PRODUCTION SECTION

LIFE CALCULATIONS FOR HEADER –
PGV-1000 STEAM GENERATOR CONNECTOR WELD JOINTS
UNDER NPP SERVICE CONDITIONS

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The procedure for calculating the life of header – steam generator connector weld joints is proposed. It allows for running out the material plasticity reserve upon static cyclic elastoplastic loading as well as operating conditions, local stress concentrations, and residual stresses after welding.

Keywords: life, header, steam generator, weld joint, residual stresses.

Introduction. Damages in ‘hot’ header – PGV-1000 steam generator connector weld joints at nuclear power plants with WWÉR-1000 reactor pressure vessels are detected after operating periods much shorter than their design life [1, 2]. It was established that damages (cracks) were localized in similar zones of weld joints irrespective of the welding technique used (symmetrical or asymmetric edge preparation, automatic or manual welding, with or without buttering). It points to common reasons of this phenomenon. Besides, not all the loading and deformation features of the material were accounted for in strength calculations at the design stage.

The present study is devoted to service life calculations for the weld joint after its repair on the basis of refined stress-strain state evaluation.

Weld Joint Loading and Its Operating Conditions. Detailed analysis of the stress-strain state in the weld joint was presented earlier [3], some results are outlined below.

The structure of the weld joint is shown in Fig. 1. The most loaded part of the joint is its thinned portion. This portion is affected by the loads on the side of the primary system pipe, by the header and coolant weights as well as by pressures in the primary and secondary circuits of the steam generator. The connector and header are made of 10GN2MFA steel, some of its physicomechanical properties are listed in Table 1.

Coolant pressure in the secondary circuit, i.e., in the shell of the steam generator (pressure in the primary circuit and temperature gradient in the weld joint formed in operation reduce maximum tensile stress levels caused by pressure in the secondary circuit), and bending moment due to uncompensated thermal expansion of primary circuit elements are major loading factors.

As calculation results demonstrate, maximum tensile stresses are observed on the inner surface of the ‘pocket’ (annular gap between the header and connector) in the local area below the mating line of the fillet with the inner cylindrical surface of the connector on the stretched side of the primary pipe bend, which corresponds to actual fracture zones found on all damaged weld joints (Fig. 1). In hydrostatic tests for strength and leak-proofness, maximum stresses in this local area exceed the yield strength.


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The joint is subjected to static cyclic loading, including cycles of hydrostatic tests (pressure increase in the RPV primary and secondary circuits above an operation level, its maintenance and reduction) and of normal operating conditions (attainment of rated operating conditions, planned and unplanned outages). Its loading with bending moment as a result of thermal elongation of the primary system pipe is also of cyclic nature: the moment is growing upon heating, maintained at a constant level under normal operating conditions, and decreases upon RPV shut-down cooling [3].

This joint is also affected by corrosive deposits in the ‘pocket’ and by the chemical composition of water. To reduce corrosive deposits, the ‘pocket’ is periodically blown through, which gives rise to additional thermocyclic loading of the metal. These factors in combination with high stresses and temperatures lead to so-called low-rate strain corrosion cracking (LRSCC) of the metal at the metal–water interface [1, 6].

The life calculation for the weld joint after repair is given below. It allows for the above loading parameters assuming that crack-like defects in the weld joint are absent. Mechanical properties of the metal in the repair zone are believed to correspond to the initial ones, i.e., preceding running time is not taken into account. Thus, first, the configuration of the calculation zone of the joint completely corresponds to the initial one, second, materials used for repair possessed physicomechanical properties similar to those of the materials which steam generators are made of, third, repair and production technologies, including thermal treatment, are also close. The calculation takes account of residual stresses (welding ones, in this case) and local defects (pores, blisters, corrosion pits or cutting traces), which can increase maximum stress levels, as well as of a reduction in plasticity of the metal as a result of corrosive medium and temperature effects.

The weld joint life under static cyclic loading can be calculated by summing damages appearing in the metal at each loading cycle due to a local reduction (running-out) of its plasticity reserve. At the same time, only those loading cycles should be accounted for, which cause elastoplastic deformation of the metal.

Elastoplastic deformation in the vicinity of the defect (stress concentrator) and damage accumulation should be examined more closely.

**Analysis of Elastoplastic Deformation of the Material in the Vicinity of the Defect.** As it was mentioned above, in hydrostatic tests for strength and leak-proofness, maximum stress levels in the local subsurface area in the ‘pocket’ near the fillet mating line exceed the yield strength. Outside this area, loading–unloading results in elastic deformation of the material. Thus, at high load levels inelastic cyclic deformation in the above area leads to an

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**TABLE 1. Physicomechanical Properties of 10GN2MFA Steel [4]**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>T, °C</th>
<th>(R_{p_{0.2}}^{T}), MPa</th>
<th>Narrowing (Z^{T}), %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>130</td>
<td>320</td>
</tr>
<tr>
<td>Yield strength</td>
<td></td>
<td>343</td>
<td>318</td>
</tr>
<tr>
<td>Narrowing</td>
<td>55</td>
<td>54</td>
<td>51</td>
</tr>
</tbody>
</table>

Fig. 1. Weld joint fragment: (1) part of the primary system pipe; (2, 4) welds; (3) header; (5) ‘pocket’; (6) steam generator connector; \(A\) is the fracture initiation zone.

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