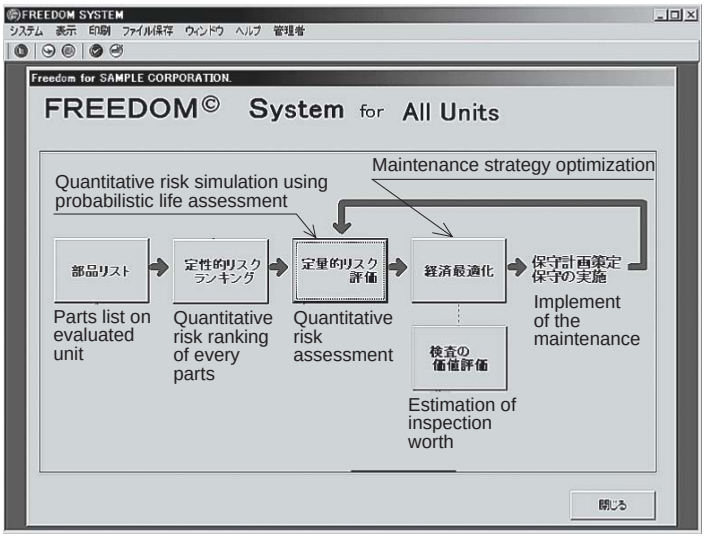

Development of Maintenance Optimization System for Aged Fossil Fired Power Plants

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1. Introduction

With the further progress of deregulation of electric market in the power industry near at hand, the circumstance surrounding the maintenance service of thermal power plants has been undergoing significant change. Reducing maintenance costs effectively and utilizing maintenance services in a valuable manner are essential to reducing the cost of power generation. Within response to such circumstances, Mitsubishi Heavy Industries, Ltd. (MHI) has developed and commercialized a new maintenance optimization system for the major components of thermal power plants, known as FREEDOM (the Financially and Reliably Enhanced Optimal Maintenance System).

The system consists of analytical tools for qualitative risk ranking, probabilistic life estimation, risk simulation, and maintenance optimization. These tools are used to determine the probability of failure for each major component of a thermal power plant for each failure mode. In addition, the risk of the occurrence of failure can be objectively grasped for each component, taking into consideration the significance of each power generating unit. Accordingly, the tools of this system facilitate the development of an economically optimized maintenance plan based on the future operation plans for the unit, by describing the timing when each component should be repaired or replaced so as to minimize maintenance related expenditures throughout the total life of the unit. As a result, the system makes it possible to distribute a limited budget most adequately for the components. This system is actually being applied at present to eight practical thermal power plants in Japan, contributing to the preparation of their maintenance plans.

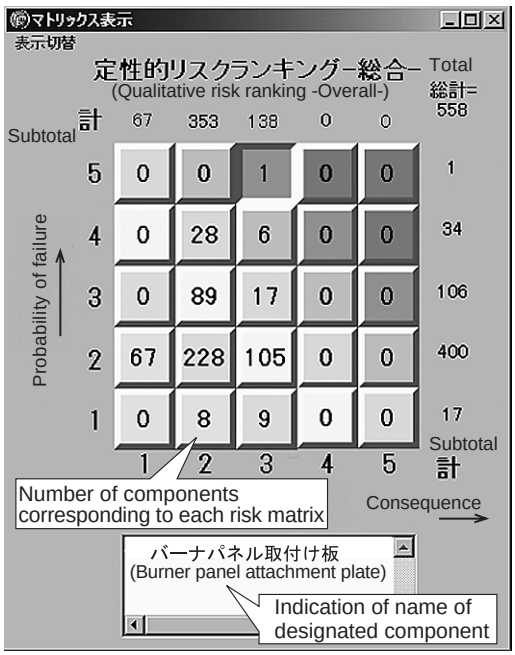

Fig. 1 Risk plot based on qualitative risk estimation

2. Summary of FREEDOM

2.1 Outline of system

A simulation system is embedded in the FREEDOM system that enables users to choose the most economical maintenance strategy (including the proposal of optimum maintenance methods and timings) from various choices including replacement and repair. In order to avoid fatal damage in a unit, the simulation system predicts risks that would result in the deterioration or failure of any component in the unit due to long operation leading to shutdown in which the operation of the unit cannot be continued. The first screen display in the monitor of the system is shown in the figure above. In this system, the list of the components of an object unit is first prepared based on a qualitative risk evaluation, after which a risk plot table consisting of a matrix is prepared as shown in **Fig. 1**. The upper right portions in the risk plot table indicate the components with the higher risks. Quantitative risk evaluations are then car-

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ried out for these higher risk components. Various candidate maintenance methods for each component are compared, based on the difference (i.e. net present value) between the risk reduction (i.e. cash-in) obtained by implementing each maintenance method and the cost (i.e. cash-out) required for implementing the method. Then, the most effective maintenance method for each component is chosen and proposed. The same risk evaluation is carried out for every component needing a quantitative evaluation. After these evaluation results are examined overall for all the components, the maintenance strategy for the entire power generating unit is determined so as to minimize the expenditure throughout the total life of the unit.

2.2 Probabilistic life evaluation

The risk of each component is defined as the product of the probability that the component is damaged due to age deterioration and the economic loss due to the failure (the sum of the restoration costs of the damaged component and the opportunity loss due to the forced shutdown of power generation). The procedure for obtaining probability of failure has been developed by applying life estimation techniques that themselves have been developed through the accumulation of long experience by MHI. Essentially, the time until a component failure is changeable according to variations in the operating conditions, the material properties and manufacturing quality. In the FREEDOM system, after such dispersions are calculated using measurements of the temperatures, stresses, dimensions, etc. for the unit or other similar units, the failure probability for each component is derived based on an analysis using the Monte Carlo simulation method. Therefore, the conventional evaluation method (the definite theoretical life estimating method) has been improved in the FREEDOM system, by taking into consideration the dispersion of material properties, stresses, etc. This makes it possible for the system to cope with various failure modes such as creep, fatigue, corrosion, etc. Variations in failure probability due to the various patterns of operation can be taken into account, by applying analyses for each starting mode when the failure mode is fatigue and for each operation load when it is creep.

Furthermore, for the components that have already undergone inspection, the estimation accuracy of the failure probability can be effectively improved by utilizing these past inspection results.

2.3 Optimization of maintenance plan

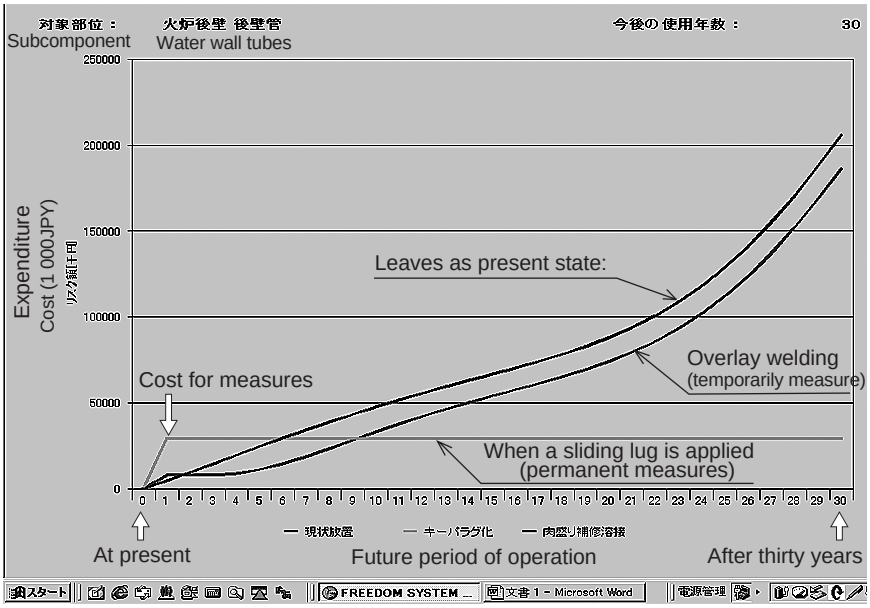
In FREEDOM system, the economic worth of a given measure is derived by the following equation, based on the risk calculated through the methods explained above.

Economic worth of a given measure
= Profit (cash-in) obtained by reducing economic risk through the measure
− Cost (cash-out) required for the countermeasure

Practically, economic worth is given as the net present value used in the Discount Cash Flow (DCF) method, that is, the future expenditure for a given measure is evaluated by converting (discounting) it to present worth.

Fig. 2 shows the expenditure-versus-time diagram of a welded part in the sliding lug of a boiler as an example of the calculation results for an optimized maintenance plan. As can be seen in this example, the FREEDOM system can be used to confirm the results of optimized measure for each individual component.

Fig. 3 shows a summary of all the optimization re-



Example of calculated results for operation for thirty years from now

The best choice is to implement permanent measures after one year of operation. (This gives the lowest total expenditure for the next thirty years.)

For reference:

- When the future operation period is limited to nine years or less, simple measures are suitable.
- When the period is limited to one year or less, it is most economical to leave the present state as is without taking any measures.

Fig. 2 Example of display of economic optimization results
Expenditure-versus-time diagram of welded part of a boiler sliding lug is shown.

Rank	Sub-component
1	2ry reheater tubes
2	Economizer tubes
3	Economizer hanger tubes
4	Water wall tubes
5	Main steam pipes
6	1ry reheater tubes
7	2ry superheater tubes
8	4ry superheater tubes
9	Additional air port panel tubes
10	3ry superheater tubes

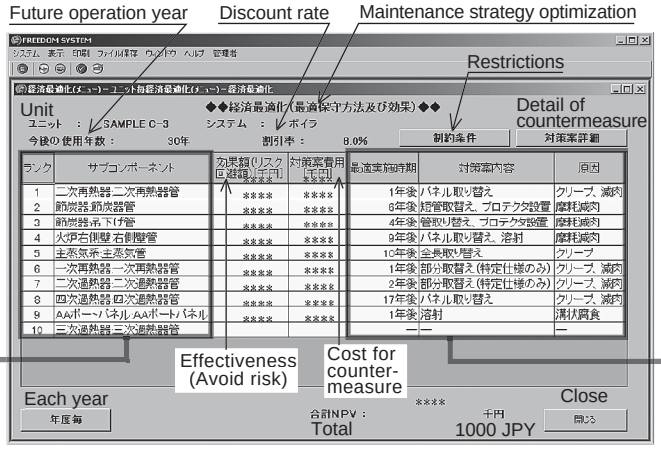


Fig. 3 Example of monitor display of optimization results
Effectiveness ranking of components is shown.

Action year	Countermeasure	Cause
1 years later	Replacement all tubes	Creep
6 years later	Partialy replacement of tubes & addition of protecters	Ash erosion
4 years later	Partialy replacement of tubes & addition of protecters	Ash erosion
9 years later	Partialy replacement and metal spray	Ash erosion
10years later	Replacement all pipes	Creep
1 years later	Replacement of weakest tubes	Creep
2 years later	Replacement of weakest tubes	Creep
17years later	Replacement all tubes	Creep
1 years later	Metal spray on tubes	Corrosion
–	–	–

sults that are calculated for all individual components. As shown in this figure, this system is also capable of indicating a priority ranking, in which a higher ranking is given to a component with a higher net present value. In this way, it can indicate a list that contains such information as the optimum year for implementing each maintenance measure, the contents of the optimum measures, the economic effectiveness, etc. needed to carry out a given maintenance plan. In addition, this system can cope with the variations in conditions to be investigated, such as operation plans and economic conditions, so that it can be used to derive those optimum measures that best conform to the ambient and operating conditions. Moreover, the system can determine whether an inspection is worth being performed or not by estimating whether the accuracy of failure probability is improved by performing the inspection. If it is worth the effort, the system can define the number of components to be inspected and the best year for the inspection.

3. Application to actual plants

The FREEDOM system is provided as a software application that contains data and programs for life estimation. Necessary data such as plant operation conditions, owner's damage due to failure, etc. are input into the system by the owners of the thermal power plant. As a result, the system provides optimum maintenance strategies for either individual components or entire plants. Furthermore, the maintenance strategies for the multiple plants can also be covered, if necessary. The practical effectiveness of the system can be summarized as follows:

(1) The risks contained in components are quantitatively defined.

(2) The system determines whether measures are necessary or not, and, when any measures are necessary, the system defines the optimum methods and timing to be carried out. Accordingly, economically optimum maintenance strategies can be provided, taking into consideration the operation plan and significance of each unit and planned budget.

(3) Excessive maintenance is avoided thereby reducing maintenance costs.

The system has already been adopted in seven boilers and one turbine in existing thermal power plants in Japan.

4. Conclusion

The thermal power plant maintenance optimization system "FREEDOM" has been developed and commercialized as a tool to support the preparation of maintenance plans by the owners of thermal power plants. This system has already been adopted for use in eight existing plants and the effectiveness of the system is highly evaluated by customers. This system shifts decision-making for maintenance from skilled staff to computers that use financial engineering techniques such as the DCF method, and hence helps to perform decision-making more accurately.

MHI intends to provide this system as a tool for optimizing the maintenance strategies and reducing the maintenance costs of both the overall and important components of thermal power plants, and spread this system further as a service business contributing toward helping thermal power plant owners who are striving to reduce maintenance costs, while complying with the deregulation policy of the government.

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