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APPLICATION OF RISK-BASED MAINTENANCE WITH LIFE AND FINANCIAL ASSESSMENT ON FOSSIL-FIRED POWER PLANTS

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ABSTRACT

A risk-based maintenance (RBM) technique has been generated to optimize inspection and maintenance plans for fossil-fired power plants which will be deregulated in Japan. In the present study, technological advances and problems are considered that have resulted from the application of the RBM to actual boiler plants with operating times exceeding 100,000 hours. Risk is defined as the product of the likelihood of damage in plant components by the consequence due to failure of the components or system. The present study found that the RBM is a useful decision tool for determining inspection priority, mitigation of undesirable risk, extension of the inspection period, and other improvements in maintenance practice. At the same time, serious potential problems are brought out.

KEYWORDS

Risk-based maintenance, Fossil-fired power plant, Inspection, Likelihood, Consequence, Residual life prediction, Damage, High temperature component

INTRODUCTION

Risk-based maintenance (RBM) provides strategies for optimizing safety as well as maintenance costs for degraded components of boiler plants that have accumulated operating times exceeding 100,000 hours. The maintenance strategy consists of plans for inspections, repair, refurbishment, and replacement based on the risk assessment. The risk is defined as the product of likelihood of failure by the consequence severity. In Europe and the United States, major oil companies have already implemented RBI (Risk-based inspection) technique several years ago. As a result, several guidelines [1,2,3,4] have been published for RBI/RBM techniques. Some papers [5,6,7] were published on practical use of RBI/RBM to petrochemical plants and fossil-fired power plants. Furthermore, the practical guideline [8,9] and the standard [10] for nuclear power plants have also been published. In Japan, the RBI/RBM has lately attracted considerable attention as a new technique for maintenance planning of fossil-fired power and petrochemical plants that will be deregulated. In this study, the RBM technique has been provided as a systematic analysis of qualitative and semi-quantitative judgments for failure likelihood and consequence by calculating the risk ranking. As results of the application of RBM intended for actual boiler plants with accumulated operating times exceeding 100,000 hours, many advances and problems of the technique are considered to frame optimized risk scenarios.

PROCEDURE AND RESULTS OF RBM INTENDED FOR THE 600MW BOILER PLANT

Procedure of RBM

The overall procedure of RBM is shown in Fig.1.

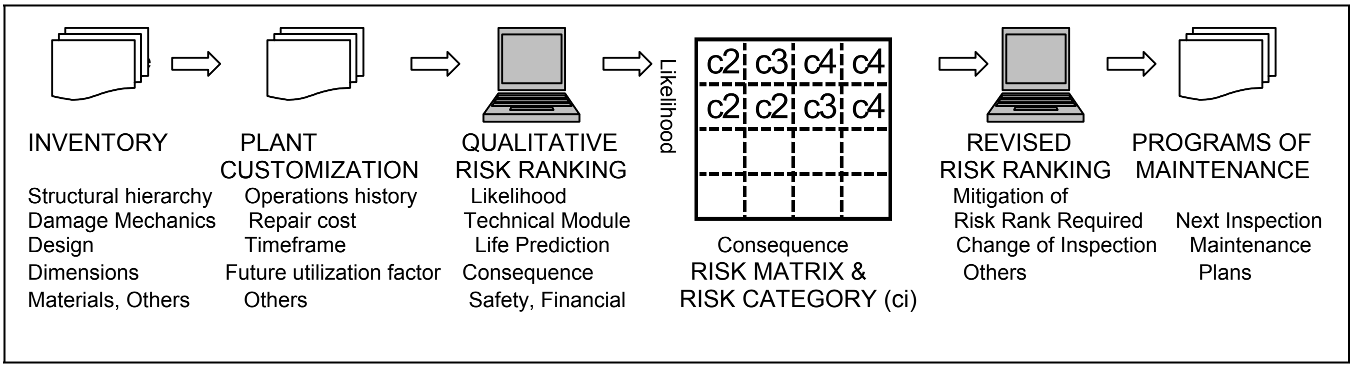


Figure 1: Procedure of RBM

Inventory and plant customization

The first step is to classify components and locations of a plant with a hierarchical structure in terms of the risk assessment and to define the risk of components and locations in the plant considering the operating conditions in terms of a standard rule. The aim of inventory is to include all relevant components, and identify all potential degradation locations. Table 1 shows the reheater system that consists of 8 components such as header, tube and so on in the 600MW boiler plant. Furthermore, those are divided into 43 locations as assessed locations with collection of each material specification, dimension, design data, and operating history and so on. Number of all locations in the 600MW boiler plant is about 500. Damage mechanisms to be fear at each location were defined for the risk assessment with inspection records and the residual life assessment data concerning the operating history.

TABLE 1

INVENTORY FOR THE ESTIMATED REHEATER SYSTEM IN THE 600MW BOILER PLANT

Unit	System	Component	Location (Number of Locations)
K- Power Plant No. N-Boiler	Reheater	Reheat inlet Header	Shell weld etc. (7)
		RH tube-Inlet short tube	Tube etc. (2)
		RH tube-Horizontal Lower Stage	Tube, Oval Tie Lugs etc.(4)
		RH tube-Horizontal Middle Stage	Tube, Oval Tie Lugs etc. (5)
		RH tube-Horizontal Upper Stage	Tube, Oval Tie Lugs etc. (4)
		Tube-Vertical Upper Stage	Tube (SUS321, STBA24) etc. (6)
		Tube-Unheated Region	RH outlet tube etc. (7)
		Reheat Outlet Header	Shell Seam and Circ weld etc. (8)
Total Number		8 Components	43 Locations

Table 2 shows the plant customization included the operating condition for the estimated boiler. The assessment time is defined as the number of operating hours expected to be accumulated up to the next but one inspection. In order to demonstrate the utility of the method for validation of extension to the inspection period, the risk assessment assuming that an extension of inspection period from 24 months to 48 months, can be carried out in this study.

TABLE 2

CUSTOMIZATION FOR THE ESTIMATED REHEATER SYSTEM OF 600MW BOILER

Item	Subject	
Operating history	Boiler On-Load	about 117,000 hours
	total number of hot starts, warm starts, cold starts	about 600 times
Assumed Current Inspection Plan	Outage Frequency	24 months
	Expected Utilization	70 %
	Service hours at next outage	about 137,000 hours
Assumed Revised Inspection Plan	Outage Frequency	48 months
	Expected Utilization	70 %
	Service hours at next outage	over 150,000 hours
Cost of one day outage		about ¥ 8 million

Risk Assessment

As mentioned before, the risk is defined as the product of likelihood of failure and the consequence. Likelihood of failure ($L=F$ x M) can be derived from multiplication of failure frequency (F) from the database based on general failure cases or personal experiences by a revised factor (M). The revised factor M can be obtained from considering factors of inspection program (monitoring), degradation of materials, conditions of construction, and operating conditions of the past and the future by following each module for judgment. The factor M needs to have weighting factors in terms of their likelihood. This idea is according to standard ideas in RBI/RBM through API [1,2] and ASME [3,4] guidelines. The consequence of failure can be calculated from safety consequence (injury or death) and financial consequence (plant outage, repair cost, and injury or death of plant operators). Financial consequence is usually expressed by cost or money.

Skilled engineers on the design, the maintenance, operating, inspection, metallurgy, and structural strength perform the risk assessment with the systematical judgment procedure under the following two steps.

Primary qualitative risk category of each location is decided in the timeframe of 24 months assumed as a current inspection period. Any potential degradation mechanism that can cause component failure is assessed using the qualitative / semi-quantitative risk ranking (QRR) procedure. This involved assessing the likelihood of failure, and separately, the consequence of failure of that specific location, by the damage mechanism. Safety risk ranking and financial risk ranking are both determined, using the risk matrix as shown in Fig.1. Following the risk category plotted in the matrix, actions to reduce the risk are required. The risk category and required actions are expressed as shown in Table 3.

TABLE 3

REQUIRED ACTIONS FOLLOWING THE RISK CATEGORYS WITHIN THE TIMESCALE

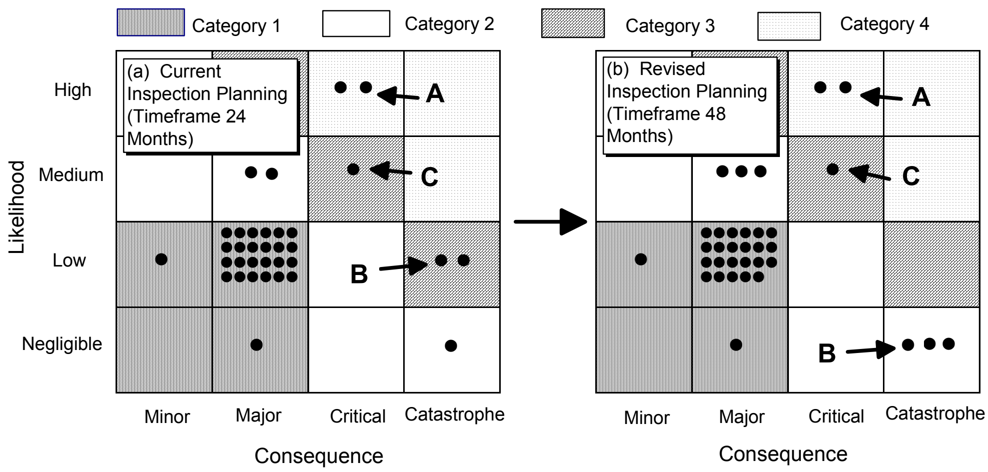
Risk Category (Fig.1)		Required Actions
Category 1	Acceptable	No inspection or other actions are required, considered unless to safety national legislative requirements
Category 2	Acceptable with controls	Define and implement an appropriate revised inspection, assessment strategy to support risk ranking judgment
Category 3	Undesirable	Mitigate to Risk Category 1 or 2 within the timescale of the next overhaul, in the following actions (1) Improved inspection procedures (2) Improve operating practices or controls (3) On-line plant monitoring (4) Engineering measures to mitigate consequence
Category 4	Unacceptable	Mitigate immediately to Risk Category 1 or 2 as above

Assessed locations with the high risk (Category 3 or Category 4) are considered to reduce the risk to Category 1 or 2 by effective inspection methods or actions. Consequently, necessary actions are determined to obtain “Acceptable or Acceptable with controls” conditions.

In the next step, revised qualitative risk ranking (RQRR) is carried out. In this study, the mitigation of the risk category with actions according to Table 3 is considered. At the same time, the risk change due to extension of the inspection period of 24 months to 48 months is assessed.

Results and consideration on RBM for 600MW boiler plant

Figure 2 shows the plots of risk matrices for assessment results on typical locations. Fig. 2(a) describes the risk ranking within the current inspection requirement (every two years for regular inspection). Most of the components in the matrix were ranked as "Category 1; Acceptable". Fig. 2(b) shows results of the revised risk ranking in assumption of the inspection period of every four years. Results shown in Fig. 2(b) expressed the effects of both extension of inspection period and the required actions considered in revised risk ranking (RQRR).



(a) Current Inspection Planning (b) Revised Inspection Planning

Figure 2: Examples of RBM assessment results on the reheater system of 600MW boiler

As shown in Fig.2 (b), almost of the locations were plotted in the "Category 1; Acceptable", even though extension of the inspection period from two years to four years was assumed. Risk at the location (B) in the figure was mitigated by the revised risk assessment. High risk at some locations (A, C) expresses not to change the Category after considering required actions or improvement of the inspection.

Details of assessment at the high-risk locations (A, B, and C in Fig. 2) are described as follows.

Location (A); Reheater Outlet Tube (STBA24 unheated tube) – thinning of wall

The residual life at this location was assessed to be just over two years by consideration of thinning rate at the tube wall due to both oxidation and calculating the creep life. Therefore, the result indicated that the risk was too high for the likelihood of failure. Although the safety consequence was "Negligible", the financial consequence was "High" according to the failure. Consequently, final risk assessment of the location was "Category 4; Unacceptable". In the revised risk assessment (RQRR) to clarify the problem, any solutions or actions to reduce the risk could not been found. Finally, urgent replacement of the component was decided as the only action to reduce the risk. This result was in consistent with the actual action that the component had been replaced at an outage recently.

Location (B); Reheater Outlet Header - creep damage of seam weld

At the location, initiation and growth of internal cracks due to circumferential stress have been reported in abroad. According to experiences in the oversea plant, the likelihood at the location should be ranked as "High". In Japan, there is, however, no experience of the failure at the location. Consequently, the risk rank as "Low" was considered. Furthermore, the current inspection methods of PT (Dye Penetrant Test) or MT (Magnet Particle Test) were not enough to assess the internal damage of the header wall. The financial consequence was ranked as "Catastrophe". According to this assessment, the risk of the component was assessed as "Category 3; Undesirable". In the revised risk assessment (RQRR), the risk ranking was reduced by improvement of the inspection technique, using UT (Ultrasonic Test, TOFD method) to be possible to detect the internal damage. Finally, the action allowed the risk to be reduced to “Category 2; Acceptable with Controls”.

Location(C); Reheater Outlet Vertical Tube - damage by oxidation and creep

At the location, the excessive wall-thinning rate has been found recently with continuous periodic measurement of wall thickness by the ultrasonic equipment. Although problems in terms of inspection methods and locations of measurement concerning the reason of excessive thinning were considered, it was not possible to reduce the risk from “Category 3; Undesirable” to “Category 2; Acceptable with Controls” by any actions. Therefore, the replacement should be considered. Consequently, the obtained result in the assessment was consistent with the actual replacement of the component that had been replaced at a outage recently the same as reheater outlet tube plotted as A in Fig.2.

ADVANDAGES AND FUTURE TASKS OF RBM

As the results of RBM assessment, many advantages were found in the maintenance planning as follows.

(1) Covering all locations of a unit concerning the damage by inventory. (2) Effective information handed down from experiences of the experts in consistence with RBM results. (3) Improvement of the safety assessment with global standards and damage mechanisms (4) Decision making of maintenance items among several units of the plant based on the priorities decided by RBM. (5) Clarifying the reasons of inspections and repairs for reaching a consensus among the maintenance department, the investment department in the plant customer, public inspection organizations and others. (6) Omitting the current inspections at locations assessed as low-risk categories. (7) Smooth transition of inspection record stored by papers to the electric system. (8) Others.

At the same time, future tasks are justified on the basis of development of risk scenarios. The consequence scenarios concerning financial factors should include systematically the assets assessment due to the scale of power generation, the type of usage of the boiler (utility or industrial), financial strategy of the plant customer, and others as shown in Fig. 3. The quantitative judgment system that could reflect the subjective probability of expert opinions and experiences with the numerical data of the residual life assessment should be developed in the likelihood ranking.

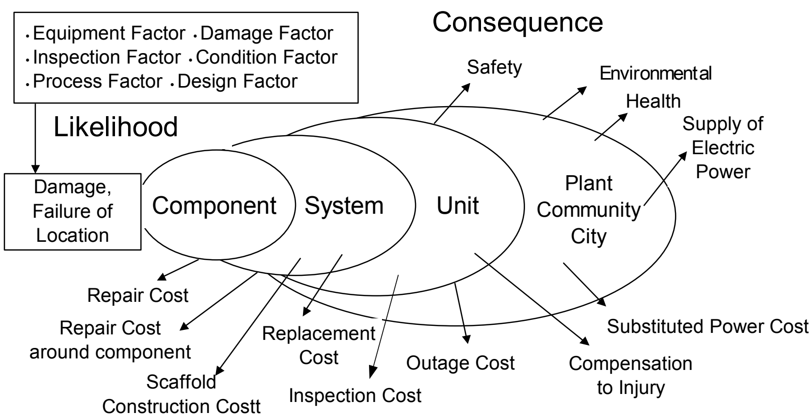


Figure 3: Development of consequence scenario

CONCLUSIONS

Risk based maintenance (RBM) technique has been applied to the actual fossil-fired power plants. As results, it is concluded that many advantages for the maintenance planning is expected. The

RBM could be attracted considerable attention as a new technique for maintenance planning of fossil-fired power plants that will be deregulated in Japan. At the same time, the systematic and quantitative method for framing risk scenarios such as the assets assessment should be developed. Valuable databases of failure cases and knowledge-based information by expert's experiences are also required to apply the RBM effectively to various plants and structural components.

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