World Journal of Engineering Research
Print ISSN: 2959-9865
Online ISSN: 2959-9873
DOI: https://doi.org/10.61784/wjer3036

CURRENT STATUS AND APPLICATION TRENDS OF EQUIPMENT FAILURE PREDICTION AND HEALTH MANAGEMENT TECHNOLOGY

Jie Liu
China Special Vehicle Research Institute, Jingmen 448035, Hubei, China.
Corresponding Email: 1499703502@qq.com

Abstract: With the rapid advancement of science and technology, the integration, complexity, and intelligence of weapons and equipment have significantly increased. Traditional fault diagnosis and maintenance support technologies are becoming increasingly inadequate in meeting emerging requirements. To address the demands of information warfare for rapid, reliable, and accurate operation of military systems, Prognostics and Health Management (PHM) technology has progressively evolved. PHM represents an innovative approach to health condition management, developed by leveraging the latest advancements in modern information and artificial intelligence technologies. It constitutes a systems engineering discipline derived from practical engineering applications, continuously refined into systematic and structured methodologies focused on monitoring, predicting, and managing the health status of complex engineering systems. Today, PHM technology is receiving widespread attention globally and is considered a core enabler in the development of next-generation weapons systems and the realization of autonomous logistics support. This article provides an overview of the current applications of PHM technology, aiming to serve as a reference for its implementation in equipment management.
Keywords: PHM; Failure prediction; Health management; Current status

1 INTRODUCTION

With the ongoing advancements in the complexity, integration, and intelligence of modern weaponry and equipment, along with evolving maintenance concepts and reforms in maintenance methodologies, Prognostics and Health Management (PHM) technology has progressively matured. PHM involves the real-time monitoring of various operational status parameters and characteristic signals through advanced sensor technologies. It leverages intelligent reasoning algorithms and models to assess equipment health conditions, predict potential faults prior to their occurrence, and generate maintenance and support decisions by integrating available resource information, thereby enabling condition-based maintenance [1-3]. A comprehensive PHM system typically encompasses functionalities such as fault prediction, fault isolation, fault diagnosis, health management, and life tracking. For complex systems and equipment, PHM should be capable of performing multi-level and hierarchical diagnostics, prognostics, and health management. The workflow of a PHM system generally consists of seven core processes [4,5], as illustrated in Figure 1.

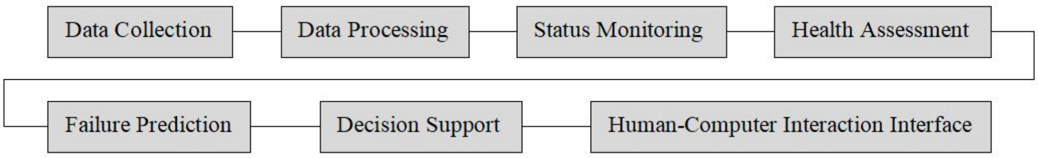

Figure 1 The Framework of the PHM System

2 THE CURRENT STITUATION OF TECHNOLOGICAL DEVELOPMENT AT HOME AND ABROAD

2.1 The Current Situation of Technological Development Abroad

The development of PHM technology abroad has progressed through five distinct stages: external programming, built-in testing (BIT), intelligent BIT, comprehensive diagnosis, and PHM integration. Concurrently, the evolution of maintenance decision-making technology has encompassed post-failure maintenance, periodic preventive maintenance, condition-based maintenance (CBM), and intelligent maintenance[6-9]. At the application level, PHM implementation has advanced from component-level and subsystem-level solutions to system-level integration that encompasses all major subsystems across the entire platform. Currently, PHM technology is being extensively researched and widely adopted by leading military powers such as the United States and the United Kingdom. It has become a critical component in the development and deployment of next-generation weapons systems, including aircraft, ships, and armored vehicles. A notable example of its application can be found in the F-35 fighter jet and related equipment systems.

2.1.1 Application of the PHM system in the F-35 aircraft

The F-35 aircraft represents one of the most prominent implementations of PHM technology. Its PHM system comprises both airborne and ground-based components. The airborne system employs a hierarchical intelligent reasoning architecture, integrating various types of diagnostic and predictive software at multiple design levels. This structure enables the comprehensive application of fault diagnosis and prediction technologies, spanning from individual components to the entire system level. The ground-based system integrates status data, performance metrics, trend analysis, fault diagnostics, prognostics, and remaining useful life predictions for both individual aircraft and fleets. Based on an expert system framework, this integration supports large-scale maintenance forecasting for entire combat units and facilitates autonomous logistics support.

According to statistics from the U.S. military, after the F-35 fighter jet incorporated PHM (Prognostics and Health Management) technology, the non-repeatable fault rate decreased by 82%, maintenance manpower requirements were reduced by 20% to 40%, logistics support scale was cut by 50%, the number of spare parts types increased by 25%, aircraft operation and maintenance costs dropped by 50% compared to previous models, and the service life reached 8,000 flight hours. These figures clearly illustrate the significant effectiveness of PHM in reducing maintenance and support expenditures, enhancing the safety, availability, and reliability of military equipment, ensuring mission success, and improving overall combat capability.

2.1.2 Engine PHM system design abroad

Rolls-Royce's T900 series Engine Health Management System (EHMS) comprises both onboard and ground station components. The onboard system primarily employs sensor technology to monitor engine conditions and collect operational data, performing preliminary data processing, storage, and triggering alarms when necessary. The ground station is responsible for advanced signal processing and data analysis based on the collected information, enabling comprehensive fault diagnosis and predictive maintenance.

Pratt & Whitney has developed a universal architecture for aero-engine PHM systems based on data fusion techniques. This architecture utilizes appropriate algorithms to analyze high-frequency signals obtained from structural health and vibration monitoring sensors, which are then calibrated using low-frequency signals from airway and fuel/lubrication oil sensors. The calibrated signals from gas path and lubrication systems first pass through an analytical module that identifies performance variations across engine modules, integrates oil system parameters, and detects anomalies in the gas path. Subsequently, all characteristic information is transmitted to the advanced fault diagnosis and gas information fusion module. By integrating this data with the fault code information from the engine’s full-authority digital electronic controller, the module generates a comprehensive health assessment of the engine and identifies potential faults. Finally, by incorporating input from maintenance personnel and pilots along with historical engine maintenance records, the fault isolation inference engine module formulates a recommended maintenance plan.

2.1.3 The common application situations of PHM systems abroad

The application situations of common PHM systems in foreign countries such as the United States and the United Kingdom are shown in Table 1.

Table 1 The Application Situation of PHM Technology Abroad

Category	PHM system	Application situation
Spacecraft	IVHM、ISHM	X34; X37
Fixed-wing aircraft	PHM、HUMS	F-35; F-22; R-2; C-130; C-17; RQ-7A/B; P-8A; EF-2000
Helicopter	HUMS、JAHUMS	AH-64; UH-60; CH-47; RAH-66; EH-101; NH-90

2.2 Current Situation of Domestic Technological Development

China started relatively late in the field of PHM technology and has a weak research foundation. In the late 1970s, the maintenance of aviation equipment had been following the traditional experience-based maintenance methods of the 1930s and 1940s abroad. The inspection time and content were directly determined by experience, and the maintenance was carried out by senses in accordance with the prescribed time and content. Since the 1980s, China has vigorously developed research on PHM-related technologies such as condition monitoring, fault prediction and reliability maintenance. And it was included in the national "863" development program.

2.2.1 Theoretical exploration and in-depth research on PHM technology in China

In terms of the design of engine PHM systems, Sun Jianzhong from Nanjing University of Aeronautics and Astronautics has conducted research on the health management issues of the new generation of domestic military and civil aviation engines in three aspects: condition monitoring, health status assessment, and remaining life prediction modeling. This provides reliable methods and technologies for improving the health management level of domestic civil aviation engines. To solve the problem of fault prediction for liquid rocket engines, Shen Jiao from National University of Defense Technology proposed a fault prediction method based on error prediction correction. This method has significantly improved the prediction accuracy and adaptability compared with the single process neural network prediction model.

In terms of the design of the PM system for weapons and equipment, Yang Hongjun from the 76327 Unit of the People's Liberation Army of China, based on the analysis of the characteristics of level 3 faults of faulty equipment in the armored command information system, and starting from the actual needs of the maintenance and support of armored command information system equipment, designed the architecture and functional composition of the PHM system for armored command information system equipment. And effective theoretical exploration was carried out on the construction of the PHM system. He Xianwu and others from the Naval Aeronautical Engineering College have studied the effectiveness and feasibility of applying PHM technology in the maintenance and support of anti-ship missiles, and designed the PHM system structure of the anti-ship missile weapon system and the sensor network structure in the maintenance and support of anti-ship missiles. Zhang Liang and others from the Air Force Engineering University have focused on the technical characteristics, difficulties and maintenance and support requirements of the new generation of combat aircraft of our military Various schemes of the airborne PHM system architecture were compared and analyzed, and a hierarchical architecture integrating four layers, namely module/unit level PHM, subsystem level PHM, regional level PHM and platform level PHM, was proposed.

In the design of the PHM system for unmanned aerial vehicles (UAVs), the research group led by Feng Guoqiang from the Air Force Engineering University utilized the self-equilibrium theory in biology to design the fault-tolerant control and fault diagnosis system for UAVs. By designing the "equilibrium point", they determined the safe state of the UAVs and applied fault-tolerant control and fault diagnosis to fault prediction and health management. Su Xujun and others from Army Engineering University proposed a method for predicting faults in unmanned aerial vehicle (UAV) systems using BP neural networks, and presented the modeling and calculation methods of BP neural networks. The calculations show that this method can be used for UAV fault prediction. Peng Lelin and others from the Liberation Vehicle Artillery Academy established the topological structure of the system equipment based on the fault characteristics of the unmanned aerial vehicle (UAV) system, and on this basis, constructed the logical architecture of the UAV PHM system. Lei Yaolin and others from the 54th Research Institute of China Electronics Technology Group Corporation designed an unmanned aerial vehicle (UAV) health prediction and health management system based on telemetry data and intelligent interpretation. They also conducted simulation experiments on the fault prediction algorithm using simulated fault samples, indicating that the UAV health prediction system has a good fault detection capability.

2.2.2 PHM technology by the Air Force Radar Academy

Wang Hanzhong from the Air Force Radar Academy, in view of the system structure and fault characteristics of modern radar equipment, adopted a hierarchical and modular fault diagnosis method, organically combined intelligent diagnosis technologies such as neural networks, expert systems and fuzzy reasoning, and designed a comprehensive intelligent fault diagnosis system for modern radar equipment. He also focused on the knowledge acquisition, knowledge base and reasoning construction of the system. In-depth research was conducted on the main functional modules and key issues such as the extraction of characteristic parameters of diagnostic information. The simulation results show that the system can conduct efficient and accurate automatic diagnosis of complex faults, overcome the limitations of traditional diagnosis methods, and effectively improve the fault diagnosis ability of modern radar equipment.

2.2.3 Technical applications of PHM technology in fields such as aviation, aerospace, shipping, and weaponry

In the aviation field of our country, focusing on model technology research and development, we have carried out test design and verification for flight control actuator systems, rotary actuator drive equipment, hydraulic power systems, component casings, power supply systems, avionics processing machines, and metal composite material airframe structures. Research and related verification on diagnosis and performance table regression prediction technologies: In the aerospace field. At present, the satellite power system mainly conducts in-orbit status monitoring, performance degradation prediction, operation management and life extension of solar cell arrays, batteries and controllers. Manned spaceflight has also carried out status monitoring and fault-tolerant control for some key systems. In the field of shipping, technical applications such as condition monitoring, fault diagnosis, operation and auxiliary maintenance decision-making have been carried out for key equipment in the main and auxiliary systems. In the field of weaponry, engineering applications such as on-board condition monitoring and auxiliary maintenance guidance in a network environment, enhanced diagnosis in the monitoring center, and auxiliary decision-making for tasks and maintenance have been implemented for launch vehicles.

3 DEVELOPMENT TRENDS

The future development of PHM technology will gradually move towards intelligence, networking and specialization. The development of PHM technology in China should fully draw on foreign research achievements, focus on independent innovation, and at the same time, do a good job in theoretical research on PHM technology, technological innovation, infrastructure construction, and the cultivation of soft power of talents. Form a PHM technology system with Chinese characteristics and oriented towards the new generation of equipment for the future.

3.1 Intelligence

In recent years, with the continuous deepening of theoretical research and development of condition monitoring and diagnosis technologies, and the continuous breakthroughs and industrial applications of modern sensor technologies with high precision, high performance and high information volume have been achieved. New methods for condition monitoring and fault diagnosis are constantly emerging, such as expert diagnosis, fuzzy diagnosis, neural network diagnosis, and the combination of the above-mentioned various diagnoses. Intelligence has become the future development trend.

3.2 Networking

Through networked online equipment monitoring, the transmission of equipment status and data storage and analysis are achieved, realizing full coverage, dynamic and continuous monitoring of equipment. Moreover, diagnostic analysis of monitoring data can be conducted to predict and determine the current damage degree and risk level of the equipment, ensuring the safe and stable operation of the equipment. Through intelligent diagnosis and analysis, the networked online monitoring system not only provides monitoring for the operational status of the equipment but also offers a scientific basis for regular and irregular safety inspections and maintenance of the equipment.

3.3 Specialization

In the future, the technology of equipment condition monitoring and fault diagnosis in our country will develop in a specialized direction, with increasingly detailed division of labor. The implementation of condition monitoring and fault diagnosis will mainly be integrated. Overall solution providers that can offer professional equipment condition monitoring and fault diagnosis software and hardware systems and have rich diagnostic technology talents will become the mainstream. China will gradually form industry-wide, regional and even national-level equipment condition monitoring and fault cloud diagnosis centers.

4 CONLCUSION

As a cutting-edge technology, Prognostics and Health Management (PHM) plays a crucial role in improving the reliability, safety, maintainability, and supportability of equipment. This paper reviews the current research status of PHM technology both domestically and internationally, and discusses its future development trends, with the objective of laying a solid foundation for the further advancement and practical application of equipment PHM systems.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Jinzhen Kong, Jie Liu, Jingzhe Zhu, et al. Review on Lithium-ion Battery PHM from the Perspective of Key PHM Steps. Chinese Journal of Mechanical Engineering, 2024, 37(04): 14-35.

[2] Wang Hong, Kulevome Delanyo Kwame Bensah, Zhaozi an. An integrated PHM framework for radar systems through system structural decomposition. Journal of Systems Engineering and Electronics, 2025, 36(01): 95-107.

[3] Yao Zhao, Li Hejia, Tu Chao, et al. Application of Fault Prediction and Health Management in Vehicle Control System. Journal of Physics: Conference Series, 2021, 1852(4). DOI: 10.1088/1742-6596/1852/4/042069.

[4] Hu Nannan, Su Xiaohao, Baolong Liu. A Review on Prognostics and Health Management. International Journal of Advanced Network, Monitoring and Controls, 2018, 3(1): 115-121. DOI: 10.21307/ijanmc-2018-022.

[5] Cao Yang, Liu Hongtian, Song Chao, et al. Research on a fault test system based on fault injection. Journal of Physics: Conference Series, 2021, 1894(1). DOI: 10.1088/1742-6596/1894/1/012023.

[6] Shen Shilei, Ma Linlong. Research on the Built-in Test Design of Civil Aircraft Flight Control System. Journal of Physics: Conference Series, 2022, 2252(1). DOI: 10.1088/1742-6596/2252/1/012010.

[7] Huang Jian Xin, Bian Ya Qin. Research on BIT Intelligence Maintenance Decision of Weapon Materiel. Applied Mechanics and Materials, 2011, 128-129(128-129): 224-228. DOI: 10.4028/WWW.SCIENTIFIC.NET/AMM.128-129.224

[8] Drees R, Young N. Role of BIT in support system maintenance and availability. IEEE Aerospace and Electronic Systems Magazine, 2004, 19(8): 3-7.

[9] Straka Ondřej, Punčochář Ivo. Distributed design for active fault diagnosis. International Journal of Systems Science, 2022, 53(3): 562-574. DOI: 10.1080/00207721.2021.1963501.