Maintenance Scheduling Method of Equipments Based on Deterioration Prediction and Reliability

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Abstract

In recent years, various kinds of maintenance jobs of equipments exist for the purpose of maintaining reliability for stable operation of equipments, improving efficiency as well as reducing total cost. However, maintenance jobs are usually carried out based on experience of experts and/or regulations, in some cases, without evaluation based on quantitative measurement of deterioration nor explicit decision criterion of deterioration. In this research, decision making method of maintenance scheduling, which is suitable for various kinds of equipments, was proposed. The proposed method was applied to analysis on the judgment of replacement and/or reparation of equipments in a thermal power station.

1. Introduction

Maintenance is important work for various systems in order to keep stable operation of the systems. Frequent maintenance gives high reliability of the systems, but maintenance cost will be increased. On the other hand, malfunction of the systems caused by lack of maintenance gives serious problems. Hence, maintenance will be decided on the balance of cost and reliability.

Many researches of maintenance problems have been investigated for various problems[1]-[11]. The authors have also proposed maintenance decision making method for timely washing of substation insulators[12, 13, 14].

In this research, the previously proposed decision-making method of maintenance was generalized for various kinds of equipments[17, 18, 19]. The proposed method can be adopted for any kinds of equipments due to its general consideration of the judgment of replacement and reparation.

2. Method

2.1 Outline of Maintenance Scheduling

Purpose of maintenance scheduling is to keep the system reliability and reduce the total cost including maintenance, by

avoiding excess repair and replacement. Deterioration prediction of the system is introduced for maintenance scheduling based on the deterioration prediction model and the reliability is taken into account by the confidence interval of prediction.

Figure 1 shows the flow chart of the proposed maintenance scheduling method. The proposed maintenance scheduling method is done by following steps.

1. Deterioration of the system occurs.
2. Deterioration of the system is measured as y_t (deterioration measurement value).
3. Deterioration of the system is evaluated from the deterioration measurement value as d_t (deterioration management value).
4. Future deterioration of the system is predicted by the deterioration prediction model as $\hat{d}_{t+1}$.
5. Reliability of the predicted deterioration management

Figure 1: Flow chart of the proposed maintenance scheduling method

value $\hat{d}_{t+1}$ is evaluated by the confidential interval as $\hat{d}_{t+1} + r\sigma_{t+1}$.

6. Maintenance is decided by comparing the confidential interval $\hat{d}_{t+1} + r\sigma_{t+1}$ and the threshold value λ .

The each step of the proposed maintenance scheduling method is explained as following subsections.

2.2 Unification of Data Format

Measurement data for maintenance are usually acquired with various formats, which depend on property of equipments and/or vendor of equipments. To determine maintenance decision making of various equipments in a unified method, data sets acquired from various equipments are converted into the same format[15, 16]. The identically formatted data is referred as processed data for analysis. Figure 2 shows the unified format of processed data for analysis. The upper table in Fig. 2 shows the format of the processed data for analysis and the lower table shows an example of actual processed data for analysis. In the proposed maintenance scheduling method, the processed data for analysis are used as a unified format of the acquired data.

2.3 Deterioration Evaluation Based on Deterioration Management Values

Deterioration of equipments is observed from measurement data. Evaluation of deterioration, however, depends on the respective equipments. Measurement data y_t at time t relevant to deterioration is converted into deterioration management value d_t as

$$d_t = f(y_t). \quad (1)$$

2.4 Prediction of Deterioration

(a) Deterioration Related Parameters

To construct a deterioration prediction model, parameters which affect to the deterioration management value must be known. The parameters which affect to the deterioration of the equipments and are also depend on time t such as time itself, are defined by deterioration parameters p_t as

$$p_t = \{p_t^1, p_t^2, p_t^3, \dots\}. \quad (2)$$

(b) Data Classification by Deterioration Factors

Factors which are related to the deterioration and are independent in time t such as measurement points, are defined by deterioration factors c as

$$c = \{c^1, c^2, c^3, \dots\}. \quad (3)$$

In some cases, the accuracy of the deterioration prediction

model depends on the classification by the deterioration factors. Classification is adopted if the classified models can predict accurately compared with the non-classified models. The accuracy of the model can be evaluated by the standard deviation. If the standard deviation of the classified model $\sigma(C)$ ($C \subseteq c$) is much less than that of the non-classified model σ

$$\sigma(C) \ll \sigma \quad (4)$$

the classified model is applied. Here C means a classification of deterioration factor c .

(c) Deterioration Prediction Model

Deterioration prediction model is constructed for each deterioration factor c^i . The model is defined by the function of the past deterioration management values ($d_t(c^i), d_{t-1}(c^i), d_{t-2}(c^i), \dots$) and the past deterioration parameters ($p_t(c^i), p_{t-1}(c^i), p_{t-2}(c^i), \dots$) as

$$\hat{d}_{t+1}(c^i) = g(d_t(c^i), d_{t-1}(c^i), d_{t-2}(c^i), \dots, p_{t+1}(c^i), p_t(c^i), p_{t-1}(c^i), \dots) \quad (5)$$

2.5 Decision Making Rule for Maintenance Scheduling

The standard deviation of the prediction

$$\sigma_{t+1}(C) = h(\hat{d}_t(c^j), \hat{d}_{t-1}(c^j), \hat{d}_{t-2}(c^j), \dots, d_t(c^j), d_{t-1}(c^j), d_{t-2}(c^j), \dots, p_{t+1}(c^j), p_t(c^j), p_{t-1}(c^j), \dots), \text{ where } c^j \in C \quad (6)$$

is used for the accuracy of the prediction. Deterioration prediction value $\hat{d}_{t+1}(c^i)$ is assumed to have some probability distribution and the confidence interval for reliability R is derived as

$$P\left(\frac{|d_{t+1}(c^i) - \hat{d}_{t+1}(c^i)|}{\sigma_{t+1}(C)} > r\right) = R. \quad (7)$$

Finally, repair of the equipments is proceeded if the maximum value of the confidence interval exceeds a threshold value λ as

$$\begin{aligned} \hat{d}_{t+1}(c^i) + r\sigma_{t+1}(c^i) &\geq \lambda && \text{(deterioration increase case)} \\ \hat{d}_{t+1}(c^i) - r\sigma_{t+1}(c^i) &\leq \lambda && \text{(deterioration decrease case)} \end{aligned} \quad (8)$$

where the threshold value λ is given by respective equipment from its manufacturer through reliability and safety.

Figure 3 shows decision making rule for deterioration increase case.

		Address data C (Address of measurement point, Maintenance items, etc)
		Design data(Example:Threshold λ) (Data determined by each address, independent of time)
Time $t(1,2,3,\dots)$	Operation data P_t (Operation, time, Weather condition, etc,)	Data (Example: y_t) (Measurement value, Detection position, property, etc)
		<div style="text-align: center;"> $\bullet$ $\bullet$ $\bullet$ </div>

i									
j									
k									
l		1	2	3	4	5	6	7	8
t	Δt	$d(1,1,1,1)$	$d(1,1,1,2)$	$d(1,1,1,3)$	$d(1,1,1,4)$	$d(1,1,1,5)$	$d(1,1,1,6)$	$d(1,1,1,7)$	$d(1,1,1,8)$
1	9631	6.5	6.4	6.4	6.4	6.3	6.4	6.4	6.4
2	5518	6.3	6.2	6.2	6.2	6.1	6.2	6.2	6.2
3	6748	6.2	6.0	6.0	6.1	6.0	6.2	6.0	6.2
4	11258	6.2	6.0	6.0	6.1	6.0	6.2	6.0	6.2
5	11319	6.2	6.0	6.0	6.1	6.0	6.2	6.0	6.0
6	11220	6.1	5.9	5.9	6.0	5.9	5.9	5.9	6.0
7	11823	6.1	5.9	5.8	6.0	5.8	5.9	5.9	5.8
8	13005	6.1	5.9	5.8	6.0	5.8	5.9	5.8	5.8

Figure 2: Format of the processed data for analysis in order to determine maintenance decision making of various equipments in a unified method

3. Application to Boiler Tube in Thermal Power Station 3.1 Maintenance Scheduling

The proposed maintenance scheduling method was applied to boiler tube maintenance in a thermal power station.

Figure 3: Rule for decision making of the maintenance (deterioration increase case)

Figure 4 shows the boiler outline in a thermal power station and its measurement points. Thickness of boiler tubes gets thinner with time. If the tubes get ripped open, the boiler suffers serious damage. Hence, the thinned tube must be repaired before broken. Deterioration of boiler tube is evaluated by its thickness. Thickness of tube is measured periodically. Data were acquired from Matsuura thermal power station in Kyushu Electric Power Co. The total data number of boiler tubes were 9504 (4×22×3×36) per one measurement time, and the total measurement times were 7.

Measurement data of the boiler tube is thickness y_t and the deterioration management value d_t in eq.(1) is the thickness itself as

d_t = y_t. (9)

Deterioration related parameter p_t in (2) for boiler tube is the time interval Δt from the previous measurement time $t - 1$ to the present measurement time t as

p_t = {Δt}. (10)

Data classification is the deslagger placement layer i , deslagger number j , measurement layer k and measurement tube position l . Hence, the classification in (3) is expressed by

$$c = \{i, j, k, l\}. \quad (11)$$

where

$$\begin{aligned} i &= 1, 2, \dots, I(I = 4) \\ j &= 1, 2, \dots, J(J = 22) \\ k &= 1, 2, \dots, K(K = 3) \\ l &= 1, 2, \dots, L(L = 36). \end{aligned}$$

For the boiler tube case, the deterioration tendency depends on the measurement tube position l and the other deterioration factors i, j, k had little effects to the deterioration tendency, the deslagger affects to the boiler tube deterioration. Hence, the classification described in section (b) for the measurement tube position l was adopted as $C^T = \{\{1\}, \{2\}, \dots, \{21\}, \{22, 23, \dots, 32\}, \{33\}, \dots, \{36\}\}$. One deterioration model for the boiler tube position $l \in \{22, 23, \dots, 32\}$ was constructed and each deterioration model for the other tube position $l \notin \{22, 23, \dots, 32\}$ were constructed, respectively. The deterioration model where the deterioration was progressed in proportion with time interval was introduced. The predicted deterioration management value was calculated by

$$\hat{d}_{t+1}(i, j, k, l) = d_t(i, j, k, l) + v(C)\Delta t_{t+1} \quad (l \in C) \quad (12)$$

where $C \in C^T$ and the standard deviation $\sigma_{t+1}(C)$ was calculated as

$$\sigma_{t+1}(C) = \Delta t_{t+1} \sqrt{\frac{\sum_{u=1}^t \sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l \in C} \{e_u(i, j, k, l)\}^2}{t I J K \sum_{l \in C} 1}} \quad (13)$$

where

$$e_t(i, j, k, l) = \frac{d_t(i, j, k, l) - \hat{d}_t(i, j, k, l)}{\Delta t}.$$

For the boiler tube case, the deterioration management value is decreased when the deterioration is progressed. Then, the final decision of tube repair is made by

$$\hat{d}_{t+1}(i, j, k, l) - r\sigma_{t+1}(C) \leq \lambda \quad (l \in C). \quad (14)$$

3.2 Results

Fig. 5 shows the deterioration prediction result of one boiler tube. The boiler tube need not repair at time $t = 90000$ [hour].

Table 1 shows the decision making results and standard deviations at time $t = 80552$ [hour] by the non-classified model and the classified model. The results shows the effectiveness of the data classification. Table 2 shows the total results of exchange points. The results by using the non-classified deterioration prediction model were also included in Table 2 for comparison. From the results, the excessive repair was carried out for actual data. Compared with the non-classified results, the number of repair by using the proposed classified deterioration model is small under the same reliability condition. The results shows the effectiveness of the proposed maintenance scheduling method.

4. Discussion

4.1 Application to Other Equipments

In this paper, the proposed maintenance scheduling method was applied to the boiler tube maintenance in thermal power station. The method was also applied to other equipments in thermal power station such as coal pulverizer, and gave satisfactory results. We believe the proposed maintenance scheduling method can be applied not only to equipments in thermal power stations but also to general equipments which require

(a) Conceptual figure of boiler tube and non-regular part

(b) Measurement point of around deslagger

Figure 4: Measurement of boiler tube non-regular part

Table 1: Decision making results of boiler tube maintenance at time $t = 80552$ [hour]

(a) Non-classify			(b) Classify		
C	σ (C)	Number of Repair	C	σ (C)	Number of Repair
1	0.00000607	0	1	0.00000607	0
2	0.00000603	0	2	0.00000603	0
3	0.00000615	0	3	0.00000615	0
4	0.00000614	0	4	0.00000614	0
5	0.00000646	0	5	0.00000646	0
6	0.00000652	0	6	0.00000652	0
7	0.00000691	0	7	0.00000691	0
8	0.00000663	0	8	0.00000663	0
9	0.00000659	0	9	0.00000659	0
10	0.00000648	0	10	0.00000648	0
11	0.00000680	0	11	0.00000680	0
12	0.00000640	0	12	0.00000640	0
13	0.00000640	1	13	0.00000640	1
14	0.00000595	0	14	0.00000595	0
15	0.00000630	0	15	0.00000630	0
16	0.00000595	0	16	0.00000595	0
17	0.00000665	0	17	0.00000665	0
18	0.00000632	0	18	0.00000632	0
19	0.00000678	0	19	0.00000678	0
20	0.00000628	0	20	0.00000628	0
21	0.00000563	0	21	0.00000563	0
22	0.00000703	0	22-32	0.00000796	6
23	0.00000836	1			
24	0.00000864	1			
25	0.00000849	3			
26	0.00000827	0			
27	0.00000793	2			
28	0.00000855	4			
29	0.00000811	1			
30	0.00000775	0			
31	0.00000701	1			
32	0.00000720	0	33	0.00000671	0
33	0.00000671	0	34	0.00000652	0
34	0.00000652	0	35	0.00000637	0
35	0.00000637	0	36	0.00000651	0
36	0.00000651	0	Sum		7
Sum		14			

Table 2: Total results of boiler tube maintenance

Time t [hour]	Exchange points		
	Actual	Non-classify	Classify
55694	0	1	0
67517	108	14	14
80522	3	14	7

Figure 5: Prediction and decision making result for one boiler tube

maintenance.

4.2 Decision Making Rule for Maintenance Timing

In subsection 2.5, maintenance timing of equipments is pre-determined and the decision of requirement is made by the rule in (8). However, the maintenance timing is also determined by using a little modification, i.e., the rule in (8) is replaced by

$$\hat{d}_{t^*} + r\sigma_{t^*} \geq \lambda \quad (15)$$

where t^* is the maintenance timing. Fig. 6 shows the decision making process of the maintenance timing. For the decision making of the maintenance timing, the deterioration related parameters p_{t^*} is required.

5. Conclusion

Maintenance scheduling method of equipments was proposed. For the unified procedure of various equipments, acquired data were converted into the same format. Decision of maintenance was made by the deterioration prediction based on deterioration prediction model and reliability consideration based on the confidence interval.

The proposed maintenance scheduling method was applied to maintenance of boiler tubes and coal pulverizers in thermal power stations, and the number of exchanges were remarkably reduced from actual maintenance. The results show the effectiveness of the proposed maintenance scheduling method.

Acknowledgement

The authors are grateful to Mr. K. Yasukouchi, Saga University for his computer programming and M. Shirakibara, Kyushu Electric Power Company, Inc., for his valuable comments and data acquisition.

Figure 6: Decision making of maintenance timing

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