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SELECTION OF MAINTENANCE RANGE FOR POWER MACHINES AND EQUIPMENT IN CONSIDERATION OF RISK

The operational safety of power units depends upon many factors, including the methods of their operation, their working conditions, age, regularity and range of maintenance. The scope of the paper is the analysis of maintenance options for power machines and equipment. The assumed criterion for the selection of the range of repair works is the level of technical risk posed by a given facility below the accepted allowable level. Detailed discussion is focused on the water and steam system of the boiler. The influence of the maintenance on the probability of failure of certain components is described on the grounds of Kijima's model. For the assumed maintenance periods minimal sets of equipment were determined, the repair of which should secure the operation of the water-steam system for a successive interval with the risk level lower than the allowable one.

Keywords*: power equipment, operation, maintenance, risk.*

1. Introduction

The operational safety of power units depends upon many factors, the most important of which are: design and technology of their components, working conditions and methods of their operation, age, quality and regularity of the conducted maintenances. A good measure of their operational safety is the level of technical risk posed by the facilities. The possibility of influencing the level of risk, i.e. risk management, arises at each phase of their operation as well as during overhauls and standstills. The control of the processes and phenomena occurring in the course of the operation of particular machines and equipment is commonly provided by acting on the process parameters with the use of various monitoring and control systems: for example, thermal limitations blocks (BOT) [1, 2]. Such blocks are prepared for boilers and turbines, enabling the tracking of the level of stresses in all components and, depending on the recorded values, controlling the parameters of steam so as not too exceed the allowable values of the stresses.

Diagnostic tests play an important role in the assessment of the probability of damage of certain components and the ensuing risk posed by such damage. The results of the tests may be used to reduce the level of uncertainty in the estimation of the technical condition of the component and verification of theoretical analyses [3]. A proper selection of the tests, in terms both of their range and regularity should secure the technical risk on the allowable level.

Another method of risk management are applicable maintenance procedures, not only as far as current small repairs are concerned, but also general overhauls. In the planning of the range and period of the maintenance the level of the risk posed by particular components should always be considered, leading to the reduction of the risk involved in the successive operational intervals. The planning of maintenance range shall be discussed in more detail in consideration of such risk, with the main focus on the water and steam system of the boiler.

2. The risk management procedures

A general scheme of the procedures of managing the technical risk involved in the operation of power machines and equipment is shown in Fig. 1. At the first stage of the procedures, the analyzed system is separated and divided into subsystems and elements [4]. Such division is made in consideration of the structural and functional connections between particular elements. The second stage, i.e. the assessment of risk, requires the definition of the hazard scenarios, that is, of all potential events that may result in the damage of the elements and subsystems of the analyzed system. For these scenarios , or, in other words, undesirable events, the probability of their occurrence and its changes in time should be estimated. The next step in the risk assessment procedure is the estimation of the consequences involved in the failure of particular elements, which may have financial implications, environmental impacts, or potential casualties. The estimated probability of failures and their implications make it possible to calculate the technical risk posed by a certain element, and, subsequently, the risk posed by the whole system. The comparison of the calculated risk with the levels allowable under definite operational conditions leads to the conclusion about the safety of the system. If the current risk level is regarded as too high, the elements that contribute the most to such risk should be identified and various options of reducing the risk level considered. Among potential methods of risk management the option of operational control should be taken into account [5], or, optimization of the diagnostic procedures, or proper selection of the range and regularity of maintenance and repair works.

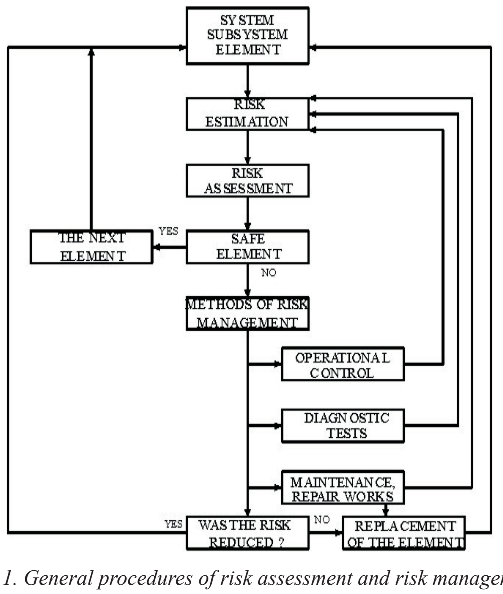

Fig. 1. General procedures of risk assessment and risk management

3. Assessment of the technical risk posed by the water-steam system of the boiler

The subject of detailed analysis is the water-steam system of a steam boiler. Basing on the operational data of several power units of the same type, collected in the course of many years of their operation, the elements and events that cause most frequent damages of the system have been identified. Accordingly, the following fault tree describing the damages of the water-steam system was derived (Fig. 2).

The following primary events were assumed:

- damage of the economizer – event A,
- damage of the boiler drum –event B,
- damage of the waterwall - event C,
- damage of the first section of steam superheater (IPPP)- event D,
- damage of the second section of steam superheater (IIPPP)- event E,
- damage of the fifth section of steam superheater (VPPP)- event F,
- damage of the second section of steam reheater (IIPPW)- event G.

The elements enumerated above are characterized by the biggest rate of failure. The damages of the remaining elements, including, among others, other section of steam superheaters, reheaters, supply pipes of superheaters and coolers were marked as event H in the above diagram.

It was concluded, on the grounds of the data on real failures of these elements, that the most common reasons of the damage of the water system are leakages caused by:

- defects of the welds,
- material faults,
- assembly errors,
- ash and water erosion,
- low-oxygen corrosion,

as well as by the boiler drum overflow and leakages in measuring instruments. As far as the steam system is concerned, the leakages caused by the same reasons dominate. Other causes include: creep, overheating, fatigue, cracking, improper compensation of the strain, mechanical damages. Thanks to the data on the failure rate, the time of the operation and failure periods of particular elements were established, giving grounds for the identification of the type and parameters of the distribution of the time between failures. On the basis of Kołmogorov's tests, in all analyzed cases, the Weibull's distribution was assumed in the following form of the cumulative distribution function CDF:

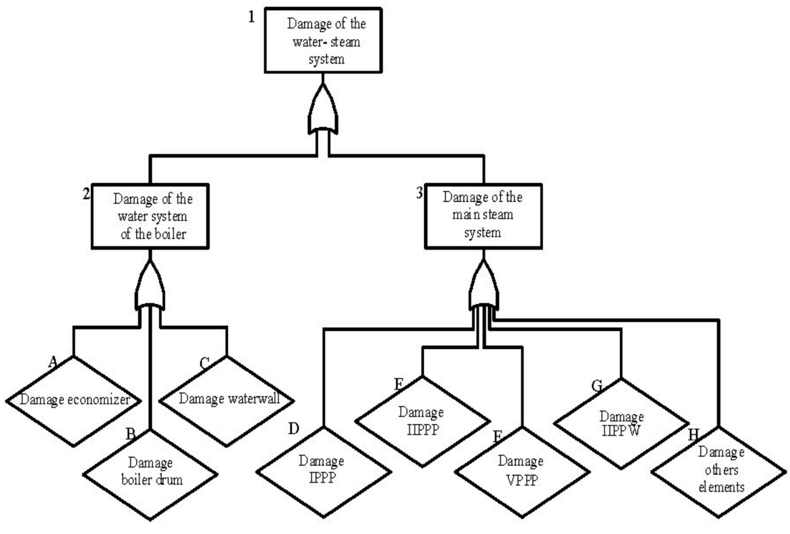

Fig. 2. Fault tree of the water-steam system of the boiler

$$F(t) = 1 - \exp[-(t^{\beta})/\alpha] \quad (1)$$

where: α- scale parameter, β- shape parameter.

The graph of the cumulative distribution function in time for particular elements is shown in Fig. 3. The graph of the failure rate function is presented in Fig. 4.

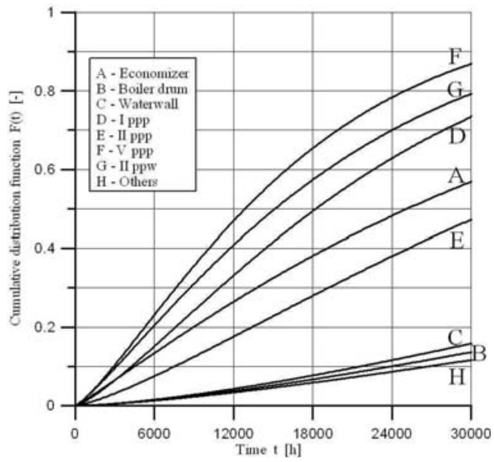

Fig. 3. Cumulative distribution function of the water-steam system

Thanks to the availability of the data on the costs incurred upon the failures of particular facilities, the technical risk involved in their operation was assessed. The risk was calculated from the following equation:

$$R = P \cdot C \quad (2)$$

where P is the probability of failure of a given element calculated from equation (1); whereas C is the average cost of the failure, including both the costs of the ensuing repair works and the losses made by the standstill of the unit due to the failure. The costs were presented in a relative percentage scale in comparison with the average costs of the standstill of the unit caused by typical failures, without the costs of the repair.

The value of the probability of failure of particular facilities and the costs incurred due to their failures are indicated on the risk diagram in Fig. 5. The levels of the risk posed by particular elements after 6000h of their operation were demonstrated in Fig. 6. The changes in the value of the risk in time are shown in Fig. 7.

Among the analyzed elements of the water-steam system, the highest level of risk is posed by the second section of reheater and the fifth section of steam superheater. The lowest risk is involved in the operation of the boiler drum.

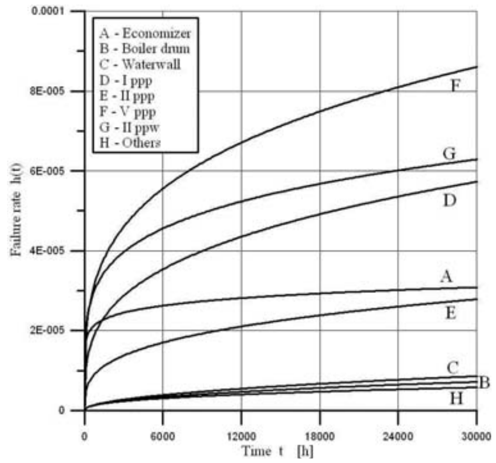

Fig. 4. Failure rate function for the elements of the water-steam system

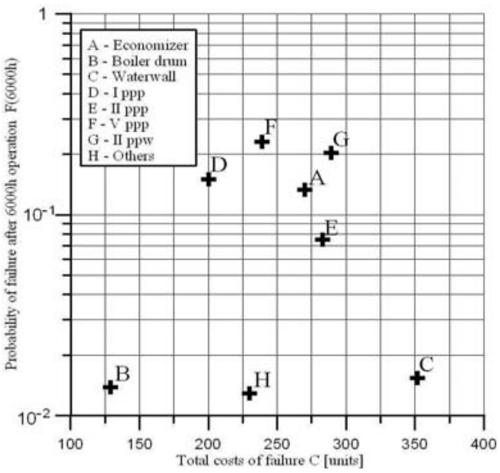

Fig. 5. Risk diagram

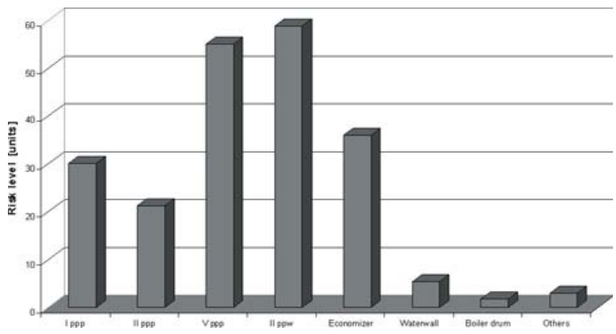

Fig. 6. Risk of particular elements after 6000 h of their operation

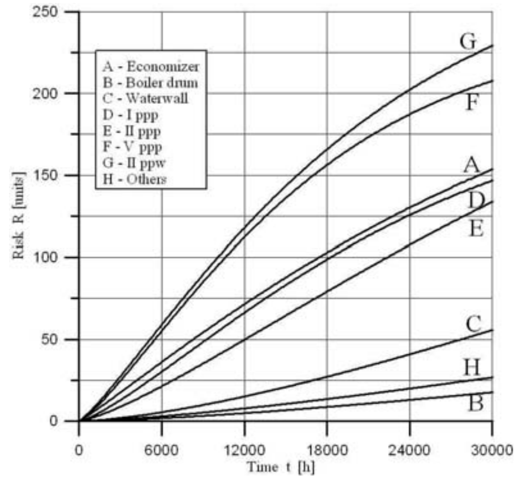

Fig. 7. Risks posed by the elements of the water-steam system in the course of operation

4. Selection of the range of repair works of the water-steam system in the boiler

The research task of the rationalization of the range of maintenance was formulated in the following way: to select the ranges of maintenance for the water-steam system conducted at specified time intervals, so that the risk involved in the operation of the system does not exceed the accepted allowable level.

Such formulation stems from a specific nature of the operation and repairs of power units, entailing variable demand for thermal energy during the calendar year and the resulting necessity of conducting the required repairs at the time when the demand is the lowest. Accordingly, the period of the maintenance is more or less planned for the same time each year. It was assumed in the analysis that the maintenances are conducted at regular intervals, after every 6000 hours of the operation of the facility in question. The second assumption was the allowable risk level for the water-steam system amounting to 400 units. Such level may result from the risk analysis made for the entire power unit, or, from the financial standing and the size of a given power plant.

The assessment of the entire risk posed by all elements of the water-steam system at the first stage of the repair period reveals that it is almost two times lower than the allowable level, which might indicate the absence of the necessity of conducting the repair works. However, if the system was operated without any maintenances for the successive period, the risk would exceed the allowable level at the end of the time interval. As it was assumed that the repairs must be conducted at specific times of the year, it is required that the initial works should be administered after the first 6000h of the operation of the system. Accordingly, the selection of the range of the repairs, i.e. the elements that should be repaired, was made in accordance with the criteria of the greatest probability of damage and the minimal number of the elements in question. It was decided that the first stage of the repair works should cover: the economizer, waterwalls and the fifth section of steam superheater (VPPP). The next stage, after 12000 operational hours, should cover: the first and second section of steam superheater (IPPP, IIPPP) and the second section of reheater (IIPPW). The third stage of the repair works should cover the economizer, waterwalls and V PPP. At the fourth stage of the repair works, the range of the second stage repairs should be repeated. The course of the risk is described by curve B in Fig. 8.

The options and combinations described above do not exclude the range of all possibilities, yet, they fulfill the accepted assumptions. The level of risk may also be reduced if the second section of steam superheater is repaired at the first stage. Accordingly, in the second stage the second and fifth section of steam superheater should be repaired, and in the third one- economizer, the first section of steam superheater and the second section of reheater , as well as the waterwalls; subsequently, the next stage should cover the repairs range from the second stage. The graph of the risk for such course of the procedures is illustrated by curve

C in Fig. 8. Additionally, lines A in Fig. 8 indicate a rise in the risk level when no repair works are administered.

It was assumed in the above analysis that the repairs should restore the technical condition close to the initial one, corresponding to the so called Kijima's model of the first type with the life reduction ration "*a*" equal to zero [7, 8, 9]. According to the model, the failure rate after each successive operation period *T* and the administered maintenance is defined as:

$$h_{i+1}(t) = h_i(t + a_i T_i) \quad (3)$$

where: $t \in (0, T_i)$, $0 \le a_i \le 1$

The graphs of the failure rate function *h(t)* for particular elements are shown in Fig. 9.

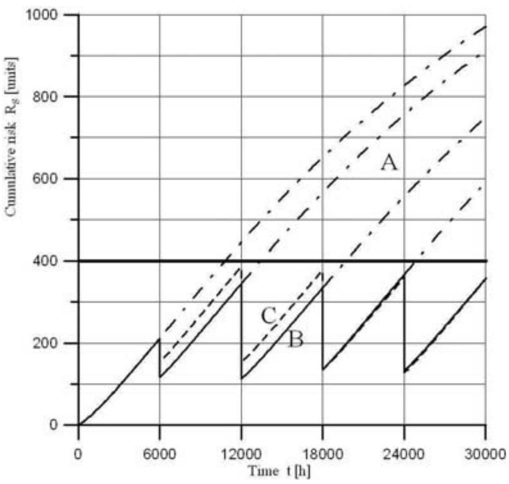

Fig. 8. Technical risk posed by the water-steam system in consideration of maintenances

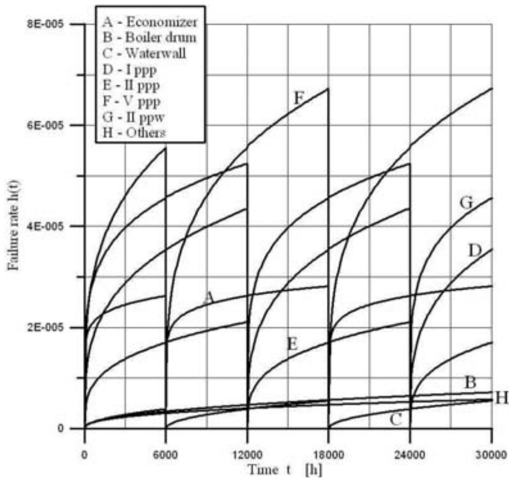

Fig. 9. Failure rate function in consideration of maintenances

5. Conclusion

The discussed method of selecting the range of maintenance for power machines and equipment takes into account a specific nature of repair procedures followed in power engineering. The repairs are conducted in distinct time frames, and the selection of their range is a very pertinent issue. On the example of the water-steam system of the boiler that constitutes one of the subsystems that are very prone to failure, the options of selecting the range of maintenance at particular stages are discussed. The assumed selection criterion is the principle of keeping, throughout the analyzed operation period, the level of technical risk below the limit values. Different options of the sets of facilities subjected to repair works and fulfilling the assumed criteria are presented. The decisive criterion of the optimal solution is the minimization of the costs of the maintenance.

6. References

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