Reliability Engineering and System Safety 95 (2010) 786–796

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Development of an optimized condition-based maintenance system by data fusion and reliability-centered maintenance

Gang Niu [a,b,*], Bo-Suk Yang [b], Michael Pecht [a,c]

[a] Center for Prognostics and System Health Management, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong
[b] School of Mechanical Engineering, Pukyong National University, San 100, Yongdang-dong, Nam-gu, Busan 608-739, South Korea
[c] CALCE Electronic Products and Systems Consortium, University of Maryland, College Park, MD 20742, USA

ARTICLE INFO

Article history:
Received 5 August 2009
Received in revised form
24 February 2010
Accepted 28 February 2010
Available online 10 March 2010

Keywords:
Condition-based maintenance
Reliability-centered maintenance
Data fusion

ABSTRACT

Maintenance has gained in importance as a support function for ensuring equipment availability, quality products, on-time deliveries, and plant safety. Cost-effectiveness and accuracy are two basic criteria for good maintenance. Reducing maintenance cost can increase enterprise profit, while accurate maintenance action can sustain continuous and reliable operation of equipment. As instrumentation and information systems become cheaper and more reliable, condition-based maintenance becomes an important tool for running a plant or a factory. This paper presents a novel condition-based maintenance system that uses reliability-centered maintenance mechanism to optimize maintenance cost, and employs data fusion strategy for improving condition monitoring, health assessment, and prognostics. The proposed system is demonstrated by way of reasoning and case studies. The results show that optimized maintenance performance can be obtained with good generality.

1. Introduction

With the fast development of industry and the highly competitive international market, especially the areas of electronic products, nuclear power, automobile, shipbuilding, and aircraft, cost-effective and accurate maintenance shows increasing importance in improving plant production availability, reduce downtime cost, and enhance operating reliability.

Maintenance can be performed in two major types: corrective maintenance and preventive maintenance, as shown in Fig. 1. Corrective maintenance, similar to repair work, is undertaken after a breakdown or when obvious failure has been located. However, corrective maintenance at its best should be utilized only in non-critical areas where capital costs are small, consequences of failure are slight, no safety risks are immediate, and quick failure identification and rapid failure repair are possible [1].

Preventive maintenance is carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of functioning of an item (see SS-EN 13306). Preventive maintenance is divided into two types: predetermined maintenance and condition-based maintenance (CBM).

Predetermined maintenance is scheduled without the occurrence of any monitoring activities. The scheduling can be based on the number of hours in use, the number of times an item has been used, the number of kilometers the items has been used, according to prescribed dates, etc. CBM, on the contrary, does not use predetermined intervals and schedules. It monitors the condition of components and systems in order to determine a dynamic preventive schedule. A comparison of different maintenance approaches is shown in Table 1.

The open system architecture for CBM organization (OSA-CBM) [2] divides a standard CBM system into seven different layers, with technical modules solution as shown in Fig. 2. The core functions, corresponding to maintenance decisions among the architecture, can be summarized as condition monitoring, health assessment, and prognostics ranging from layer 3 to layer 5. Condition monitoring involves comparing on-line or off-line data with expected values; if necessary, it should be able to generate alerts based on preset operational limits. Health assessment determines if the health of the monitored component or system has degraded, and conducts fault diagnostics. The primary tasks of prognostics involve calculating the future health and estimating the remaining useful life (RUL).

In reality, however reliable and effective CBM faces some challenges. First, initiating CBM is costly. Often the cost of instrumentation can be quite large, especially if the goal is to monitor an equipment that is already installed. It is therefore important to decide whether the equipment is important enough

* Corresponding author. Tel.: +851 34425938.
E-mail address: gangniu@cityu.edu.hk (G. Niu).

0951-8320/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2010.02.016

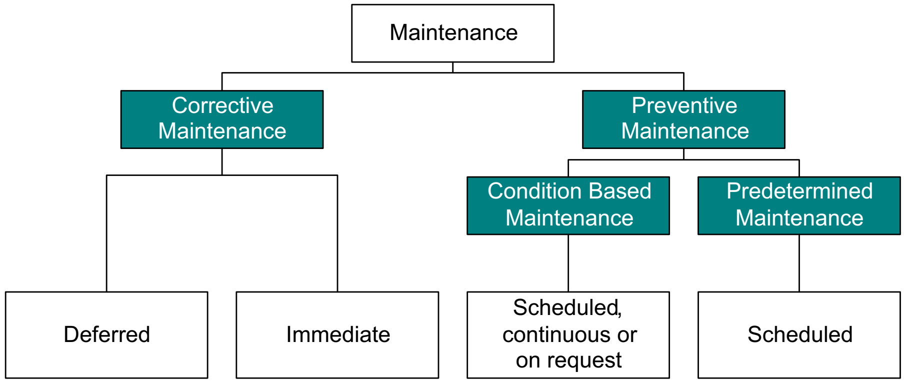

Fig. 1. Overview of different maintenance types.

Table 1
Range of maintenance approaches.

Category	Maintenance approaches			
Sub-category	Corrective	Preventive		
	Run-to-fail	Predetermined	Predictive	
	Fix when it breaks	Scheduled maintenance	Condition-based maintenance diagnostics	Condition-based maintenance prognostics
When scheduled	No scheduled maintenance	Maintenance based on a fixed time schedule for inspect, repair, and overhaul	Maintenance based on current condition	Maintenance based on forecasting of remaining equipment life
Why scheduled	N/A	Intolerable failure effect and possibility of preventing the failure effect through scheduled overhaul or replacement	Maintenance scheduled based on evidence of needs	Maintenance need is projected as probable within mission time
How scheduled	N/A	Based on the useful life of the component forecasted during design and updated through experience	Continuous collection of condition monitoring data	Forecasting of remaining equipment life based on actual stress loading
Kind of prediction	None	None	On and off-line, near real-time trend analysis	On and off-line, real-time trend analysis

to justify the investment. Second, while the goal of CBM is accurate maintenance, it is not always easy to achieve due to variables such as complexity of the environment, the inner structure of equipment, obscure failure mechanisms, etc.

For cost-effective maintenance, CBM is best implemented under an advanced maintenance management mechanism. When the functions of the component and its importance need to be considered at the same time, reliability-centered maintenance (RCM) seems an appropriate choice [3]. Usually, the aim of RCM is to maximize results with regard to system reliability or outage cost reduction [4].

For accurate maintenance, data fusion techniques containing signal- level fusion, feature-level fusion, and decision-level fusion are suggested [5]. Applying fusion techniques in engineering practice has been receiving increasing attentions in recent years. Especially, with the rapid progress of advanced sensor and signal processing technologies, fusing large mutual informations becomes possible. These developments are expected to bring about accurate CBM. A number of fusion techniques have been identified for improving accuracy of machinery faults diagnostics, for example, engine fault diagnostics using Dempster–Shafer evidence theory [6], electric motor fault diagnostics using multi-agent fusion [7], tank reactor diagnostics using multiple neural networks fusion [8], and cutting tool diagnostics using fuzzy fusion [9]. However, the applications of data fusion technology in machinery condition monitoring and prognostics have not received sufficient attentions yet, and relevant cases are rare.

This paper develops a novel CBM system that integrates data fusion strategy with traditional CBM within the architecture of RCM management. Using data fusion strategy can increase maintenance accuracy, while RCM can scheme CBM with optimal cost benefits. The remaining parts of this paper are organized as follows. Section 2 briefly introduces background material of CBM, RCM, and data fusion. In Section 3, the proposed system is introduced in detail; the basic contents of each part are explained. Section 4 describes two practical cases involving condition monitoring, diagnostics, and prognostics using data fusion strategy to demonstrate effects of the proposed system. At last, conclusions are summarized in Section 5.

2. Description of relevant background knowledge

This section covers a brief introduction of the relevant knowledge used in the proposed system. The materials contain the development of CBM, RCM, and data-fusion techniques.

2.1. Development of CBM

Traditional CBM is a maintenance program that recommends maintenance actions based on the information collected through condition monitoring. CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of abnormal behaviors of a physical asset [10].