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Calculation and experimental method for determination of stress state of the NPP coolant input units into NPP vessel elements

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Abstract. The method of experimental and calculation determination of a stressed state in the NPP cases coolant input units in the conditions of rapid temperature changes is considered. A monitoring algorithm using strain gauge control and an algorithm based on solving direct and inverse problems of experimental mechanics is proposed.

1. Introduction

The estimated life of the NPP equipment contains reserves related to the difference in the real history of changes in the stress-strain state (SSS) of the critical structural elements compared with the design estimates, suggesting the maximum possible impact of operational loading factors. Despite the progress made in the possibilities of numerical methods for calculating the SSS of complex structures, their use at the design stage does not take into account the actual loading history because it is impossible to predict multivariate processes of temperature change, coolant flow, changes in mechanical loads and combinations of various parameters of operation. To determine the real history of SSS changes, monitoring systems based on measurements of the equipment parameters state are created, by which stresses, strains, and displacements of elements are determined using design models. The greatest difficulty is the creation of such models for zones located on the internal surfaces of the coolant circulation circuits. To determine the SSS in these zones, especially for operation modes with rapid changes in the coolant temperature, it is possible to use experimental and calculation methods based on processing the measurement results for accessible construction points [1] and algorithms based on solving direct and inverse problems of experimental mechanics [2].

2. Research methods

Unfortunately, at present, there are no strain gauges in the standard monitoring systems for NPP parameters, which remain operable during the operational period. Experimental data on the SSS can be obtained during startup and commissioning tests (SCT) of nuclear power plants, carried out with the parameters of the power unit that are different from the normal operating ones. At the same time, during the SCT period, it is possible to obtain experimental data necessary for the formation of computational algorithms that allow determining the SSS from standard measured parameters over the entire life cycle. In this paper, we consider the construction of a similar algorithm for the zones of the



coolant input nozzles into the vessel elements of heat exchangers, in particular for the emergency water supply branch pipe (EWBP) for VVER-1000 steam generators. EWBP is designed to supply water to the steam generator (SG) in water supply cessation mode in the steam generator by means of main branch pipe during de-energization of nuclear power plant and design basis accidents associated with a significant decrease in the water level. The feed water to the EWBP is supplied through emergency pumps; its temperature (about 40 ° C) is significantly lower than the temperature of the vessel and the internal components of the SG.

The data on temperature differences of the coolant in EWBP for the most critical loading conditions causing significant damage to the metal of the constructions is shown in Table 1.

Table 1. Critical loading SCT modes of the Kozloduy NPP power unit No. 6

Number in order	The cause of the impact load	Temperature drop in EWBP Δt , °C
1	Scheduled pumps TX10,20D01 test	100
2	Emergency protection system action during load shedding to idle	255
3	Emergency cooldown in conditions of the power unit de-energization	210

During operation, the nozzle is loaded with pressure of the secondary loop ($P = 6.46$ MPa), self-compensation efforts from the external pipeline of emergency feedwater and the intracasing collector, as well as uneven temperature field causing significant temperature stresses, especially in areas of geometric inhomogeneities. Figure 1 shows the variants of the branch pipe design, differing constructive options for the supply of water to the steam generator. Initially, the design of the EWBP received the form shown in figure 1a). To reduce the thermal stresses during the supply of emergency feedwater, it was proposed to exclude the direct contact of cold water with the heated bottom by using an intra- collector, as shown in figure 1b).

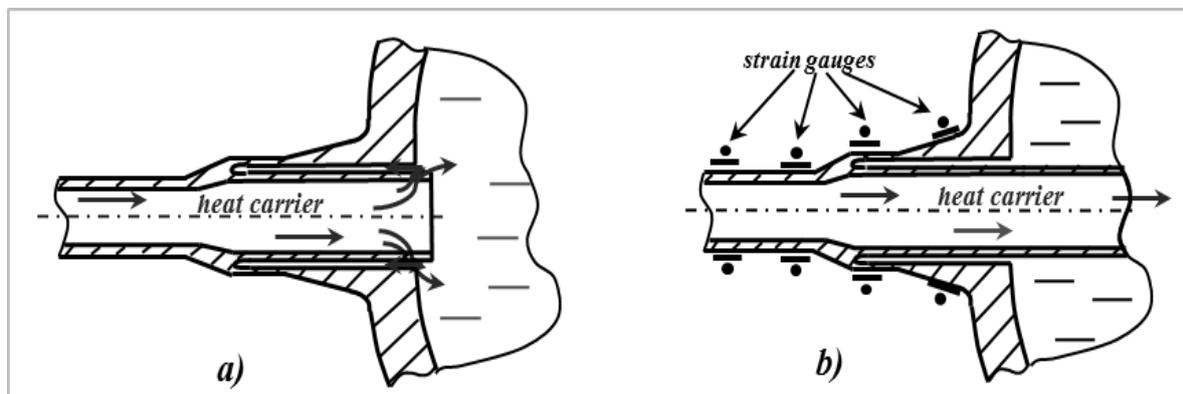


Figure 1. Coolant supply schemes: a) directly into the internal volume; b) with a diversion of the incoming stream.

The strain gauges shown in fig. 1 on the right, were part of the measuring instruments of the SPNI system of the Kozloduy NPP 5th (head) power unit, and were not installed on subsequent serial units. As the analysis performed in this work has shown, it is the experimental data obtained from these strain gages (the SPNI measurement points also included thermocouples installed near the strain gages), allow solving the problem of forming an algorithm for calculating and experimental monitoring of the SSS when the feedwater flowing through EWBP. The standard means of measuring NPPs (temperature sensors of the coolant at the inlet of the nozzle and the temperature of the outer surface of the nozzle zone) have significant thermal inertia, and at realizable rates of temperature change do not provide sufficient information to form the boundary conditions for determining the

temperature fields. In addition, as a result of the lag effect of the measured temperatures of the external surfaces in the SSS calculation, the processes of changing temperatures, pressures and self-compensation efforts of pipeline systems are not synchronized. Therefore, when using only the values of the standard sensors, it is necessary to use the maximum calculated estimates of many input parameters (heat transfer coefficients, compensation efforts, etc.), which leads to overestimate of the stresses that arise. Use of indications shown in fig. 1 strain gage allows to create the following updated algorithm.

1. The signals of the strain gauges installed on the pipelines horizontal section (4 pairs in section, left in the figure) determine the bending moment in the pipeline and its change over time (there is no thermal inertia for the strain gauges).

2. The same strain gauges and, additionally, those installed in the second left section, allow to establish the exact time of the beginning of the thermal process according to the change in intensity caused by the heat flow on the inner surface.

3. The readings of the strain gauges in the left section and the thermocouples installed next to them make it possible to form the initial data for solving the inverse problem of thermoelasticity, the solution of which is the function of temperature variation of the internal surface of the pipeline [3]. The solution of the inverse problem is possible if the components of the stress tensor are caused by the loading of the pipe fragment only by the radial temperature field and do not contain components related to other factors. This means that from the measured strain values it is necessary to exclude the components caused by the internal pressure and the components of paragraph 1, associated with the self-compensation of the pipelines.

4. Using the temperature change functions obtained in paragraph 3, the functions of changing the coolant temperature and heat transfer coefficients are selected that are most appropriate for the data obtained in paragraph 3. For this, direct problems of heat conduction are solved and the results are compared with the results obtained in paragraph 3.

5. The determined functions of the coolant temperature changing and the values of the heat transfer coefficient are used to calculate by the FEM methods the temperature fields of and then - the SSS of the analyzed area of the structure.

6. The obtained calculated results are compared with the readings of the strain gauges shown in the right sections in fig. 1. If necessary, the intermediate results of paragraphs 3 and 4 are corrected.

3. Results

Experimental data obtained during startup and commissioning tests (SCT) made it possible to calculate temperatures for both variants of pipe designs, shown in Fig.1. As the results showed, the maximum temperature differences across the wall thickness for the section in the transition zone of the external pipeline to the nozzle body arose in mode No. 3 (Table 1): for the initial variant a) - 149 ° C (at the time of 9.4 s); for option b) - 129 ° C. Thus, the temperature stresses for the upgraded version should be lower than for the original one, which was confirmed by further analysis.

The obtained temperature fields are used to determine the SSS of the EWBP zone under the most dangerous loading mode (No. 1, Table 1), taking into account the loads from the internal pressure, connected pipelines and temperature gradients. Fig. 2 shows the results of determining the SSS for both variants of the structure at the points in time at which the stresses are maximum (9.4 s and 7.4 s).

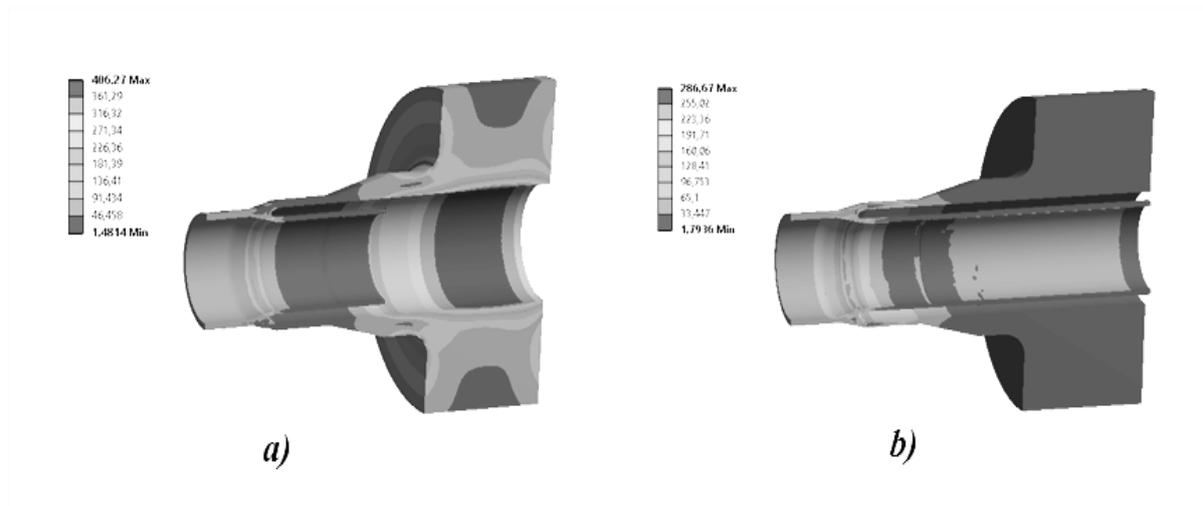


Figure 2. The results of the calculation and experimental determination of the SSS:a) original and b) upgraded EWBP versions

A comparison of SSS for both EWBP versions shows that the upgraded construction is optimally designed in terms of the resulting thermal stresses, but is more vulnerable to loads from the attached pipelines.

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