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Decreasing thermal stresses in steam generator collector weld's area using external cooling

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Abstract

Numerous WWER-440 steam generators showed a very serious problem of cracking in weld joints which are connecting primary collectors to the steam generator's vessel. As a cause of this cracking was determined stress corrosion cracking mechanism. The weld is connecting austenitic steel collector to the carbon steel vessel, so it is a dissimilar metal weld. There are two approaches how to lower the possibility of stress corrosion cracking in the weld. First one is to improve the secondary water chemistry in the weld's surrounding to stop the corrosion and second one is to decrease presented stresses in weld's area. It is better to combine both approaches. This paper deals with the second approach of possibilities to decrease presented stresses. Inspired by Russian study of external cooling on WWER-1000 steam generators, it was an attempt to adapt the external cooling idea on the WWER-440 steam generators and their problem of weld cracking. It was shown that by using the external cooling it is possible not just lower the presented tensile stresses but to change the tensile stresses into compressive stresses. This will of course result in significant reduction of stress corrosion cracking possibility in the steam generator primary collector weld's area.

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Keywords: steam generator; thermal stresses; external cooling; stress corrosion cracking; dissimilar metal weld

1. Introduction

On various WWER-440 nuclear power plants (NPPs) steam generators (SG) occurred quite serious problem of cracking in weld joints connecting primary collectors to the SG vessel's nozzle (Fig. 1). The cause of this cracking is stress corrosion cracking (SCC) mechanism. The crack rises and grows on the interface between different kinds of material, austenitic steel 08CH18N10T on one side and carbon steel 22K on the other (Fig. 2).

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On the SG secondary side, there is a space between the SG nozzle and the primary collector, which is also called "pocket". In this pocket, due to poor possibilities of effective blowdown, exist the secondary media of higher corrosive potential. The existence of corrosive media together with existing stresses can cause intergranular corrosion and cracking in this area. Existing stresses are combination of thermal stresses from different thermal expansion properties of austenitic and carbon steels, and external stresses on the SG nozzle from the primary circuit. Thermal stresses are in this case higher and thus more important.

Dissimilar metal welds are of Vitkovice Machinery and Russian design. It can be seen that the crack is propagating between the two different materials, austenitic and carbon steels (Fig. 2).

The mechanism of crack initiation and propagation was studied in detail on different institutes. Results show that the initiation process is electrochemical corrosion on the inner surface of the collector pocket. The pocket is difficult to clean of deposits (Fe_3O_4, Fe_2O_3, graphite, etc.) and the water there contains higher concentration of chlorine and other ions. This makes the pocket ideal environment for such electrochemical corrosion mechanism.

In the next phase, the crack can grow due to stress corrosion cracking mechanism, because of existing thermal and external stresses. The growth of the crack is still caused by corrosion and assisted by stresses in the material.

Fracture toughness of Russian and Vitkovice Machinery weld design were measured. Fracture toughness was measured on specimens in initial state (290 °C) and real conditions simulated after 30 years (290 °C). Fracture toughness at 0.2 mm elongation $J_{0.2}$ was taken 147 N/mm.

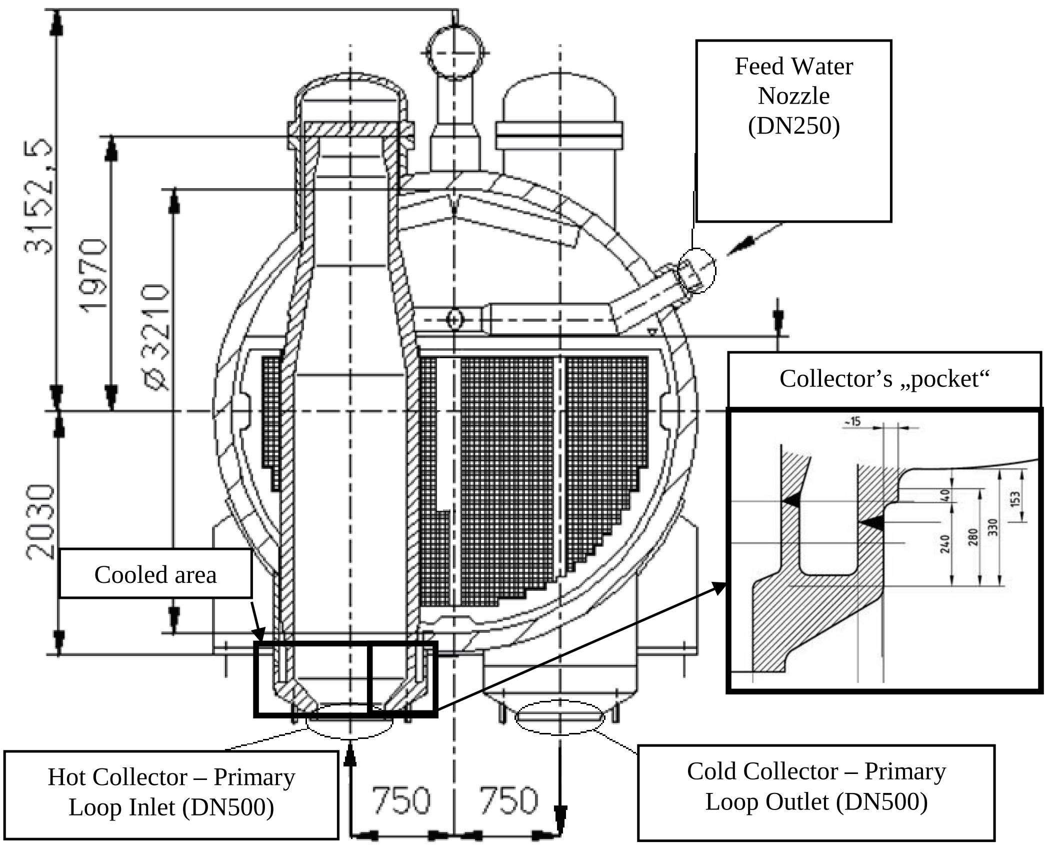

Fig. 1. Steam Generator PGV-440 cross section (through the Hot Collector).

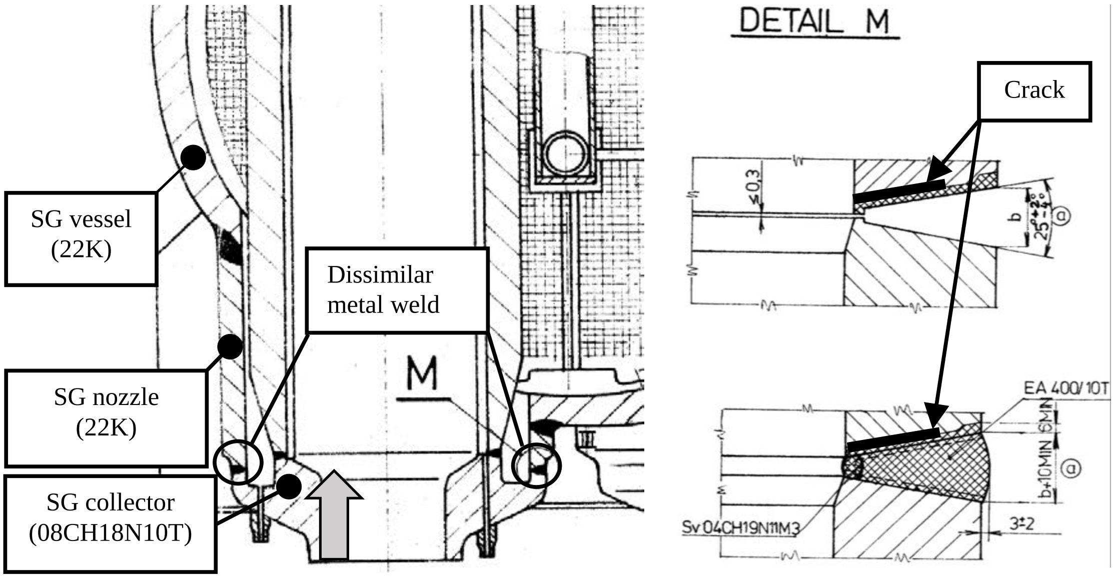

Fig. 2. PGV-440 steam generator collector's weld area.

2. Decreasing stresses

There are two approaches how to decrease the possibility of crack occurrence and growth. The first one is to try keeping the steam generator collector pocket as clean as possible (clean from deposits), it means to try to improve the effectiveness of the pocket's blowdown. And the second one is to try to decrease existing stresses. Of course both approaches can be combined. The stresses are combination of thermal stresses, stresses coming from external forces on the collector's nozzle and possibly also residual stresses in the weld area. From previous analyses is known that the most significant are the thermal stresses here.

Recently, there were presented some studies of external cooling of this area from Russia. Those studies were done on WWER-1000 steam generators, but from similar reason. And because the SG primary collector's joint is similar to WWER-440, we tried to make similar analyses here.

The external cooling of the SG primary collector weld joint is done by placing external "cooling sleeve" (Fig. 3) around it, with inlet and outlet nozzles. The cooling media could be air from the reactor's containment, which is driven inside inlet nozzles by cooling fan of specific power.

The placement of the inlet and outlet nozzles will be according to desired increased cooling in some specific radial position on the weld's surface.

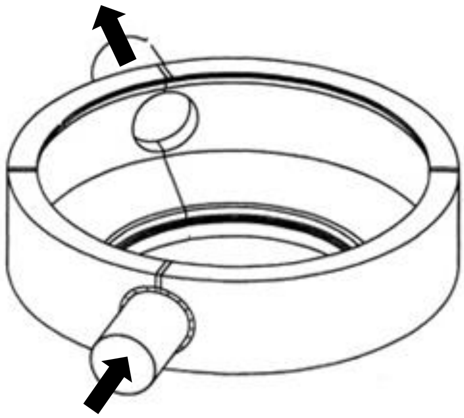

Fig. 3. Steam generator collector's cooling sleeve design.

3. Numerical analyses and results

Computational fluid dynamics (CFD) analyses and subsequent finite element analyses (FEM) were performed, with the objective to compare stresses in the weld area with and without external cooling.

The CFD 3D numerical model covered lower half of the steam generator with both collectors and cooling sleeves attached.

Figure 4 shows the collector's pocket area in detail with weld joint and on the other picture also areas of stress evaluation. Of most importance were of course stresses in the weld area, because they cause the cracking there, but stresses in radiuses were also observed.

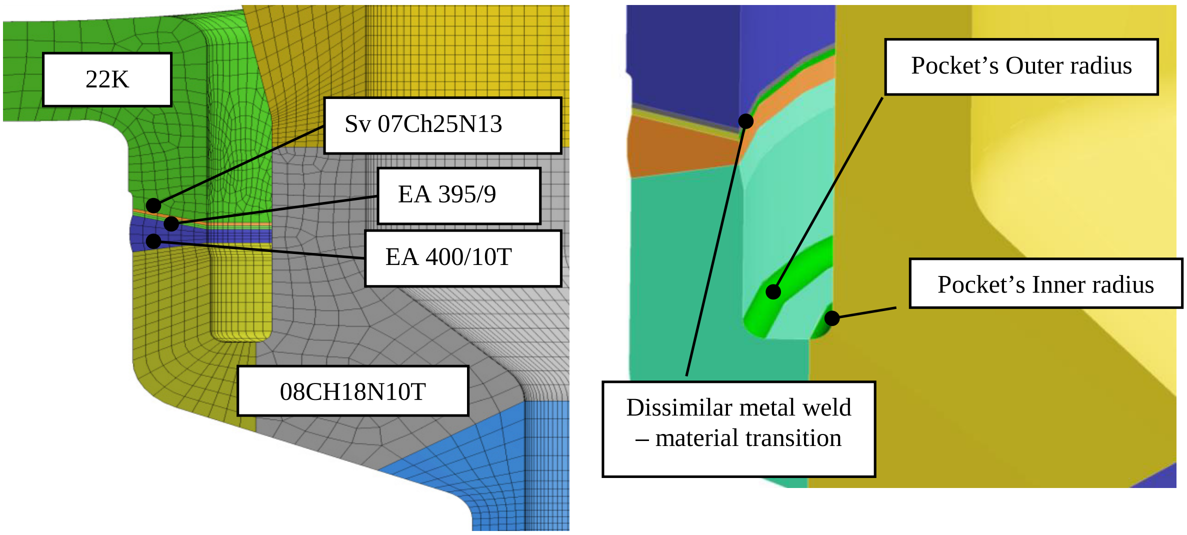

Fig. 4. Cooled area in detail with material description (left) and stress evaluation areas (right)

In following figures are shown results from numerical analyses. In Fig. 5 is shown the dependence of calculated minimal temperatures on the weld's outer surface on cooling air volume flow. It can be seen that with volume flow above 1.5 $m^3 s^{-1}$ the temperature comes below 100 °C.

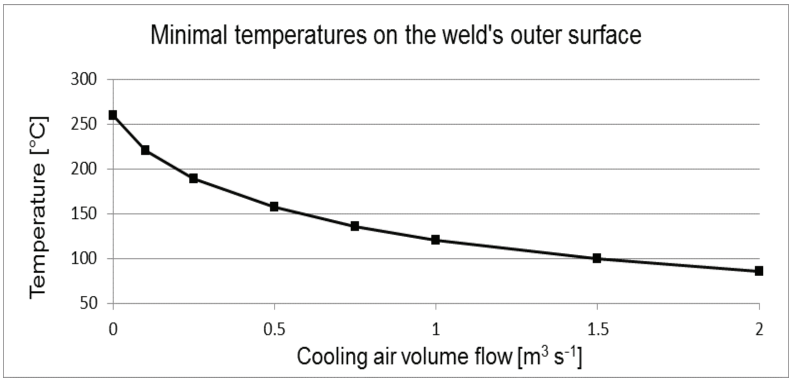

Fig. 5. Calculated minimal temperatures on the weld's outer surface depending on cooling air volume flow.

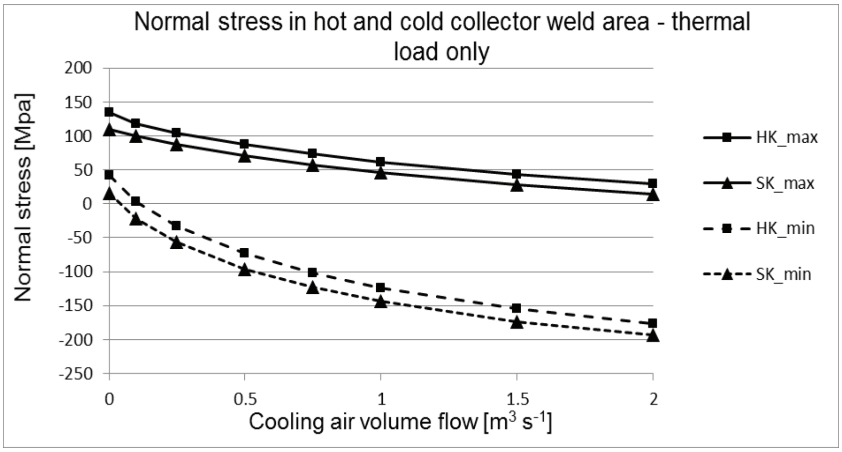

Fig. 6. Maximal and minimal normal stresses in weld area depending on cooling air volume flow – thermal load only.
(HK – Hot Collector, SK – Cold Collector)

Maximal and minimal calculated normal stresses in weld area are shown in Figs. 6 and 7. Figure 6 shows only stresses from thermal loading, and the combination of thermal and external loading are shown in Fig. 7. It is obvious that thermal loading has the biggest impact on stresses in this area. From these figures, it is visible that without cooling of weld area the tensile stresses are all around the circumference, but with proper external cooling (above 2 $m^3 s^{-1}$) the stresses are compressive on almost all around the circumference.

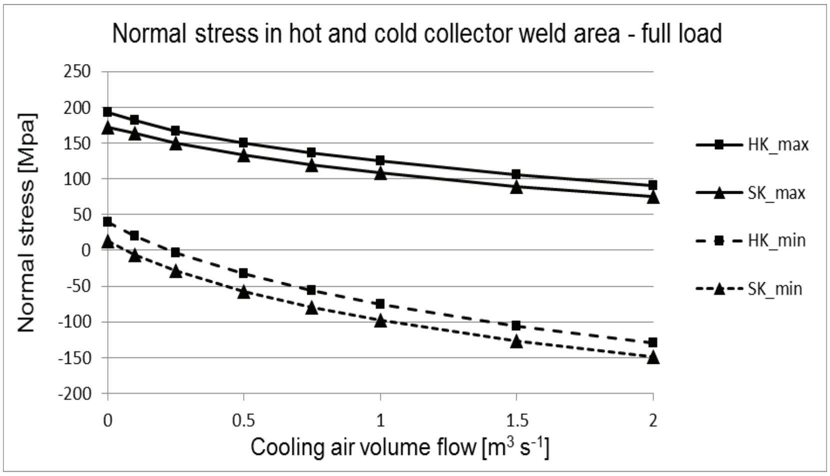

Fig. 7. Maximal and minimal normal stresses in weld area depending on cooling air volume flow – full load. (HC – Hot Collector, CC – Cold Collector)

4. Summary and conclusions

Results of analyses showed that by proper external cooling of the weld area it is possible not just to decrease significantly existing tensile stresses, but to completely change the tensile stresses into compressive ones. This of course would have great impact on crack growth prevention. In combination with improved chemistry in the collector's pocket it can significantly decrease the possibility of cracking in the steam generator primary collector weld's area.

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