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Study and application of Reliability-centered Maintenance considering Radical Maintenance

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A B S T R A C T

Radical Maintenance (RM) takes the root causes of failures as executive objects to make maintenance decisions. A Root Cause Analysis (RCA) is carried out on the function failure of equipment to perform RM and to create a maintenance plan using the combined methods of Failure Mode, Effects and Criticality Analysis (FMECA), and Fault Tree Analysis (FTA). Evaluation criteria and matrixes of criticality are used to evaluate the criticality level of failure modes. Moreover, Minimum Cut Sets (MCS) and importance calculation are applied to analyze the fault tree quantitatively. Based on our research, the concept and the analysis process of Reliability-centered Maintenance (RCM) considering RM are proposed and then applied to an actual engineering project in the petrochemical industry. The results of the application are presented through a maintenance strategy based on the project analysis by establishing the evaluation criteria and matrixes of criticality for petrochemical rotating machines and a fault tree of compressor vibrations. The direct causes of the induction of vibration faults in rotating machinery are classified according to the fault mechanism and frequency domain features in this paper. The research shows that using RM in the traditional RCM can help assign maintenance resources rationally and improve the quality of maintenance strategies.

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1. Introduction

Reliability-centered Maintenance (RCM) analyzes the functions and failures of a system and identifies the consequences of these failures to implement preventive measures using a standardized logical resolution procedure (Moubray, 1997). Traditional RCM focuses on the function failures of a system. It determines a maintenance plan by considering failure probability statistics and consequences; the analysis does not involve in-depth research to identify the failure mechanism and the real causes of function failures. Radical Maintenance (RM), on the other hand, considers the fundamental factors that cause failures and investigates the elements affecting the reliability and safety of a system and equipment. In this article, Failure Mode, Effects and Criticality Analysis (FMECA), and Fault Tree Analysis (FTA) were used to implement RCA on a system failure to perform RM, which was then combined with RCM analysis to improve the quality of maintenance strategies. The proposed theory and analysis procedure of RCM considering RM were applied to an ethylene plant in China. An ethylene refrigerant compressor was taken as a demonstration model, and its failure modes were studied to conduct CA and establish a fault tree.

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2. Concept of RM

As a type of Proactive Maintenance (PM), RM involves the detection and prediction of the root causes of failures and then takes measures to eliminate them or the conditions that induce them (Gao, 2005). The executive object of RM is to identify the root cause, which is the basic factor that may induce failures in the main body of the fault cause, such as the components of a machine. For example, a steam turbine with intense vibrations could be diagnosed as having an unbalanced rotor. Conventional maintenance involves conducting field dynamic balancing or dismembering the unit and transporting the rotor to a factory to improve its dynamic balance. On the other hand, RM further investigates the reasons leading to rotor imbalance. If the fault is due to rotor scaling, for example, flushing the rotor under low speeds can solve the imbalance. However, a better method is to monitor and govern the quality of water of the boiler to avoid the scaling of the rotor by steam generated from the boiler. The RM involves any type, or a combination, of preventive maintenance works, differing only in specific objects (Cheng, Jia, Zhao, Jia, & Gan, 2003).

Generally, RM is not considered for all equipment because the latter either has little effect on the system and production or does not require high reliability. It is only for important equipment that RM is implemented to analyze the root causes of fault, thereby ensuring reliability and safety, as well as the maximization of their service life, from root cause generation to function failure occurrence (Gan, Cheng, & Jia, 2004). Moreover, RM execution requires corresponding techniques for monitoring and detection; relevant maintenance jobs are also indispensable. Therefore, labor and materials are necessary for conducting RM. The relationship between investments and benefits should be considered in determining whether or not RM must be executed. All function failures do not have effective root causes, as some are induced by human factors or periodic exhaustion. Although root causes occur in this type of failure, they do not play a substantive role in the maintenance method. In this situation, conventional maintenance should be carried out by considering the function failures in the formulation of the service plan.

3. Concepts and the analysis procedure of RCM considering RM

3.1. Execution of RM

Consisting of a series of structural problem-solving methods aimed at methodically identifying the root causes of failure, RCA execution corrects and eliminates root causes that may minimize failure recurrences instead of simply focusing on obvious failure symptoms (Anthony, 2004; Cameron, Holmes, & Chen, 2008). Its basic elements include material, equipment, environment, management, and operating method, among others. Various RCA techniques include Five Whys, Failure Mode and Effects Analysis (FMEA), FTA, Pareto Analysis, Bayesian Inference, and the Ishikawa Diagram.

Of these, FMEA is a type of systematic reliability analysis that determines all the possible failure modes of a product from bottom to top and ensures the influence of the fault on the system (Cai & Wu, 2004). This is followed by Criticality Analysis (CA) (Guo, Gao, Yang, & Kang, 2009), which aims to classify every failure mode determined by FMEA according to the associated influence of criticality level and number/probability. Both techniques are unified in this paper, thereby forming FMECA. FTA is a deductive method that assumes system failures from top to bottom and analyzes the possible reasons for a failure. As such, a combination of the complementary FMECA and FTA techniques has been adopted to conduct RCA. Here, the highly critical failure modes are captured and used as the FTA objects (top event). An inverted tree diagram illustrates the deduction of direct fault causes from top to bottom, showing the logical relationship between hardware/software factors (various bottom events) and system failures (top event). The fault factors that may exist in the system include component failure, environmental impact, human mistakes, and procedure handling. After establishing the fault tree, the combination modes and spread paths affecting the top event by each bottom event are qualitatively analyzed to identify the possible failure modes of the system. And the degree of the effect is calculated quantitatively to obtain the probability of the system failure.

All Minimum Cut Sets (MCS) are determined to show the weakest parts of the system. Many MCS and elementary events in an FTA exist because modern systems have become larger and increasingly complicated. In this paper, root causes were found from FTA elementary events according to the historical data of the equipment and the situation of the facilities in the same industry and type. The elementary events, which associated with high value in the importance calculation (Institute of integrated security engineering research, 1989) by using frequency data, were considered to be the most important to the system. Therefore, the maintenance measures must first be taken for them.

3.2. Analysis procedure of RCM considering RM

Reliability-Centered Intelligent Maintenance System (RCIMS) is used based on a system of monitoring and detection by applying the concept of RCM and RM to set up a self-organizing mechanism. The mechanism includes users, maintenance plan management, spare parts management, and the maintenance department among others.

Fig. 1 shows the flow chart of the RCIMS, which consists of six parts. The first part involves basic information collection, which includes information on the related equipment, process fluids, and maintenance records. The second part involves system division. The production system can be divided into several interconnected but relatively independent sub-systems. The third part has to do with an importance evaluation of the facilities. According to the evaluation criteria of importance, the facilities are divided into three risk levels, namely, high, medium, and low. The fourth part involves FMECA, which aims to study facilities associated with high and medium risks and then to analyze their failure modes and causes. Here, CA is conducted for the failure modes. The fifth part has to do with FTA, which analyzes failure modes associated with high and medium-criticality. The sixth part involves maintenance strategy formulation. Against the failure modes, corresponding maintenance strategies are proposed considering the fault causes. The three anterior parts are the same as the flow chart of traditional

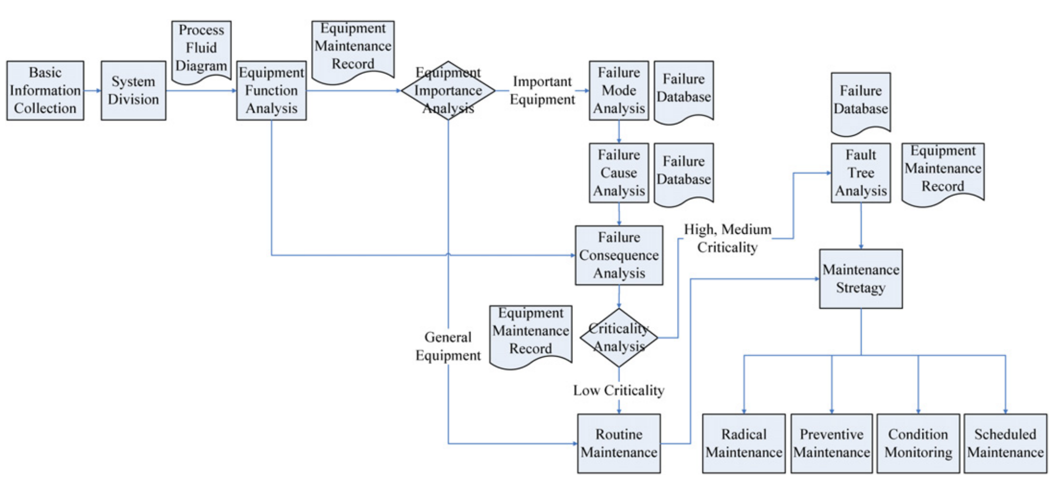

Fig. 1. The flow chart of RCIMS.

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