Development of Boiler Life Estimation System

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Since many power plant boilers in operation have already reached 150,000 to 350,000 hours of operating time, determining the amount of remaining life is becoming increasingly important to prevent the problem of boiler tube leakage due to long-term operation. It has so far been difficult, however, to logically determine the appropriate time of inspection, resulting in great cost and effort. Based on a statistical analysis of inspections over more than 30 years, with data classified by boiler specifications such as operational age, type of combustion, design pressure and design temperature, etc., Mitsubishi Heavy Industries, Ltd. (MHI) has created a boiler life estimation system intended to direct the determination of detailed inspection times by predicting the tube creep remaining life and the remaining life of tube thickness reduced by corrosion. This paper introduces an outline of the system.

1. Introduction

As boiler plants show age deterioration through long-term operations, the remaining life of each section must be evaluated and necessary repairs – as well as the periodical replacement of components – must also be implemented. This allows the prevention of accidental failures and problems and enables continuous, safe, long-term operation until the next planned shutdown.

Accordingly, as a support tool for determining appropriate inspection times, we have created a remaining life estimation system, i.e., a creep remaining life estimation for high temperature parts (superheater tubes and headers) that operate at temperatures around 500 ºC in which tube thickness reduction is taken into consideration and a corrosion remaining life estimation of tubes (water tubes, furnace tubes and economizer tubes) that operate at around 300 ºC, based on boiler type and operational characteristics. Furthermore, this system has another feature that assists with inspection planning by displaying the key inspection points of a particular boiler using a database of past damaged examples. The contents of this system are described below.

2. Input of boiler specifications

Figure 1 shows the login screen of the system. A user of the system can make evaluations and change input conditions while accessing the administrative server over the Internet and consulting with the boiler user.

Figure 2 shows the input screen of the particular boiler type and its operational specifications: identification name of boiler, boiler type, steam pressure, steam temperature, combustion system, fuel and completion year, etc. These specifications constitute some of the parameters for the tube creep and corrosion evaluations, which are described below and are registered as individual boiler data. These data can be utilized as necessary.

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In addition, on the screen below to the right, the number of past incidents of damage in the furnace tube, superheater tube and header, etc., of the same type of boiler is displayed based on the operational age of the particular boiler being evaluated.

Figure 1 Login screen of system
A user of the system can make evaluations and change input conditions while accessing the administrative server over the Internet and consulting with the boiler user.

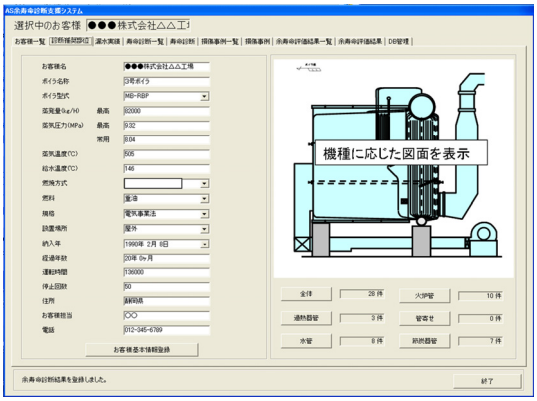

Figure 2 Input screen of the particular boiler type and its operational specifications
When selecting the boiler type, a drawing of the selected boiler type is displayed automatically. Input data such as steam pressure, steam temperature and fuel, etc., are subsequently reflected in the creep and corrosion lifetime estimation of the boiler.

3. Extraction function of past damage examples

When selecting the "number of past incidents of damage" section on the above screen, the operational age, the frequency of damage and the replacement results of each section are displayed in a column chart (**Figure 3**) and the current operational age of the particular boiler being evaluated is also indicated by an arrow, so the positioning of the particular boiler is confirmed compared with the frequency of past damage. By using the tabs at the top of the screen, a list of past damage examples can be selected (**Figure 4**). When selecting the targeted point from the list, a situational photograph, the causes and a summary of the countermeasures for the particular damage at the targeted point are displayed (**Figure 5**), which helps the user understand the phenomenon that occurred.

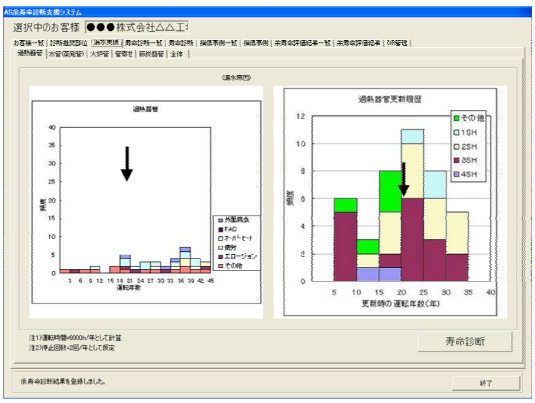

Figure 3 Operational age vs. frequency of damage and replacement results (example for the superheater tube)
The relationship between the operational age and frequency of damage by factor and the replacement results of the superheater tube can be displayed. The operational age of the particular boiler is also indicated by an arrow in the figure.

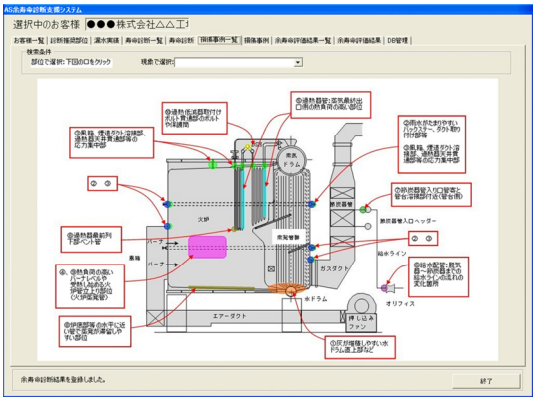

Figure 4 Screen to select damage examples for each point
Points where incidents of damage are likely to occur are displayed. When selecting a point, concrete examples of damage are displayed (Figure 5).

Figure 5 Display of damage examples
Past damage examples, their causes and countermeasures are indicated for each selected point.

4. Creep remaining life estimation for superheater tube

The creep remaining life estimation for the superheater tube is conducted according to the following procedures.

(1) Input data

Input the nominal thickness, outside diameter and material (selected from a list) for the superheater tube, in addition to the boiler type and operational age described in chapter 2.

(2) Evaluation factors

The following evaluation factors are automatically selected by the system, where a database is created based on an analysis of in-house and external data, taking into consideration the tube material and boiler type that were entered.

(i) Larson-Miller parameter constant for each material
(ii) Corrosion rate equation, where design temperature is a parameter
(iii) Scale deposit rate equation, where design temperature is a parameter
(iv) Temperature correction coefficient based on past examinations of cutting tubes

(3) Life estimation method

In each year from start up, tube-temperature increase values affected by scale thickness and tube-stress increase values affected by tube thickness reduction by corrosion are calculated and then the creep damage rate for each year is totaled. The point where the totaled damage rate exceeds 100% is determined as the remaining life. In addition, the relationship between the tube temperature and scale deposit rate is exemplified in **Figure 6** and the relationship between the tube temperature and tube thickness reduction rate is exemplified in **Figure 7**. As such discrepancies in the data for each evaluation factor are taken into consideration, the remaining life evaluation is calculated as the range of the upper limit and lower limit.

Figure 8 shows an example of the remaining life evaluation results.

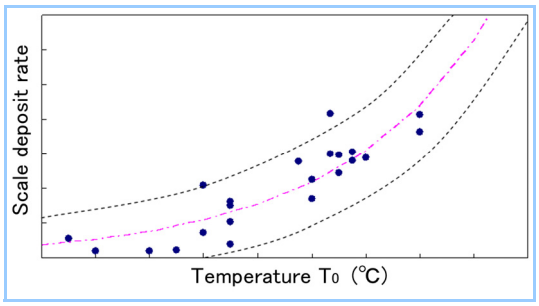

Figure 6 Example of the relationship between tube temperature and scale deposit rate for the superheater tube
Boilers that have a high design temperature have a tendency toward considerable scale deposits in the superheater tube, which contributes to the increase of tube temperature and toward a reduction in the creep remaining life for the superheater tube over time.

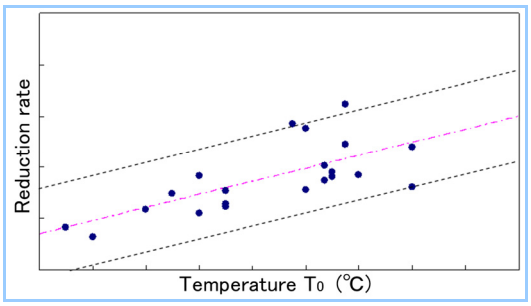

Figure 7 Example of the relationship between tube temperature and tube thickness reduction rate for the superheater tube
Boilers that have a high design temperature have a tendency toward considerable tube thickness reduction in the superheater tube, which contributes to the increase of tube stress and toward a reduction in the creep remaining life for the superheater tube over time.

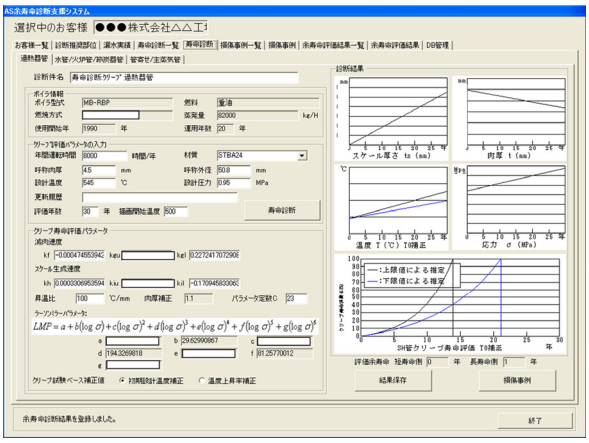

Figure 8 Example of creep remaining life estimation for superheater tube
When selecting evaluation conditions such as tube material, etc., the operational age versus scale deposit thickness and tube temperature variation due to heat transfer deterioration are displayed, as are the operational age versus tube thickness reduction by corrosion and tube stress increase. Furthermore, the creep remaining life estimation results are displayed with consideration for the above.

5. Corrosion remaining life estimation of water tubes, furnace tubes and economizer tubes

The corrosion remaining life estimation of water tubes, etc., is conducted according to the following procedures.

(1) Input data

Input the nominal thickness, outside diameter and material (selected from a list) of the particular tube, in addition to the operational age and combustion system, etc., as described above.

(2) Evaluation factors

Based on automatic selection by the system, a corrosion rate equation that varies with the combustion system and fuel (heavy oil, multi-fuel, gas and coal, etc.) is selected for each tube, i.e., water tubes (generating tube), furnace tubes and economizer tubes. In addition, if the boiler is situated outdoors, exterior corrosion of the tubes due to rainwater may occur. In this case, when selecting an installation location as outdoors when entering boiler specifications in chapter 2, a rainwater corrosion evaluation is also conducted.

(3) Life estimation method

First, according to JIS B 8201, an allowable stress value (σ_a) corresponding to the design temperature for each tube material is extracted and then the required thickness of the tube (t_{sr1}) is calculated using the allowable stress value (σ_a), the outside diameter of the tube and the design pressure of the tube, pursuant to the same standards. In a comparison between the required thickness of the tube (t_{sr1}) and the minimum thickness of the tube (t_{sr2}) differently determined corresponding to the outside diameter of the tube, the greater value is taken as the required minimum thickness of the tube (t_{sr}).

Furthermore, the tube thickness reduction by corrosion is calculated for each fuel and for each combustion system and, in the case of outdoor installation, the tube thickness reduction by rainwater corrosion is also calculated. The point of time where the tube thickness falls below the required minimum thickness of the tube (t_{sr}) is determined to be the lifetime of the tube.

Figure 9 shows an example of input data and evaluation results described above.

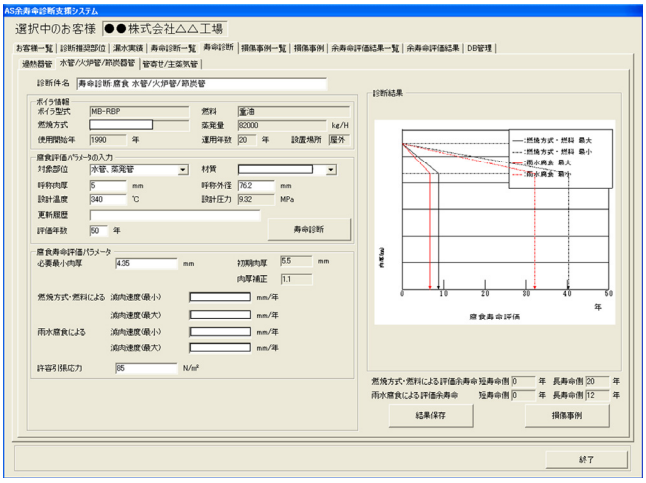

Figure 9 Example of corrosion evaluation of water tube, furnace tube and economizer tube
When selecting conditions such as combustion system and fuel, etc., the tube thickness change versus operation age is displayed. The point of time where the tube thickness falls below the required minimum thickness of the tube is determined to be the lifetime of the tube.

6. Creep remaining life estimation of header and main-steam pipe

The creep remaining life estimation of the header, etc., is conducted according to the following procedures.

(1) Input data

Input the particular location and tube material (selected from a list), in addition to the operational age, etc.

(2) Evaluation factors

Based on automatic selection by the system, an equation for the creep remaining life consumption rate for the header and main-steam pipe is selected, where a database is created by statistical analysis based on conventional inspection results for each material.

(3) Life estimation method

The range of life is calculated using both the upper and lower limit equations of the creep remaining life consumption rate.

Here, the inspection results data of the header and main-steam pipe for this evaluation database are acquired from the "damage classification method," the "number density of creep cavity method" and the "A parameter method," etc. Therefore, since it is considered that this method has a greater error of estimation than that of creep remaining life estimation for the superheater tube described above in which sample tubes have been drawn and creep tests have been conducted, the 50% point of the remaining life obtained by this method is used as the estimated remaining life, according to "the guidelines concerning remaining life evaluation" by the Ministry of Economy, Trade and Industry.

Figure 10 shows an example of input data and evaluation results described above.

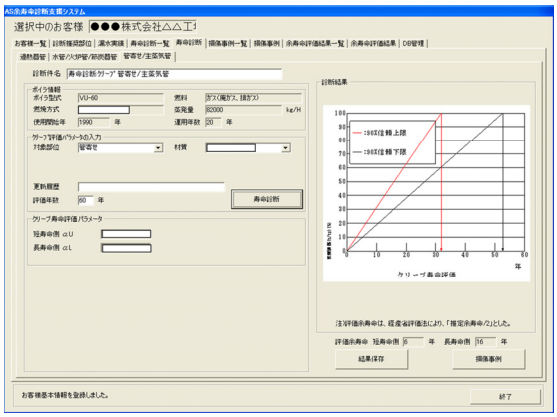

Figure 10 An example of creep remaining life estimation of header and main-steam pipe

When selecting conditions such as tube material, etc., the creep remaining life estimation results are displayed.

7. Conclusion

We have created a boiler life estimation system to predict the creep remaining life of superheater tubes, etc. and the corrosion remaining life of water tubes, etc., by using operating conditions such as the boiler type, operational age, fuel and combustion system, etc., based on the extensive inspection and replacement data obtained from 1,500 cases of industrial boilers over more than 30 years. This system allows us to predict the future risk of malfunctions in boilers currently in operation prior to carrying out detailed inspections, helping in the creation of practical maintenance plans.

In addition, since the number of new boilers, such as biomass boilers, etc., has increased recently, we are also accumulating data regarding these new boilers. We are committed to continuing to meet the needs of various maintenance services in the future.

References

1. Japanese Industrial Standard JIS B 8201 (2005)
2. Nishimura et al., Mitsubishi Power Boiler and Piping Life Assessment System to Extend Legal Inspection Interval, Mitsubishi Juko Giho, Vol. 37 No.1 (2000) pp. 46-49
3. The Guidelines Concerning Remaining Life Evaluation, NISA-234c-05-7 (2005), by Nuclear and Industrial Safety Agency, Ministry of Economy, Trade and Industry