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Assessment of operational risk of steam turbine valves

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Abstract

The paper estimates the technical risk associated with the operation of power machines. The sources of risk are presented with possible scenarios of failures. The risk involving the operation of steam turbine valves is discussed in more detail. The point estimation technique for reliability analysis and the finite element analysis of thermal stresses are applied. Calculations of the probability of failure are made for random loads and random properties of materials. On the basis of the real data, mean values of stresses and strains under transient operating conditions were calculated, as well as the level of stresses under creep conditions. The calculated values were used for estimation of the probability of valve failure and the value of technical risk.

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1. Introduction

Despite the advance of technology and the creation of modern systems of automatic control and protection, failures of technical systems have not been eliminated. Although awareness of the risk of such failures has been widely disseminated, the assessment of the level of risk and prevention is often made intuitively on the basis of experience. Generally, the rational analysis of risk should be based on the theory of probability, addressing the following issues [1,2]:

- How big is the risk associated with the existence of a given technical system?
- How may this risk be reduced?
- What are the costs involved in the reduction of the risk in question?
- What level of risk is acceptable?

The issue of the assessment of risk associated with conventional power stations has received more attention in recent years [3,4]. This results from changes in the world market for energy, involving mergers of power corporations, sale and purchase of power stations with often ‘unknown’

history of operation. At the same time, the equipment of many power stations has become obsolete. The operational life of many power units has already exceeded the design life. Furthermore, serious accidents occurring in the energy sector, including failures of turbine rotors [3] have contributed to the problem. In the face of fierce competition high values of reliability and availability indices and reduction of unplanned shut-downs have become an operational priority focused on the reduction of technical risk.

The scope of this paper is to determine the technical risk associated with the operation of power machines. In particular, the analysis of the risk associated with the operation of stop valves in steam turbines is discussed in detail. Apart from rotors and cylinders, valves constitute the most important components of turbines bearing the highest load. Operational experience indicates that the symptoms of wear may be observed in turbine valves, which reduces the durability of the entire turbine. The risk associated with the operation of valves may play an essential role in the operational risk of a turbine and the power unit as a whole.

2. Technical risk

2.1. Quantitative assessment of risk

The analysis of the technical risk associated with operation of a given system must follow the following

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procedures [2]:

- definition of a system,
- identification of the hazards and situations threatening the entire system as well as its particular elements,
- assessment of the probability of the occurrence of hazards,
- assessment of the consequences in the case of hazards,
- assessment of risk,
- design of activities associated with the existing level of risk.

Technical risk should include all possible events resulting from the existence and operation of a technical system. In a quantitative approach, such risk is calculated as

$$R = \sum_i R_{E_i} = \sum_i P_{E_i} C_{E_i} \quad (1)$$

where R_{E_i} is the risk associated with event E_i , P_{E_i} is the probability of the occurrence of event E_i , and C_{E_i} is the consequence of the occurrence of event E_i .

The probability of the occurrence of events may be assessed on the grounds of the analysis of statistical data derived from observations, opinions of experts, or probability models. As far as the assessment of the probability of failure of a power unit is concerned, first and foremost, as it is a complex technical system, a detailed analysis of the risk of failures of its particular components is required. This paper assesses the risk associated with the operation of a stop valve in a steam turbine, constituting one of the principal components of a power unit.

2.2. Sources of risk

The fundamental source of the operational risk of machines is the absence of the certainty of performance by every single component at any operating time

$$Z > L \quad (2)$$

where Z is generalized strength and L is generalized load.

This results from the random nature of many data [5], including for example, geometrical dimensions, material properties, such as: yield stress, material toughness, creep rupture strength, load, including thermal loads. These last data are because of random temperature fields, especially in unsteady states.

The degree of the loss of strength should also be treated as a random variable. The above mentioned factors indicate that the durability of a machine component should be treated as a random variable and in its successive operating periods the probability of damage should be assessed.

Human errors are also sources of risk. The identification of the sources of risk makes it possible to design possible hazards.

3. Hazards

3.1. Hazards evoked by degradation processes

The operation of power machines, including heat turbines, has a cyclic nature. At the beginning of the cycle there is a start-up. Once the working medium reaches its nominal parameters, steady-state operation follows. Shut-down occurs at the end of the operating cycle, followed by natural or forced cooling of machine components. At each phase of operation the material is subjected to gradual degradation and loss of durability of machine components leads to complete loss of machine life. During start-up, the main process of life consumption is low-cycle fatigue. To determine the essential properties of the start-up processes almost 100 start-ups of a 200 MW turbine were subjected to statistical analysis. The curves of temperature changes of main steam at start-up from the cold, warm and hot state were analyzed in detail, as shown for a cold start in Fig. 1.

From computer simulations [6] it was possible to obtain the time variations of stresses and strains at any valve point. The processes of life consumption are mainly at stress concentration points. Exemplary time variations of maximum effective stresses for some selected start-ups from the cold, warm and hot state are shown in Fig. 2. The distribution of stresses presented in Fig. 2 indicates that, contrary to theoretical start-ups, real ones evoke several stress amplitudes and, accordingly, strain amplitudes. Thus, low-cycle fatigue life consumption during a single start-up

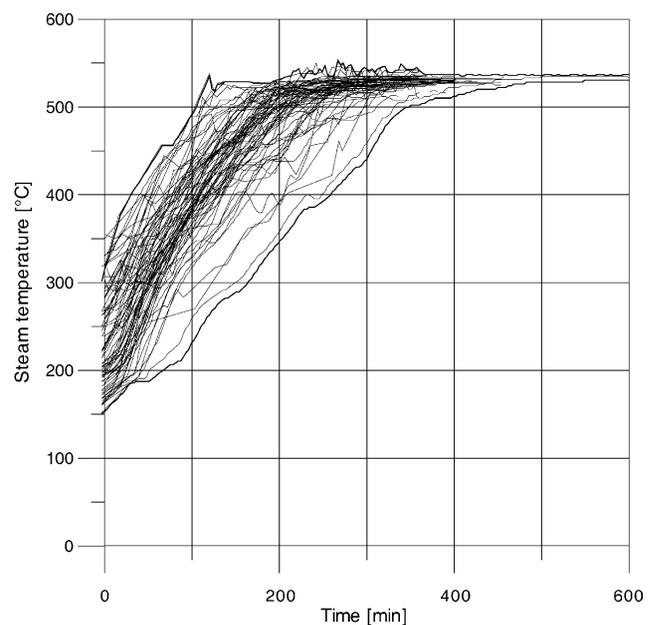


Fig. 1. Time variations of the temperature of steam at the start-up from the cold state.

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