated logistic support capability, it has been an issue and debate topic for domain experts on how to apply PHM technology to it. This paper based on the actual demands of integrated logistic support, as well as combined the system design and operating characteristics of the domestic missile weapon system, purposed an improved and adapted technical application framework pattern of PHM technology. Furthermore, by targeting the improvement of logistic support capability, this paper also analyzed the PHM technology application typical activities and the effects it may bring. Finally, the research results of this paper could be supportive and it provides the reference for certain domain institutions.**

Keywords- PHM technology; missile weapon system; integrated logistic support

I. INTRODUCTION

With the improvement in tactical performance and increasing complexity of weapon system, issues related to system testability, fault diagnosis, and maintenance support has been heavily concerned recently[1]. Consequently, the United States has proposed prognostic and health management (PHM) concept, as well as applied massive researches in the first place. It is comparatively successful for the United States to apply PHM to Joint Strike Fighter program. China has also engaged plenty of PHM researches in different equipment and achieved promising results in aviation, vehicle, steamship and wind tunnel domain.

PHM technology was early developed from external test to built-in-test. Furthermore, it has derived three technology subjects which are monitor, diagnosis, and prognosis. Due to the increasing requirement of equipment in intelligentization and full life cycle aspect, this technology became the PHM technology in nowadays [2]. Since PHM technology has been fully introduced and studied in extensive research literature worldwide, there will be no more PHM technology application status analyze in this paper.

Due to the particularity such as long-term stockpile and single-use purpose of missile weapon, it has been an issue and debate topic for domain experts on whether PHM technology can be able to achieve a high precision diagnosis and effective preventative maintenance in order to increase the combat capability or extend the service life of missile weapon. This debate has become one of the largest barriers on whether PHM can be successfully applied to the missile weapon system, although it may not a technological issue. All stakeholders should be considered and analyzed, as well as the tradeoff between the complexity that PHM may bring and the reliability of the missile weapon system should also be fully demonstrated in this debate. The missile weapon will not only be more reliable in terms of electronic, structural and mechanical technology development but also be more precise in terms of self-diagnosis and self-assessment in PHM in future. However, this paper studies the background and necessity, overall framework, core technology and development prospect of the application, etc., in order to discuss and analyze whether PHM technology can be studied and applied in the current stage.

II. BACKGROUND AND NECESSITY

The missile weapon features in high complex structure, high-reliability design requirement. It sustains a long-term stockpile state for at least 10 years. The core target of logistic support for missile weapon is to precisely evaluate performance and keep the missile weapon system intact. Mechanical/structural, electronic and energy are the three major classes fault pattern of missile weapon. Currently, routine or regular test and maintenance can contribute a small amount of data and yet is far from sufficient to detect the potential fault. Therefore, the lack of sufficient performance evaluation may cause a certain risk in missile weapon logistic support.

A. Targeted logistic support of missile weapon during long-term stockpile cannot be achieved with insufficient performance tracking.

The performance recession process of missile weapon is steady and extremely slow due to the high-reliability design and long-term stockpile. In the early stage, the performance intactness rate of missile weapon will be relatively high. On the contrary, as long as the stage goes closer to its storage lifetime, the performance recession will drop rapidly. Especially in the change of material parameters, material aging and stress defects are caused by chemical reactions; performance changes of electronic components and propellant due to environmental influences. At the present, the test parameters of missile weapon are obtained from the regular routine test which is

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hardly to indicate the changes above and performance tracking as well, so that the precision and effectiveness of logistic support activities will be impossible to achieve. As a result, it is necessary to apply a series of test techniques and methods to collect reliability related missile weapon full life cycle data, furthermore to achieve a more precise condition-based logistic support by evaluating the comprehensive performance.

B. The mission may not be accomplished successfully since the capability of condition monitoring is missing while the batch of missile weapon is on-duty.

Partial strategic missile weapon frequently sustains the on-duty state. In addition, it has to be launched with no delay when necessary. The missile has a much crueler environment while under duty than stockpile condition. For example, it may suffer from the vibration and structural stress of the transportation or operation process, and the environmental stress as well as fatigue during long-term standby. It is crucial and will be more meaningful to apply condition monitoring and health management to missile weapon while it is under a duty. As a result, it will provide more accurate information on missile intactness rate to achieve an accurate launch decision for decision makers. Furthermore to ensure the combat mission accomplished successfully.

C. The missile life extension analysis and the decision cannot be made due to insufficient life cycle data while the missile storage life expires.

The design life of missile weapon is generally decades long. In recent years, it has become an issue that an amount of China's missile weapons have reached the end of design life or even under extended service. Consequently, the key task for military force to resolve such issue is to master which and how long the missiles are qualified for further service, as well as which missiles can be recovered in terms of performance and quality with effective maintenance [3-9].

The product design of several missiles in the earlier model was overemphasized on functional and tactical performance. However, ignore the testability, maintainability, supportability, and verification which causes life extension of such missiles can only be achieved through reliability tests and life evaluation. As a consequence, the life evaluation on such missile weapon will remain concerns in terms of accuracy, engineering realization, and the economic costs.

D. For developing missile weapons, the latent fault may not be accurately discovered as the failure mechanisms have not been well studied yet.

With the rapid development of missile weapon technology in recent years, the tactical performance of the developing products has improved to a higher level due to the advanced design concept, sophisticated and highly integrated structure. On the other hand, the fault pattern is becoming more complex and reliability design requirement is even harder for missile weapon accordingly.

From the maintenance perspective, due to the complexity of design and composition, the study on failure mechanism is insufficient as well as the latent fault evolution process lack theoretical support in the early stage. Therefore, the maintenance support for missile weapon in stockpile will be even harder. The undiscovered latent faults will bring risk to the completion of combat missions. As a result, it is especially magnificent to develop the application of PHM technology for missile weapon.

III. PHM SYSTEM FRAMEWORK

A. OSA-CBM system framework

The OSA-OBM is a standard framework to achieve CBM (condition-based maintenance) system which was researched and verified by an industrial research team funded by the United States NAVY [10]. The OSA-CBM system framework is one of the main reference frameworks in the domain of condition-based maintenance. It bases on sensor technology to collect information from the subject. Besides, it applies various algorithms and intelligent models to monitor, diagnosis, prognosis and manage the condition of the subject. Furthermore, it combines the requirements in resource management to achieve intellectual and adequate decisions, so that anticipatory measures for maintenance services can be made.

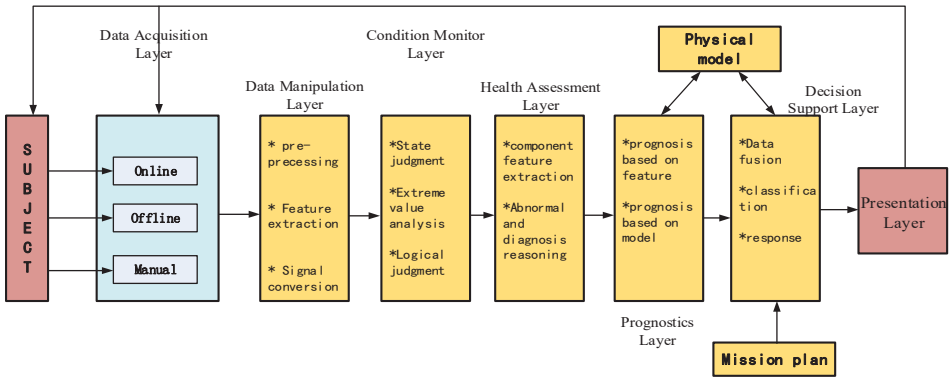

Figure 1. OSA-CBM system layers

OSA-CBM system is divided in seven layers, as Fig. 1 shows.

1) Data Acquisition Layer.

Provide an interface for digital sensor data in the CBM system.

2) Data Manipulation Layer

Receive data from data acquisition layer or any other data sources. In addition, apply signal conversion by using unique CBM feature extraction algorithms.

3) Condition Monitor Layer

Compares eigenvalue with expected value or runtime threshold and push the results to the monitor as well as trigger the alarm according to the presets.

4) Health Assessment Layer

Detect subject system or subsystem performance recession and determines the health condition. Moreover, it provides credible suggestion against failure.

5) Prognostics Layer

Obtain future health condition based on the current health condition of the subject or evaluate and estimate the remaining service life under given circumstances.

6) Decision Support Layer

Generate operation suggestions and decisions based on received data from the health assessment layer and prognostics layer.

7) Presentation Layer

It displays health evaluation, prognosis and decision suggestion data result, and provides HMI for the subject.

Due to the particularity of the missile weapon system, the main focus issues of the research for domain experts are related to data acquisition layer, health assessment layer and prognostics layer. Therefore, to improve PHM application ability without compromise the reliability has become the core research task to apply PHM technology in missile weapon. This paper based on different characteristics of weapon old and new weapon studied the adapted application framework and proposed certain application mode, workflow and key features of PHM technology.

B. PHM adapted application framework for old missile weapon

Currently, digitalization rate of old weapon equipment is relatively low since performance testing methods of each unit in major missile weapon equipment were not fully considered at the beginning of the product design. Thus, the ability of built-in-test is quite limited. Furthermore, it is impossible to equip extra sensors or test equipment for old missiles. On the other hand, although external test methods such as apply ATE equipment or off-line non-contact measurement may obtain a very limit amount of data, yet far from sufficient to drive the health management model or algorithm effectively. Besides health management model, algorithm may also not been fully studied.

As a result, the key point of apply PHM technology to old missile weapon is to obtain and evaluate performance status with limited data in limited sensor extension condition. Combines the missile weapon operation characteristics in troops, Fig. 2 shows the adapted application framework of PHM for old missile weapon.

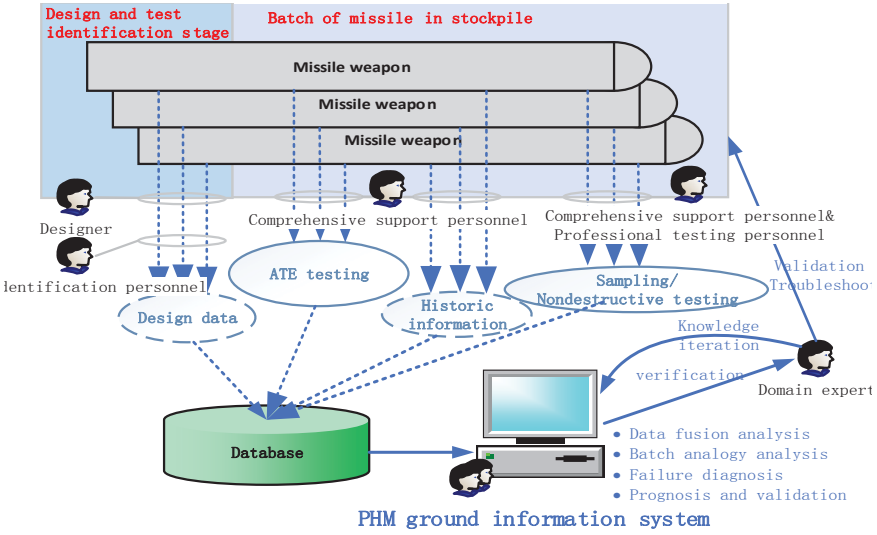

Figure 2. Adapted application framework of PHM for old missile weapon

In the meantime, there are four types data source while missile weapons in a stockpile condition which are: 1.The design data and test identification data while missile was designed and tested. 2. Recorded data from automatic test equipment while missile under regular routine maintenance. 3. Equipment history information of missile weapon while the transportation or training. 4. Performance data by using industrial CT (Computed Tomography) technology or any other nondestructive testing methods while regular routine maintenance or sampling test.

By recording the above four types of data into the database, statistical analysis, data mining, failure diagnosis and prognosis can be applied by PHM ground information system. It will also generate failure diagnosis and prognosis results according to the data for maintenance staff or expert for further verification, validation and troubleshooting as well as iteratively improve relevant knowledge in the PHM system.

All data acquisition equipment or system reference the data acquisition layer in CBM system, and PHM ground information system reference the remaining six layers in CBM framework.

It is worth to mention that the times of regular routine maintenance for missile weapon in the stockpile is limited due to the reliability concern. Therefore, for one single missile, the amount of performance data may relatively poor and yet the data from the same batch or earlier batch of missiles will be critical. To implement a batch analogy analysis is an important method to detect similar failures among other missiles during the data analysis process.

C. PHM adapted application framework for new missile weapon

In the development phase of missile weapons, the testability design of PHM applications and the reliability design of missile weapons can be improved simultaneously by making full use of advanced design methods. Furthermore, in order to establish a solid foundation for the PHM system, enhance the built-in-test ability and preset more sensors internally which can provide more detailed runtime information and performance data later on.

Fig. 3 shows the application framework of PHM for new missile weapon.

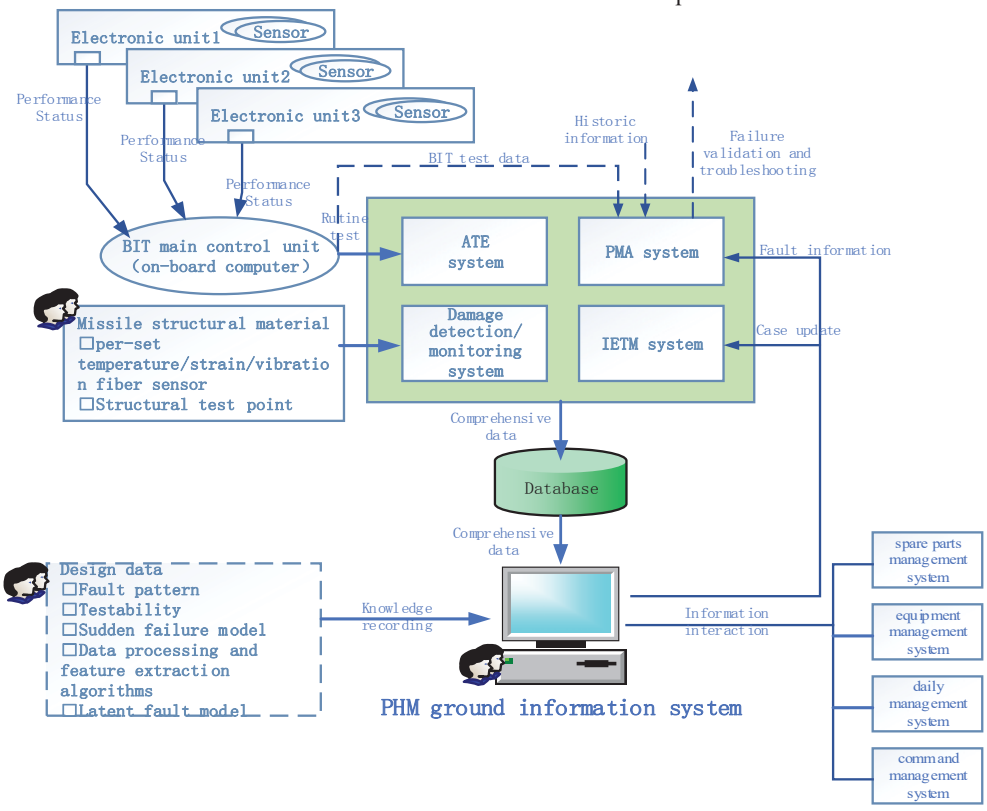

Figure 3. Application framework of PHM for new missile weapon

The demonstration of PHM application mode for new missile weapon varies from old missile weapon in three aspects.

Firstly, adopt more extensive testing methods to obtain status information from key parts of the missile weapon. To achieve a PHM application based missile weapon, it is necessary to customize the condition monitoring capability design for electronic equipment and structural materials. To be more precise, the electronic equipment of built-in-test design capability should be enhanced not only in terms of runtime status alarm, but also should base on full studies of its fault pattern to extend more sensors for the parameters which have the highest correlation with performance changes. Moreover, the data can be gathered and collected by the control unit in missile built-in-test computer, after that the data can be download by ATE or portable maintenance auxiliary equipment (PMA) through certain interfaces. In order to detect more failures on structural material, advanced material with high-strength and high reliability which embedded with the optical fiber temperature sensor, vibration sensor, and strain sensor should be considered in missile weapon structural design. For material (such as solid engine fuel tank) with the

special consideration which may not suitable to attach sensors, should implement external tests such as CT test, guided wave test or sampling test to achieve better performance results.

Secondly, pay more attention to study the fault pattern, testability and data processing algorithms designs of missile weapon. Thus, the fault pattern analysis of the missile weapon will be more complete and standardized, the fault transmission will be clearer, the design of the test points will be more rational, the correlation analysis between various types of data and fault pattern will be more thorough, and data processing and feature extraction algorithm will be more comprehensive. Consequently, the PHM application performance will be fully utilized based on an accurate failure diagnosis and prognosis result.

Finally, the supporting systems, equipment, and software around PHM system application such as the PHM ground information system, PMA and IETM will be more complete. Taking the PHM ground information system as the core, the diagnosis and prediction results are used to drive the user to validate the fault, troubleshooting, maintenance and iterative update of the PHM knowledge. Form a virtuous cycle improvement of the PHM capability for the missile weapon logistic support. On the other hand, it may interact with the daily management system, spare parts management system, equipment management system and even the command management system to drive maintenance, logistic or operational command business in an effective way and establish a true condition -based maintenance support mode.

IV. CORE TECHNOLOGY

A. General quality characteristic design technology based on PHM

The fundamental purpose of designing is to achieve a higher reliability for the missile weapon. Since the missile weapon may experiencing a relatively low reliability, PHM technology is an effective method to validate the reliability for the missile weapon. As a comprehensive tool to measure the performance and even deep-seated failure problems, PHM system is closely related to reliability, testability, maintainability, environmental adaptability, electromagnetic compatibility, and security of the missile weapon. How to develop the PHM system without increasing the complexity of equipment and reducing reliability is the first problem to be solved. Moreover, establish an internal test and external test system for missile weapon performance which can meet PHM requirements. At the same time, the supporting systems, equipment, and facilities in the logistic support stage are also important elements to be analyzed when designing the general quality characteristics of missile weapon.

B. Multi-source data acquisition technology in full life cycle

Data acquisition methods for the full life cycle of missile weapon including built-in-test based on early design, embedded sensors, preset test points, and external ATE test, PMA equipment as the regular test methods, also include non-destructive testing based on industrial CT imaging, structural damage detection based on guided wave testing, and chemical composition analysis based on non-contact or sampling test. Furthermore, due to the limitation of missile weapon long-term stockpile, it is possible to design the 'Twin missile' as it can be monitored and tested by more techniques. It brings significant application value that the corresponding test results can be used as a comparison reference with the performance for the same batch of missiles.

C. Missile weapon performance evaluation technology based on small sample data

Due to the characteristics of missile weapon, it generates a small amount of data during the full life cycle, which is fundamentally different from the systems operates cyclically in long-term, such as aircraft, high-speed railway train and automobile. The lack of data issue in missile weapon PHM system narrows down the number of adoptable failure diagnosis, performance evaluation, and prognosis algorithms, due to the majority of algorithms are based on large sample statistical analyses. Hence, it is necessary to further study PHM related methods based on small data sample, such as storage life model, environmental influence analysis, correlation analysis, analogy analysis, similarity evaluation and achieve deeper physical meaning from a single parameter, which will better satisfy the requirements of PHM in missile weapon.

D. Support strategy technology based on PHM system

In each stage of the full life cycle, the missile weapon will involve a variety of different business activities, such as transportation, disassembly, regular inspection, on-duty and so on. Compared with traditional support mode, the application of the PHM system will carry out a certain degree of change for activities and support strategies. Through sorting out the information of subject equipment, personnel, facilities and data, a complete logistic support business flow chart of missile weapon for stockpiling stage and combating stage can be formed. Analyze the application characteristics of the missile weapon PHM system, as well as the impact on resources, activities and other main elements in the logistic support. In addition, establish the guidelines for the logistic support activities and strategies in each stage of the full life cycle.

V. DEVELOPMENT PROSPECT

The design of early missile weapon in domestic often pays more attention to the tactical and technical performance, rather than more attention to fault pattern analysis and testability analysis. Internal status data of missile weapon is either yet to collect in an effective way or applies a simple comparison between data. For new missile weapon, with deeply study of PHM framework, terminal design, application capabilities, and further in-depth research on missile weapon failure mechanism and latent faults. Besides, accurately assess the PHM capabilities through missile weapon performance evaluation test and combat evaluation test.

For missile weapon already old, the continuous data collection and analysis, as well as knowledge update and iteration will significantly contribute to the application capability of PHM system for new missiles. The missile weapon in future will form more accurate, rapid and targeted PHM application capability which promotes logistic support capability reach to a new level and fully motivates the combat effectiveness for the missile weapon.

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