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Technical risk involved in long-term operation of steam turbines

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Abstract

The scope of the paper is the assessment of the technical risk involved in long-term operation of power units. Detailed analyses have been conducted for steam turbine components. The sources and consequences of risk have been identified and the probability of turbine components failure calculated. The quantitative assessment of the risk has been made and possibilities of its reduction discussed.

Keywords: Technical risk; Steam turbine; Failure analysis

1. Introduction

Serious recent failures of power systems revealed the permanent presence of real risk of the loss of the operational continuity of such systems, which may result in hard to predict social and economic effects. Thus, these days more attention is focused on the assessment of the reliability of power systems, which involves both the reliability of energy generation systems and transmission systems as well [1].

The essential factors determining the level of reliability are, among others: the structure of the system, prevailing climactic and atmospheric conditions, level of power reserves, organization of cooperation with related systems, quality of automatic control and safety systems and technical state of power units components. The last factor, concerns, first and foremost, the age of generation units, which is quite advanced in many countries. In the next 10 years over 40% of power stations located in Europe will reach the age of 40 years of operation. This may result in a prospective increase of failure frequency of power units and, consequently, reduced reliability of the whole system [2,3].

In the paper the quantitative assessment of technical risk associated with long-term operation of power units is made. Detailed considerations concern the analysis of the operational risk of steam turbines, which, beside boilers, constitute a fundamental element of a power unit. This risk is connected with the degradation processes as well as with the unexpected increased load of machine components. Other factors that may lead to failures, for example, human errors that are independent from the operation time have not been discussed.

2. Technical risk in operation of steam turbines

The fundamental source of the operational risk of machines is the absence of the certainty that the strength of every single component at any operating time is higher than its load. This results from the random nature of many data [4] including for example, geometrical dimensions of components, material properties, such as: yield stress, material toughness, creep rupture strength, as well as thermal loads. This is because of random temperature fields that are conditioned, especially in unsteady states, by random conditions of heat exchange. The components of power machines operating in aggressive environments are exposed to the loss of material strength due to the impacts of corrosion, oxidation or erosion.

The degree of the loss of strength evoked by these impacts should also be treated as a random variable. The above mentioned factors indicate that their random character should be considered in the analysis of the loss of durability of power machine components, which, accordingly, leads to the assumption of a random character

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of the level of stresses, amplitude of stresses and strains occurring in the operation cycles. In conjunction with the scatter of the strength, creep and fatigue properties, 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.

Quantitative assessment of technical risk should include all possible events resulting from the existence and operation of a power unit [5]. In a quantitative approach, such risk is calculated as

$$R = \sum_i R_{E_i} = \sum_i P_{E_i} C_{E_i}, \tag{1}$$

where R_{E_i} is risk associated with event E_i, P_{E_i} is probability of the occurrence of event E_i, C_{E_i} is the consequences 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 on the grounds of probability models of the events of failure [6]. 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. Technical risk that is the scope of the detailed analysis is understood as the risk of turbine failure during long-term operation. This risk includes the probability of failure of main turbine components, such as valves, cylinders and rotors caused by the processes of degradation and the probability of instantaneous damage caused by increased stresses or cracks in the component.

3. Probability of turbine components failure

3.1. Scenario of hazards evoked by degradation processes

The operation of heat turbines has a cyclical nature. At the beginning of the cycle there is a start-up, involving the supply of a working medium to a machine and gradual increase of the parameters. Once the working medium reaches its nominal parameters, the steady-state operation period follows, characterized by relative stability of the parameters of the working medium and the thermal state of a machine. The shut-down occurs at the end of the operating cycle, followed by the process of natural or forced cooling of machine components. At each phase of operation the material is subjected to gradual degradation and the loss of durability of machine components leads to complete loss of machine life. During start-up, the main process that evokes machine life consumption is low-cycle fatigue. The value of life consumption vary depending on the number N of turbine start-up shut down cycles. To determine the essential properties of start-up processes almost 100 start-ups of turbines were subjected to statistical analysis. The detailed analysis concerns 200 MW condensing turbine with nominal steam parameters: for HP part 535 °C and 13.5 MPa, for IP part 535 °C and 2.5 MPa. The curves of steam temperature changes at start-up from the cold, warm and hot state were analyzed in detail. Time variations of the steam temperature at the exemplary start-ups are shown in Fig. 1. These start-up curves were assumed as input data for numerical simulations of thermo-mechanical states of turbine components. Firstly the thermal boundary conditions (steam temperature and heat transfer coefficients) for different surfaces of components were determined by modeling the steam expansion in the turbine flow system. Next the transient temperature and stress distributions were calculated. From computer simulations [7] it was possible to obtain the time variations of stresses and strains at any point of turbine components.

The most stressed component of a 200 MW turbine is IP rotor, in particular rotor bore, thus, detailed calculation results given in the paper concern this part of a turbine. The distribution of temperature and stresses in a rotor after 30 min of an exemplary start-up from the warm state is shown in Fig. 2. Time variations of maximum effective stresses in the rotor bore for some selected start-ups from the cold, warm and hot state are shown in Fig. 3. The distribution of stresses presented in Fig. 3 indicates that, contrary to theoretical start-ups, real ones evoke several stress amplitudes and, accordingly, strain amplitudes as well. Thus, low-cycle fatigue life consumption Z_N during a single start-up of a turbine is equal to:

$$Z_N = \sum_{i=1}^{m} Z_i, \tag{2}$$

$$Z_i = \frac{1}{N_{fi}}, \tag{3}$$

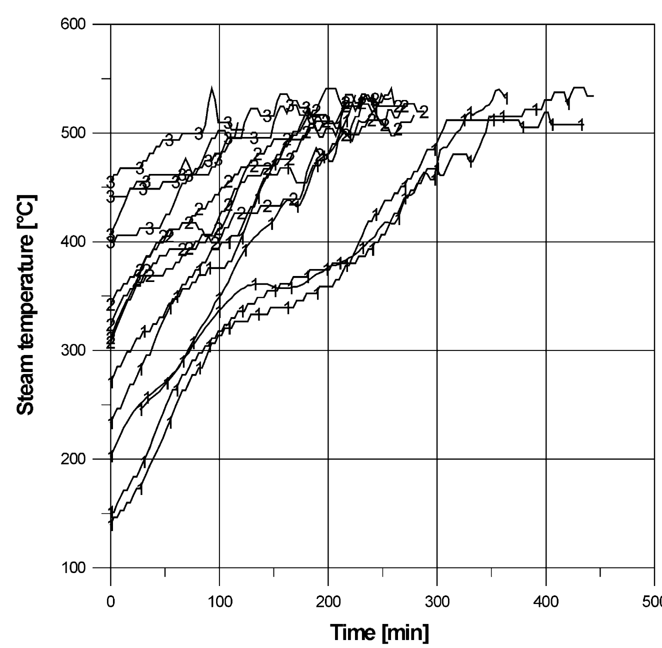

Fig. 1. Time variations of steam temperature during cold (1), warm (2) and hot (3) start-ups.