CHEMICAL ENGINEERING TRANSACTIONS

VOL. 33, 2013

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Enrico Zio, Piero Baraldi

ISBN 978-88-95608-24-2; **ISSN** 1974-9791

DOI: 10.3303/CET1333047

A Review of Current Prognostics and Health Management System Related Standards

Yang Zhou*, Jing Bo,Tang Wei

Affiliation and Address Aeronautics and Astronautics Engineering College of Air Force Engineering University, Xi'an, Shaanxi, China
rk1019@163.com

Prognostics and health management(PHM) is a promising technology to reduce the overall life cycle cost and improve flight readiness in the civil and military aviation field. As the prognostic algorithms are applied into monitoring condition of aircraft structures, avionics, wiring, control actuators, power supplies, propulsion systems and etc, more attention has been focused on establishing a common standard to validate whether the PHM algorithms or systems can reach the design requirements and compare the efficiency of the diagnostics and prognostics algorithms. Currently, there're many standards in the diagnostics and test regions, such as condition monitoring and diagnosis standard in ISO, the engine health management standards in SAE and so on. All these PHM related standards may help developing the new standard. First, this paper identifies the specification of PHM standards from different applications. And the state-of-the-art in PHM related standards is also given. Second, the current PHM-related standards in various standardizations and agencies are overviewed and analyzed according to the CBM, PHM, IVHM and HUMS classification; Lastly, some suggestions are given for PHM standardization development, and the focus of the future work and directions are also proposed.

1. Introduction

Prognostics and Health Management (PHM), as the key technologies for a new generation of equipment, has an important role to improve equipment safety and mission success, reduce security costs. PHM has a wide range application in the airborne engine systems, avionics systems, aircraft power systems and so on. It has already made significant progress in helicopters, fixed-wing aircraft and the space shuttle, as well as ground armored vehicles (Len Losik, 2012; Leonardo R. Rodrigues et al,2012). However, as a continuous development of cutting-edge technology, the PHM standardization issues in practical applications are very prominent. A well-established PHM standard should be able to regulate the following content: health management and validation assessment, diagnostics / prognostics information, available resources and the use of demand to make proper planning and decision-making of maintenance activities and system diagnostic, prognostic and health management capacity and level of validation assessment, and to achieve the above goal of the foundation is to PHM standards and design guidelines.

2. Background

With the rapid development of PHM, the standardization issue has already arouses the extensive attentions, (John W.Sheppard and Timothy J. Wilmering,2007a; John W.Sheppard et al,2007b) have focused on the existing IEEE diagnostic and test standard such as: IEEE Std-1232 series and the IEEE P1636 information exchange model. Both those standards are partly supporting the PHM applications, and they have also specified the direction of development of the PHM standard system. (Zeng et al, 2010) has analysed the current aircraft PHM system standard, and pointed out the existing standards, such as MIL-STD2165, GJB2547, GJB2072 and GJB1909, the fault detection, isolation and prediction methods and verification means can not be fully applied in the PHM system. In 2010, the U.S. Army revised and published the ADS-79C-HDBK, it can provide the design and implementation guidance in HUMS

Please cite this article as: Yang Z., Bo J., Wei T., 2013, A review of current prognostics and health management system related standards, Chemical Engineering Transactions, 33, 277-282 DOI: 10.3303/CET1333047

application for US Army CBM plus plan. In October 2011, SAE HM-1 IVHM steering group, led by Cranfield University IVHM research center, has conducted the five IVHM standards draft working in progress. In April 2012 led by the University of Maryland's CALCE Research Centre, the IEEE P1856 (Standard Framework for Prognostics and Health Management of Electronic Systems) has already began to build. Also in 2012, both the IEEE International Conference of PHM and Annual Conference of PHM set up a special panel discussion “IEEE PHM standards” for the first time, providing the open forum to discuss the related issues. Although the major standards organizations have already published relevant standards for PHM and devoted to the current PHM standardization, there is still a need for researchers to check how and which related PHM standards can be used for the current PHM standardization issues.

3. Analysis of Current PHM Related Standard

With the rapid development of PHM in recent years, the U.S. military, government agencies, industries have carried out research and development of related technologies in different applications. Generally, there are three classes: the CBM plan in the U.S. Army, the IVHM/ISHM in the aerospace and commercial aircraft field, HUMS in the helicopter field, but they share almost the same concept and methods with PHM technology. Considering the lack of a fielded PHM system, it still doesn’t have a complete set of PHM standard.

While after years of development, the condition monitoring and diagnostics (CM&D) has gradually formed a relatively complete set of standard system for system verification and product certification. Due to the inherent correlation for failure prediction with the traditional diagnostics and maintenance system, it can be learned from the following standard developed by the International Organization for Standardization (ISO), the International Electrical and Electronics Engineers Association (IEEE), Machinery Information Management Open Standards Alliance (MIMOSA), Society of Automotive Engineers (SAE), U.S. Federal Aviation Administration (FAA) and the U.S. Army (US ARMY). And the formulation of the IEEE P1856 standard draft and SAE IVHM standards work-in-progress allow researchers to see future direction of development.

Prognostics and Health Management related standards can be divided into four classes according to the different applications as shown in Table 1.

Table 1: The PHM related standards and specification

Organization	Committee	Typical Standards	Class
ISO	TC 108	CM&D series standards	
MIMOSA	——	OSA-CBM, OSA-EAI	CBM
	G-11r	CBM recommended practice	
SAE	HM-1	IVHM series standards	IVHM
	E-32	EHM series standards	
	SCC 20	IEEE Std-1232 series standards	PHM
IEEE		IEEE Std-1636 series standards	
	PHM	IEEE P1856	
SAE	HM-1	HUMS series standards	
FAA	——	AC-29C MG-15	HUMS
U.S. Army	——	ADS-79C-HDBK	

3.1 CBM relevant standards

3.1.1 ISO Standards

In the series of ISO standards, ISO TC 108 is responsible for machine CM&D series of standards. The family standards mainly contain: vocabulary; vibration condition monitoring; data processing; communication and expression; a general guideline to the use of performance parameters; forecast; personnel training and certification requirements; electrical signal analysis; acoustic emission and ultrasonic content.

(ISO:13374-1, 2004) gives information flow structure of the CM & D system, the PHM system is divided into six processing modules: data acquisition (DA), data manipulation (DM), state detection (SD), health assessment (HA), prognostic assessment (PA), and Advisory Generation (AG). It has described the information flow in the main function of each module and has generality proposed a communication method and expression. (ISO: 13374-3: 2012) is provided with an open condition monitoring and diagnostic reference information framework under the needs of the data communications, as well as a reference to the specific needs of the processing framework. Software designers need to define the communication interface to the information exchange in the software system. (ISO 13381-1, 2004) has predicted a general guideline focusing on the impact of factors, warning and alarm, the basic concept of the multi-parameter analysis and prognostic initial metrics, then the prognostic model of effectiveness and performance degradation.

3.1.2 MIMOSA standards

MIMOSA is a non-profit organization, with the member of about 50 international companies such as Boeing and some branches of the U.S. Department of Defense. It has released two standards: the open system architecture for condition-based maintenance standard (OSA-CBM); open system architecture for enterprise application integration (OSA-EAI). MIMOSA OSA-CBM, 2012 is an application of ISO 13374,its modules can be individually designed to meet the specifications of the OSA-CBM with simplifying the integration of different hardware and software process. MIMOSA OSA-EAI defines all aspects of information on equipment for storing and transferring the data structure with the enterprise applications, which contains the physical configuration of the platform, including reliability, conditions, and maintenance, systems and subsystems of the platform. Using the OSA-EAI defined data elements, OSA-CBM is seamlessly integrated into future versions of OSA-EAI. In 2009, the Boeing Company developed an aircraft ground analysis system with the OSA-CBM framework to build the embedded health monitoring of aircraft systems, which greatly reduces the cost of aircraft software update and modifies the required practice. Therefore, MIMOSA OSA-CBM framework has become a standardized framework and has been applied in the fielded system. And it’s able to provide reference architecture for the PHM system.

3.1.3 SAE Standards

In September 2011, SAE Reliability Technical Committee (G-11r) began to develop a SAE ARP6204, aiming at formal drafting and formulating the standard implementation for an organization to achieve a given condition-based maintenance architecture. It’s benchmarked the CBM framework formulation and performance specifications. And it has begun to develop a formal application specification.

3.2 PHM relevant standards

3.2.1 SAE standards

SAE Aerospace propulsion system health management Technical Committee (E-32) released a series of aircraft engine monitoring system/health management system standards, they can be divided into four categories: (1) General Guideline; (2) Life Cycle Monitoring Guideline; (3) Status Monitor Series Guideline; (4) Interactive Series Guideline. The followings are the some of the standards: Guideline to Temperature Monitoring in Aircraft Gas Turbine Engines; Guideline to Engine Lubrication System Monitoring; Prognostics for Gas Turbine Engines; Recommended Practices for Aircraft Turbine Engine Vibration Monitoring Systems and so on.

Take ARP 1587B for example, it comprehensively covers the overall framework of an engine health management system, providing a macroscopic description and emphasizing the EHM description, advantages, ability and business cases (SAE ARP 1587B, 2007). As can be seen from above, aircraft engine as the most important system, its standard research began from the earlier engine control system to the prognostics and health management system, establishment and improvement of standard of other airborne systems PHM.

3.2.2 IEEE Standard

IEEE SCC20 is established to maintain the IEEE Std1232 series of standards (AI-ESTATE) and IEEE Std1636 of series standards (SIMICA). In 2011, IEEE set up electronic systems PHM Working Group to establish electronic systems PHM framework. And it’s also responsible for IEEE P1856 draft standard construction.

IEEE Std1232 referred to as Artificial Intelligence and Expert System Tie to Automatic Test Equipment (AI-ESTATE). In 1995, IEEE has adopted and released AI-ESTATE standard (IEEE Std1232: 1995). The standard has revised and updated respectively in 2002 and 2010, and in June 2012 the formation of the IEEE Std1232: 2010 Ver.2. It has been ensured that the diagnostic information between different applications can interact with each other and support the modular diagnostic structure, test software interactive operation. By taking advantage of the ISO EXPRESS modelling language, it has defined a set of software services in order to achieve the integrated use of diagnostic reasoning machine in the test system. With the definition of PHM, it can gradually be refined to achieve the acquisition of "gray" health information to support the current performance degradation and failure process gray reasoning. This can be used for the detection of potential failure (IEEE Std 1232, 2010). IEEE P1232.3 is being developed for the AI-ESTATE User Guide providing developers with guidance compliance with IEEE Std1232 of fault diagnosis applications, usage model including IEEE Std1232 specification, services and interchange format. Other standards such as IEEE Std1522: 2004, has defined a series of tests and diagnostic metrics and formal description of the characteristics of the model, based on the definition of test and diagnostic general information model.

The IEEE Std1636 referred to as Software Interface of Maintenance Information Collection and Analysis (SIMICA). It defines series of maintenance information model, containing two additional standards: IEEE Std 1636.1 test results standard and IEEE Std1636.2 maintenance activity information standards, which provide a strong support for test and diagnostic information exchange process. IEEE Std1636.1:2007 uses test historical information (including the identification, measuring, testing the boundary, the test sequence, fault report of the unit under test). Through the XML format and information model, it can provide a method to improve the diagnosis and prognosis. IEEE Std1636.2: 2010 provides an XML program and information model focused on the maintenance process, which is easily extended to PHM areas.

IEEE P1856 standard will be the first time proposed a development standard that covers all aspects of prognostics and health management of electronic systems, including definitions, approaches, algorithms, sensors and sensor selection, data collection, storage and analysis, anomaly detection, diagnosis, metrics, life cycle cost of implementation, return on investment and documentation. This standard can provide information to aid practitioners in the selection of PHM strategies and approaches to meet their needs (IEEE P1856, 2012).

Although the above standards do not directly support the PHM process, some of their features can support diagnostic system maturing, as well as the establishment of predictive models used to achieve some PHM applications require operation, such as the maintenance of information collected in the active document can be used for data mining and data analysis in support of the diagnosis and maintenance system, also can be used to develop predictive models and systems.

3.3 HUMS related standards

3.3.1 SAE standards

SAE Aerospace propulsion system health management Technical Committee (E-32) has developed a series of standards for the HUMS system based on the Health and Usage Monitoring System Metrics, Monitoring Monitor: ARP 5783. It’s regulated the performance metrics of HUMS, the various airborne sensor interface specification, and data exchange standards to improve the interchange and availability.

3.3.2 FAA standards

FAA Advisory Circular AC 29C MG-15 is the rotorcraft health and usage monitoring systems (HUMS) airworthiness recommendations. It’s mainly used for the installation, certification and application of the HUMS, providing guide for the continuing airworthiness. It contains the definition, validation methods, installation, verification of trust, the continuing airworthiness directive and so on. With the design and development of various kinds of HUMS, it’s promising to be widely used. AC 29-2C MG-15 states that: “The certification of HUMS must address the complete process, from the source of data to the intervention action. There are three basic aspects for certification of HUMS applications: Installation, Credit Validation, and Instructions for Continued Airworthiness (ICA).”(Brian and Mark, 2007)

3.3.3 U.S. military

In 2010, on the basis of the SAE HUMS series of standards, U.S. Army issued the ADS-79C handbook, which is suit for all agencies and units of the U.S. Department of Defense. It described the condition-based maintenance system for the U.S. Army, defining the guide for Army aircraft systems and unmanned aerial vehicle systems to reach the CBM goals.

The main contents of the manual include: definitions, the general guidance (embedded diagnostics, fatigue damage monitoring, Regime recognition and fatigue damage remediation, the ground based equipment and information technology), specific guidance (technical displays and technical and information presentation, data acquisition, data manipulation, state detection, health assessments, prognostics assessments, advisory generation and so on.(U.S. Army, 2012).

3.4 IVHM relevant standards

SAE integrated vehicle health management (IVHM) Steering Group (HM-1) has been engaged in coordinating and integrating Health Management Standardisation in the SAE Technical Standards Programs. The ultimate benefit of this concept is for health management technologies to be coordinated on a vehicle level, transforming system data into operational support information, enabling maintenance actions to be optimized, improving readiness and availability, enhancing safety and reliability, extending life and leading to new product improvement. It will map and monitor IVHM relevant standards, practices and activities, identify future needs, and promote PHM and IVHM systems to key stakeholders. By roadmap IVHM standards, it will advance IVHM technologies through standards.

The steering group also provides a transparent standards development process, the details are as follows: (1) Proposed draft standard; (2) Development of the draft standard; (3) The draft standard is balloted, first by the committee, then by the Aerospace Council; (4) Required changes made and affirmation ballot; (5) Published by the SAE.

3.5 Contrast and comparison

Through the above analysis, it can be seen that various standardization organizations and related institutions have focused on the PHM standardization efforts. ISO is committed to PHM system standards development. And CM&D have already formed a relatively complete family of standards, providing a basic framework for PHM research and development. The SAE EHM series of standards and HUMS series of standards also gradually form a complete family of standards, and provide an important reference for the establishment of standards for IVHM. OSA-CBM and OSA-EAI standards in the MIMOSA organizations provide specific information expression under the framework of ISO 13374. IEEE standards focus on a general description of the tests and diagnostic information, and provide the specific guidance for the development of PHM framework of the electronic system. FAA Advisory Circular AC 29C MG-15 and ADS-79C guidance issued by the U.S. military can be seen as a refinement of the above standards and application guideline in the fielded system.

4. Suggestions

PHM standard is a newly development regions and needs to be further refined and studied, it's still a long way to go in standard maturation. While the various standardization organization have done a lot of related work above, the PHM/IVHM standard development is working in progress, there are some issues worth learning. The following will give some suggestions about the standard development.

4.1 Comprehensive Consideration

Prognostics and health management system is a multi-dimensional and multi-level complex systems, according to the technical content of the information process from the design process to the physical structure reflecting the connotation and extension of the PHM system in varying degrees. So when designing the typical PHM standard framework, it is necessary to give full consideration to the factors mentioned above. A typical PHM standard should or includes at least a main content of the following four aspects: general guideline, technical guideline, product design regulation, application and training, such as shown in Table 2.

Table 2: Main content of typical PHM standard

Document	Content
PHM General guideline	vocabulary，definition，terminology，metrics
PHM Technical guideline	test(algorithms，sensors，software，hardware); model analysis algorithms(used for fault identification and isolation, prognostics and remaining useful life estimation algorithms; software
PHM product design regulation	systems reliability(sensors and system), safety，
PHM application and training	Best practices，logistics，cost，management and training

4.2 Innovative consideration

Due to the lack of PHM fielded system, it is very important to learn from test and diagnostics standards. However, PHM is an evolving technology, and prognostics do have some difference with the test and diagnostics. So with the rapid development of next generation complex system, it must be based on independent innovation and development, providing guidance for conducting the research, design and application of PHM technology.

4.3 Systematic Consideration

PHM is an object-oriented technology, different the PHM systems typically have different performance requirements. While the relatively mature standards are targeted for a specific subsystem or specific applications, such as the ISO machine condition monitoring and diagnostics (CM&D) standards, SAE EHM and HUMS standards, and MIMOSA OSA-CBM standard and OSA-EAI standard.

In the Technical Horizon issued by U.S. Air Force, it’s specifically recommended that it should be focused on the Air Force military’s need in the PHM technology development the focus on technology development. So, the following progress should be maintained. First, PHM design and standard model should be developed at the same time. Targeting for the electromechanical systems, such as the engine and avionics systems, the primary version of the subsystem level PHM standards should be built. Second, with the cycle of application- authentication-refinement, the system level PHM standard, PHM standard design and performance specifications can gradually evolve from subsystem level to system-level model. Finally, the system-level PHM standards are summarized and formed into the establishment of the military or commercial standards for airborne system PHM design and verification.

5. Conclusion

PHM technology will be widely used in the next generation equipment, only through standardization can be able to have better interoperability to reduce costs and avoid repetitive tasks that may arise in the system design. This paper reviews the existing fault prognostics and health management standards and gives the in-depth analysis and comparison on the formulation of PHM standard. The fast development of PHM technology has already specifies the required data type, and how to identify and extend the existing test and diagnostic standards, is the next to be studied in depth, in order to cater to the development of PHM technology and standard design.

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