Selection of operating conditions and planning of diagnostic tests of turbine components working in flexible regime based on a risk analysis

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ABSTRACT

Due to the necessity to transform the Polish energy system, a change in the operation of coal-fired units with the long in-service time is observed. The increasing number of renewable sources characterized by low availability coefficients and their priority of energy generation mean, that the existing 200 MW units are forced to balance the current demand for electricity. Therefore, their operation regime is changing towards a regulatory mode characterized by high cyclicality. One of the critical elements of a coal-fired power plant is a steam turbine, for which an increase in work flexibility leads to the intensification of material degradation processes and, consequently, to serious failures. In the doctoral thesis, an attempt was made to select the operating conditions and plan diagnostic tests for individual turbine components so as to ensure the safety of further operation and maintain energy production until the development of new sources.

The consequences of the cyclic operation of steam turbines are the increase in the crack propagation rate and the development of fatigue-creep wear. In order to assess the effects of flexible work regime, calculations of the crack propagation in the rotors central bore and the life-consumption processes in the heat grooves were carried out. To take into account the random nature of the phenomena, the Monte Carlo method was used. Based on the obtained results, the probability of failure was estimated in the assumed period of 13 or 20 years.

Both the crack propagation and the life-consumption processes are strongly dependent on the stress level in the rotor during transient states, especially start-ups. For this reason, in order to ensure the requirements related to the flexibility of the unit's operation and operational safety, the heating process should be optimized. Static optimization consists in modifying the existing start-up curves. The dynamic one, in turn, consists in selecting the temperature rise of the steam in real time with simultaneous monitoring of the stress level. For the purpose of developing a dynamic turbine start-up optimization system, an algorithm of the current stress calculation was developed for critical elements, which included the rotors high and intermediate pressure parts, the turbine inner casing and the cut-off valve. It was proposed to use the concept of the modified steam temperature and a dedicated correction coefficient, which allow for taking into account the variability of the heat transfer coefficient in the calculations. Due to this solution, the algorithm based on Green's functions enable determine the stresses during the turbine operation in real time, especially during the transient states. Satisfactory compliance of the analytical results with the finite element method and universal

functioning for various types of start-ups were obtained. The stress monitoring system can also be used to online control of the wear level of individual elements by using the rainflow algorithm to count fatigue cycles and the Larson-Miller parameter to determine the creep lifetime and its subsequent loss.

Because of the increased failure risk related to the crack propagation in the turbine rotors, the anisotropy research for the rotor steel was carried out. Steel proprieties taking into consideration were brittle-plastic transition temperature and fracture toughness. Material samples were prepared from the first disc of withdrawn high pressure rotor. The Charpy test and the small punch test (SPT) were performed for the specimens collected in the radial and circumferential directions. The obtained results indicate better properties for circumferential samples, but the differences are so small that no significant anisotropy was found.

The NPV index was proposed to determine the optimal intervals for carrying out preventive activities, such as the diagnostic tests and corrective repair. The index takes into account the costs of preventive maintenance, the avoided risk of turbine failure and the risk of failure before and after the repair.

The summary of the research was the development of a strategy for further operation and maintenance for individual critical elements in energy units. Detailed analysis was performed for the rotor high-pressure part. For the assumed scenario of further operation of the power unit, the permissible stress values during start-up were selected, ensuring the maintenance of a low risk level for the next 13 years. For a longer period of 20 years, it has been proposed to use the NPV index to determine the best time for carrying out preventive activities. To ensure the required level of stress, the dynamic heating optimization process was used as a stress control system simultaneously for two risk areas (the rotor central bore and the thermal groove).