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A study of the development of a condition-based maintenance system for an LNG FPSO

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ABSTRACT

In general, the equipment failures or accidents of offshore plants during operation and maintenance (O&M) period cause catastrophic damage. Thus, it is necessary to undertake proactive maintenance in advance in order to avoid abnormal situations. Currently, owing to the emergence of information communication technologies (ICTs) and sensor technologies, it is possible to gather the health status data of important equipment and use this information for maintenance during the O&M period. It sheds light on condition-based maintenance (CBM) strategy. In this study, we introduce a case study on the development of a CBM system (CBMS) for an oil and gas offshore plant, i.e. liquefied natural gas floating production storage and offloading vessel (LNG FPSO). The study includes the introduction of the system architecture, main components, diagnostics and prognostics methods of the system, as well as a discussion of its implementation.

1. Introduction

In general, there have been various classifications of maintenance policies: corrective maintenance, breakdown maintenance, regular maintenance such as time-based preventive maintenance, etc. For more details on maintenance types, please refer to (Erbe et al., 2005). According to Ahmad and Kamaruddin (2012), maintenance strategy can be divided into corrective maintenance and preventive maintenance. The preventive maintenance has two kinds; time-based maintenance and condition-based maintenance (in similar terms, predictive maintenance, prognostics and health management (PHM); henceforth referred to as CBM). Among them, CBM has been recently highlighted. CBM can serve as a means of reducing the uncertainty of maintenance activities and is carried out according to the requirements indicated by the equipment condition (Peng et al., 2010). In recent decades, advancements in information communication technology (ICT) have accelerated growth in the CBM technology area by enabling network bandwidth, data collection and retrieval, data analysis, and decision support capabilities for large datasets of time-series data (Prajapati et al., 2012). Given this new environment, we can collect and use data on the status of equipment related to usage conditions, failures, and maintenance and service events. Using this information gives us new and challenging issues to improve the efficiency of equipment maintenance operations. We can identify and solve problems in advance before damage to equipment occurs by detecting abnormal states throughout monitoring, diagnosing abnormal types, predicting remaining useful life, and undertaking proactive maintenance, i.e. by engaging in CBM.

Capital-intensive industries such as offshore plants should be operated with high reliability and high levels of availability because the downtime due to system failure has a significant influence on the manufacturing activity and degree of safety. Because a critical failure or degradation of equipment can seriously damage the belief of customers regarding equipment reliability, maintenance enhancements to prevent failures or instances of degradation in advance should take precedence over other factors. Offshore plants have normally the long operation times. For example, an offshore wind power plant is usually operated 25 years (Münsterberg, 2016). Offshore plants have become more complex and vast. Thus, considerable costs and numerous efforts are required in the O&M phase of offshore plants. The maintenance of an offshore plant during its operation phase involves the provision of support and assessments of problems through inspections that target mechanical defects and corrosion. According to Heng et al. (2009), todays complex manufacturing systems such as on-shore and off-shore plants require highly sophisticated and costly maintenance policies. The oil majors and operating companies are paying increasingly more attention to the

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costs in the O&M phase. Increased O&M costs have become a main topic of conversation by those involved in asset integrity management (AIM) (Hwang, 2015).

Previously, conservative maintenance methods such as time-based preventive maintenance and breakdown maintenance were used during the O&M phase of an offshore plant. However, there is an increasing need to reduce operating costs through more proactive and advanced maintenance methods. One solution is CBM. CBM is currently being utilized in the petrochemical industry, with condition monitoring of both onshore and offshore oil and gas wells (Telford et al., 2011). CBM has thus become a very attractive method in the oil and gas industries. Thus far, efforts to enhance the performance of plant maintenance with CBM have drawn the attention of researchers; however, few studies have introduced instances of the CBM implementation in plant industries, and this is especially true for offshore plants. CBM remains a challenging area. Current approaches have limitations given the lack of detailed methods and validated models. Though data gathering systems are becoming relatively more mature, much work remains to be done on reliable and robust for monitoring, diagnostics, prognostics, and decision-making methods in relation to maintenance.

From 2013 to 2016, for implementing a CBM system (CBMS) for a liquefied natural gas floating production storage and offloading vessel (LNG FPSO), a Korean government funded research project has been carried out. An LNG FPSO is an offshore plant which delivers liquefied gas from a gas field to customers. According to Zhu et al. (2013), the demand for LNG FPSOs has greatly increased, and the demand for LNG-FPSO projects is predicted to continue to grow along with the increased demand for natural gas.

In this vein, this study focuses on the introduction of the case study of the CBMS development for an LNG FPSO. In the study, we introduce the system architecture, main components of CBMS, diagnostics and prognostics methods, and discussion issues required to implement the CBM system. The rest of this study is organized as follows. In the section entitled ‘Related works’, relevant previous studies are reviewed and their limitations are discussed. The section entitled ‘CBM system for an LNG FPSO’ introduces the system architecture, main components, diagnostics, and prognostics methods. The section ‘Discussion issues’ introduces the subjects to be considered when implementing the CBM system. Finally, this study is concluded with a summary and discussion of its contributions.

2. Related works

2.1. CBM study

In academia, there have been several previous works related to CBM concepts or frameworks. For example, the Machinery Information Management Open Systems Alliance (MIMOSA) designed what is known as the Open Standard Architecture Condition-Based Maintenance (OSA-CBM) approach. According to OSA-CBM (Thurston, 2001), there are seven layers required to implement the CBM concept (refer to Table 1): sensor modules, signal processing, condition monitoring, health assessments, prognostics, decision support, and presentation. Djurdjanovic et al. (2003) proposed a framework which encompassed a watchdog agent for predictive condition-based maintenance by undertaking multi-sensor assessments and predictions of machines or process performance levels. The concept of the watchdog agent based its degradation assessments on readings from multiple sensors that measure critical properties of the process or machinery under a networked and tether-free environment. The watchdog agent is an embedded system that uses algorithms which autonomously assess and predict performance degradations and the remaining lifetimes of machines and components. Bengtsson (2004) investigated standards and standardization proposals related to CBM and described several organizational aspects to be considered when determining whether to implement a CBM. Kothamasu et al. (2006) reviewed the philosophies and techniques of system health monitoring and prognostics. They surveyed health monitoring paradigms and looked into the details of health monitoring tools. In addition, they introduced previous case studies of system monitoring and control techniques. Furthermore, Groba et al. (2007) introduced the initial architecture for the CBM framework, as realized in a joint project with SAP research. They noted several aspects of CBM, including the identification, measurements, modeling and forecasting of indicators as well as considerations when making decisions. In addition, Prajapati et al. (2012) provided a brief overview of CBM with definitions of various terms; a history review; and a summary of recent developments, applications, and research challenges in the CBM domain. They also discussed how CBM could be used to optimize maintenance strategies and increase the feasibility and practicality of a CBM system. He and Ma (2012) reviewed the history of PHM and analyzed the main elements of a general PHM system, later proposing the PHM system architecture for electronic equipment. Chen et al. (2012) presented a technical framework of embedded diagnostics and prognostics (ED/EP) for complex mechanical systems as well as underlying opportunities and challenges. They also presented an example to demonstrate the implementation of the ED/EP concept. Recently, Shin and Jun (2015) addressed several aspects of the CBM approach, including definitions, related international standards, procedures, and techniques. Table 1 shows a comparison of various system layers for CBM implementation from previous works.

On the other hand, there have been numerous CBM works pertaining to specific domains. For example, Patel and Kamrani (1996) introduced a diagnosis and maintenance consultant system for industrial robots, called ROBODOC. They introduced the concepts of maintenance, artificial intelligence, and expert systems with a state-of-the-art review of diagnostic expert systems. They also provided the specifications and structure of ROBODOC, and explained the approaches used during its construction. Lee (1998) introduced a new methodology of predictive maintenance which relied on machinery

Table 1
Comparison of various system layers for CBM implementation.

ISO 13374	ISO 13374-1	OSA-CBM[a]	Jardine[b]	Chen[c]
- Data acquisition	- Data acquisition	- Sensor module	- Data acquisition	- Sensor& Data acquisition
	- Data manipulation	- Signal processing	- Data processing	
- Diagnostics	- State detection	- Condition monitor		- Condition monitor
	- Health assessment	- Health assessment		- Fault diagnostics
- Prognostics	- Prognostics assessment			- Predicting RUL[d]
- Presentation, actions	- Advisory generation	- Decision support	- Maintenance decision making	
- Postmortems		- Presentation		- Health management

[a] Thurston (2001).
[b] Jardine et al. (2006).
[c] Chen et al. (2012).
[d] Remaining Useful Life.