REPARATURNO NAVARIVANJE KOROZIONIH OŠTEĆENJA NA POSUDAMA POD PRITISKOM U HIDROELEKTRANI „ĐERDAP 1“

Repair welding of corrosion damaged pressure vessels in the "Đerdap 1" Hydro-electric power plant

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Sažetak

U ovom radu prikazan je postupak reparacije dve posude pod pritiskom koje se nalaze u Hidroelektrani Đerdap 1, u Kladovu. Predmetne posude pod pritiskom se nalaze u sistemu protiv požarne zaštite generatora turbine. Oštećenja u unutrašnjosti posuda su otkrivena od strane tehničkog osoblja Hidroelektrane Đerdap 1, prilikom priprema posuda za redovan unutrašnji pregled od strane Imenovanog tela. Oštećenja koja su se javila u ovim posudama su posledica neadekvatne antikorozivne zaštite unutrašnjih površina posude, od strane proizvođača. Posude su povezane sistemom spojenih sudova i u jednoj je radni fluid voda-vazduh a u drugoj samo vazduh. U daljem tekstu prikazana je procedura sanacije oštećenja i otklanjanja defekata, reparacija primenom ručnog elektrolučnog zavarivanja (E postupak) prema definisanoj tehnologiji. Pored toga, prikazani su i zahtevi koji moraju biti ispunjeni da bi jedna tehnologija navarivanja bila uspešno izvedena, a navarene posude budu vraćene u eksploataciju.

Abstract

The procedure used for repairing of two pressure vessels located at the "Đerdap 1" hydro-powerplant in Kladovo is shown in this paper. Pressure vessels are a part of the turbine generator fire protection system. Damages on the vessel interior were detected by the technical staff of "Đerdap 1" hydro-powerplant, during the preparations for regular internal examination. Damages that have occurred in these vessels are the consequence of inadequate anti-corrosion protection of internal vessel surfaces on the manufacturer's end. Vessels were connected by a system of connectors, and one of them contains the water-air work fluid, whereas as the other only contains air. The manual arc welding procedure (or MAW) is used for repairing of damages and removing of defects on vessels. Requirements that must be fulfilled in order for a repair welding technology to be performed successfully, which would ensure that the vessels can be put back into exploitation, as well as advice for preventing further damages, are also presented.

1. Introduction

Failure of pressure vessels represents a serious practical problem even nowadays, and cracks in pressure vessels could jeopardize their exploitation safety and the safety of the people [1, 2, 3, 4]. With adequate control and inspection, cracks can be removed, and adequate repairs can prevent further crack growth which could lead to the final failure of pressure vessel equipment. Pressure vessels should comply with regulations in terms of parent material used for their manufacturing, welded joint quality, manufacturing technology and exploitation safety [5, 6].

Hydro-electric power plant „Đerdap“ is a system that contains one dam and two river-flow hydroelectric power plants, "Đerdap 1" and "Đerdap 2" built on the Danube River at the exit from the Đerdap Gorge, on the Serbian-Romanian border, and it belongs to Serbia and Romania. HPP "Đerdap

1" was built in 1970 on the 943rd kilometer of the Danube, 10km upstream from Kladovo. Six 194 MW generators were built on the Serbian and Romanian side. The power of the generators from the Serbian side is 1.058 MW. Since 2007, HPP "Đerdap 1" is in revitalization and three of six aggregates have been revitalized. Their installed power is now 205 MW per aggregate.

Presented in this this paper is the repair of damages on pressure vessels located in the fire protection system of the turbo generator [7, 8]. The generator fire protection system consists of eight pressure vessels divided into four batteries. Each battery consists of one vessel for air and another vessel, whose volume is filled with 2/3 of water and 1/3 of air. The vessels in the battery are connected in accordance with the principle of communicating vessels. One of the water vessels (tank) in the fire protection system is shown in Fig. 1.

Figure 1 Water vessel in the fire protection system.

2. Detected damages in welded joints of the vessels

During the preparation for a regular internal inspection of pressure vessels by the appointed body, the technical staff of HPP "Đerdap 1" have discovered corrosion damages on the surfaces on the inner side of the vessels at the mantles and lids of both vessels (Figure 2 on the left). In addition, the inspection revealed more unacceptable errors, such as the incomplete penetration at the root, incisions, lack of penetration (Figure 2 right) etc. Inadequate anti-corrosion protection of the inner surface of the vessels cause the “good” conditions for the corrosion development. Besides that, environment itself and operating fluids in the vessels (water and water-air) are suitable for the corrosion creation and development.

Figure 2 Left) Corrosion damages on the vessel mantle, right) incomplete penetration at the root of the groove.

In order to determine the level of damage and make the right decision for further steps, control of the thickness was performed by non-destruction test methods. Ultrasound measurement of the thickness was performed on the mantles and the lids on both vessels, at the damaged locations. Before measuring, damaged surfaces were machined. Corrosion damages were also removed in order to obtain valid measurement results (Fig. 3).

Figure 3 Removing of corrosion damage and preparation for ultrasound measurement of thickness.

After measuring was performed, the thicknesses of pipes on the lids were obtained in the range of 9.6 - 9.8 mm, and on the mantle in the range of 6.8 - 9.3 mm. Nominal thickness of the mantles and the lids of both vessels wis 10 mm, and it was found that the thickness of the thinning was 3.2 mm. The projected additive for corrosion and wear is 1 mm, so 3.2 mm thinning is unacceptable.

Inspection of welded joints was also performed, along with the ultrasonic thickness measurement. It has been determined that errors in welded joints are present and were created during the production of the vessel. Errors that were discovered included linear porosity, clusters, edge incisions, inclusions, incomplete penetration at the root, etc.

After inspection and obtaining of results, it was decided to apply the repairing method of both vessels using the selected welding procedure. Repair welding procedure is also used to correct all errors detected during the inspection. Prior to the beginning of repair welding, the adequate technology should be developed by the IMS Institute and, after being approved by the Appointed Body, it can be used to repair the damaged surfaces and welded joints of both vessels.

3. Technical characteristics, geometry and parent material of the pressure vessels

The vessels that are the subject of this paper have the following technical characteristics, which are shown in table 1.
Vessel (reservoir) for water and air has the fabric number 31-27-87 and vessel (reservoir) for air has the fabric number 31-8-863.

Table 1 Technical characteristics of vessels [9, 10]

Vessel	-	Water and air reservoir	Air reservoir
Fabric number	-	31-27-87	31-8-863
Maximum allowed pressure	(bar)	8.0	8.0
Test Pressure	(bar)	10.4	10.4
Maximum allowed temperature	(ºC)	20	20
Volume	(m^3)	10.5	10.0
Working fluid	-	Water/air	Air
Construction	-	Horizontal	Horizontal
Diameter	(mm)	Ø2200	Ø2200
Length	(mm)	3110	2980
Mantle material	-	S235 JRG2	S235 JRG2

Lid material	-	P265GH	P265GH
Mantle thickness	(mm)	10.0	10.0
Lid thickness	(mm)	10.0	10.0

Both vessels are made of the same materials. The mantles of both vessels were made of hot rolled structural steel S235 JRG2. The chemical composition of S235 JRG2 is given in Table 2, and its mechanical properties in Table 3.

Table 2 Chemical composition of steel S235JRG2 [11]

Element	C	Si	Mn	Ni	Cr	Mo	P	S
(%)	max 0.2	max 0.55	max 1.4	max 0.3	max 0.3	max 0.08	max 0.045	max 0.045

Table 3 Mechanical properties of steel S235JRG2 [11]

Mechanical property	R_e (N/mm^2)	R_m (N/mm^2)	A_s %
Value	215	340	24

The lids of both vessels are made of steel P265GH. This steel belongs to a group of steels that are used for working at elevated pressure and temperature, and is widely applied in the manufacturing of steam generators, boilers, distributors and pressure vessels. It is used for working at temperatures up to 450 $^{\circ}$C. The chemical composition of this steel is given in Table 4, and its mechanical properties in Table 5.

Table 4 Chemical composition of steel P265 GH [12]

Element	C	Si	Mn	Ni	Cr	Mo	P	S
(%)	max 0.2	max 0.4	0.8-1.4	max 0.3	max 0.3	max 0.08	max 0.025	max 0.015

Table 5 Mechanical properties of steel P265 GH [12]

Mechanical property	R_e (N/mm^2)	R_m (N/mm^2)	A_s %
Value	265	410 - 530	22-23

4. Procedure and technology for repairing of pressure vessels

Anti-corrosion protection of the inner surfaces of the vessels has not been adequately performed during its construction and the beginning of the exploitation. As it was mentioned before, working environments of vessels, i.e. working fluids (air and water) are suitable for corrosion development, and these condition caused significant corrosion damage. After the analysis was performed, the repair technologies, i.e. the technology of performing reparations on pressure vessels of the fire protection generator system [7], developed by the IMS Institute was performed. The technology included the following activities:

- Weldability analysis
- Selection of the welding procedure
- Selection of additional material
- Removal of defects
- Processing of machined locations
- Preheating analysis
- Electrode preparation
- Performing of selected and created welding technology
- Inspection and control of welded joints

4.1 Weldability analysis

An analysis of weldability of the basic materials was performed. The Seferian procedure [13] was applied in order to calculate the preheating temperature. For the mantle made of S235JRG2 of both vessels (with thickness of 10 mm), the required preheating temperature was determined to be150 ºC, based on the following relations (1), (2), (3) and (4):

$$360[C]_h = 360C + 40(Mn + Cr) + 20Ni + 28Mo \tag{1}$$

$$[C]_d = 0.005[C]_h \tag{2}$$

$$[C] = [C]_d + [C]_h \tag{3}$$

$$T_p = 350\sqrt{[C] - 0.25} \tag{4}$$

For lids made of steel P265GH, with thickness of 10 mm, it was calculated that the preheating temperature is also 150 °C according to above given relations.

However, according to the recommendations in the literature, namely according to Russian regulations [14] for pressure vessels that work at pressures up to 16 MPa with thicknesses of 4-120 mm, pre-heating is not necessary for the used parent material. This proved to be a good assumption since the final control shows no detection of cracks in welded zones and repair welded joints.

4.2 Selection of the welding procedure

Manual arc welding is selected for repairing on the basis of parameters which influence the choice of welding process, such as the weldability of the parent material, geometric complexity, economic analysis etc. In addition to the welding process, further requirements have been set for the qualification of the welding technology in accordance with SRPS EN ISO 15614-7. Welding activities can only be carried out by an organization that is certified according to EN ISO 3834.

4.3 Selection of the additional material

During the selection of the additional material, the percentages of content of carbon and other alloying elements as well as the cleaning mechanism were taken into account. As the manual arc welding procedure was selected for the repair, and the quality of the material of the mantles (S235JRG2) and the lids (P265GH) were taken into account, the electrode EVB 50 manufactured by Železarna Jesenice was selected as an additional material.

The selected electrode is suitable for welding non-alloyed and low-alloyed steels with strength up to 610 N/mm2, as well as for welding fine-grain steels of high strength. Additional material is also chosen due to good toughness (even at low temperatures) and resistance to cracks occurrence in welded joints. The electrode has excellent welding and technological properties and a forms stable arc. The content of hydrogen in the weld is less than 5 ml/100 g [15].

Commercial label, manufacturer, chemical composition and mechanical properties of pure weld metal of EVB 50 electrodes is given in Table 6.

Table 6 Mechanical properties of additional material [15]

Commercial label	Manufacturer	Chemical composition %			mechanical properties		
		C	Mn	Si	Re (N/mm^2)	Rm (N/mm^2)	Elongation A_5 %
EVB 50	Železarna Jesenice	0.08	1.0	0.60	> 440	510-610	24

Before use, the electrodes must be dried in the ovens at a temperature of 400 °C for 1 h. Re-drying of the electrodes is permitted due to the possibility of cracking in the repeated process. After drying, electrodes should be stored in individual heaters (quivers) at a temperature

4.4 Removal of defects and preparation for welding

Corrosion affected areas in the damaged zones are at least 20 mm wide, and they are machined up to the metal shine in order to eliminate defects, corrosion traces and sharp edges. Defect removal was carried out under constant magnetoflux or penetrants control depending on the size of the zone. The appearance of the machined zone can be seen in Figure 4 on the left side.

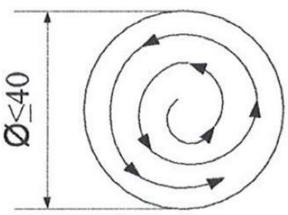
Figure 4 left) Machined zone, right) Appearance of prepared surface for welding.

Defects in welded joints that have occurred during exploitation are also removed using machining under, constant control of liquid penetrants. The appearance of the prepared surfaces after the control can be seen in Figure 4 on the right side. After removing the defects, the processing of the machined zones was performed in order to remove all sharp edges and to prepare surfaces for applying the welds. Appearance of one of the zones after additional processing and control is shown in Figure 5.

Figure 5 Prepared surfaces for welding after additional processing and liquid penetrant control.

4.5 Repair welding procedure

Welding is performed with a short arc with permanent removal of slag. Special attention is paid to filling the craters caused by breaking of the electric arches. Each subsequent weld is overlapped with previous one to 1/3 of the width. In order to reduce the residual stresses due to heat input, in the case of surfaces where grinding was performed in a spiral way with diameter less than 40 mm, welding was also performed in a spiral way, as can be seen in Figure 6 (left). For grinded surfaces with an area up to 200 cm^2, welding of the bottom and lateral sides were performed by rotating the direction of the welds by 90° for each layer, as well as rotating the direction of laying for each weld. In the case of grinding surfaces greater than 200 cm^2, the first layer is welded in the direction of the reservoir axis, but the next layer was applied as divided squares with sides of 100 mm (Figure 6 right). Each subsequent layer is welded perpendicular to the previous one.



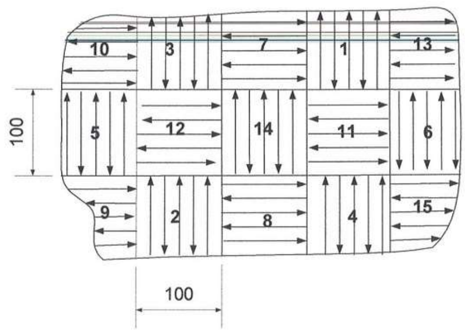


Figure 6 left) Welding procedure with spiral grinded surfaces Ø <40 mm; right) welding procedure for grinded surfaces greater than 200 cm^2 (second layer)

For narrow and long grind surfaces, welding with "backstop" was applied. The appearance of welded zones can be seen in Figure 7.

Figure 7 Appearance of welded zones.

Welding of both vessels was carried out at an ambient temperature greater than 5 °C. After welding was performed, excessive overhangs were removed and the welds were reduced to the level of the parent material. The welding parameters are shown in Table 7.

Table 7 Welding parameters

Layer	Procedure	Diameter of additional material	Current Amperage	Type of current / polarity
1	MAW	Ø2.5 mm	65-90 A	DC +
2 – n	MAW	Ø3.25 mm	110-140 A	DC +

4.6 NDT control of welds and strength pressure testing

Liquid penetrant controls have been performed on welds in order to detect possible defects, and were carried out within the scope of 100%. In addition to penetrant control, ultrasonic measurement of the thickness of repaired surfaces was performed as well as radiographic control of all welded joints and parent material in order to investigate the homogeneity of welded layers. Figure 8 shows the locations of radiograms during radiographic control.

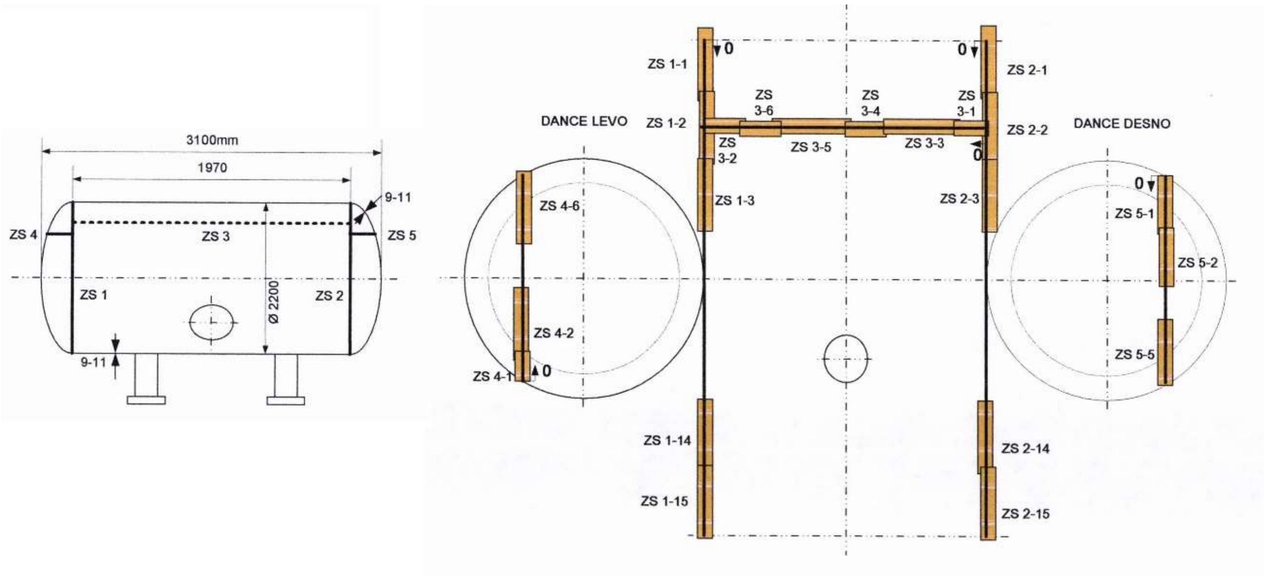


Figure 8 Radiograms distribution during radiographic control of welded joints.

The repair of the damaged surfaces of both vessels was performed successfully, in accordance with the selected technology. NDT control revealed that there are no defects in welds and welded joints on both vessels. After all of the welding processes were completed and NDT tests were carried out, strength pressure testing was performed on both vessels with cold water in the presence of the appointed body. Pressure of 10.4 bar was determined, based on the technical documentation of the vessels. The control manometer with a measuring range of 0 - 16 bars, with an accuracy of 0.6 was used. During and after the examination, there were no signs of moistening, dehumidification and leakage on the parent material and welded joints of the vessels. Signs of deformation of the equipment were not observed. Water pressure testing was performed successfully and it was concluded that the vessels can be returned in exploitation after the AKZ regeneration.

5. Discussion and conclusions

This paper presents the importance and necessity of controlling of equipment which is constantly in service. During the preparation for a regular internal inspection by the appointed body, corrosion damage was identified on both vessels, on the mantles, as well as on the lids, probably caused by and formed during the vessel manufacturing process.

In order to detect the level of damages, an independent house was hired to perform non-destructive testing of vessels in question. After detection and defining of the damage level, repair welding of vessel was carried out. For the purpose of performing repair of highest possible quality, the appointed body was hired to supervise the repair activities. The repair procedure was developed and approved by the appointed body, which has also supervised the whole repair welding procedure.

Rehabilitation was done with minimum repairs.

All tasks that were observed during this repairs were respected and include the following:

- review and approval of technical documentation by the appointed body.

- control during removal of defects and control during preparation of welding grooves
- control after welding of damaged surfaces and welded joints
- final inspections of the whole bottom panel that include strength pressure tests with cold water.

Successful repair can be expected if all welding technology requirements are fulfilled. In order to prevent residual cracks or defects that can cause failure of equipment later in service, it is necessary to carry out inter-phase control during welding at the stop points and perform NDT tests on welds and welded joints. In addition to all of the above, hiring of an appointed body for pressure equipment in order to approve and monitor the repair process throughout its duration was found to be a necessary part of these type of repairs.

Indirectly, this paper describes the importance and necessity of monitoring and quality control during the construction of equipment itself, because in this case the problem was related to inadequately applied anti-corrosion protection by the equipment manufacturer and defects in welded joints that have been made during the manufacturing of the vessels themselves.

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