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Repair of Damages that Occurred on the Welded Joints at the Body of Guide Vane Apparatus Vanes of the Vertical Kaplan Turbine

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Abstract. Vertical Kaplan turbines, with nominal power of 178 MW and manufactured in Russia, have been installed in 6 hydroelectric generating units of hydro power plant 'Djerdap 1'. Experimental tests were carried out by non-destructive methods in order to determine the turbine condition during the rehabilitation of the hydro power plant. Lack of root penetration was detected in V40 welded joints between upper and lower sleeves and bodies of guide vane apparatus vanes. Height of the lack of root penetration was in the range between 5 and 15 mm, while the allowable height of the lack of root penetration is 3 mm, according to the technical conditions. The upper sleeves were made of cast steel 25L (in accordance with GOST 977), while lower sleeves were made of steel forging St 25 (in accordance with standards GOST 1050 for chemical composition and GOST 8479 for forgings).Methodology for the repair of non-penetrated welded joints between the sleeves and body of the guide vane apparatus vane was composed taking into account the results of ultrasonic testing. By repair methodology it is necessary to, due to the structural solution and service function of guide vane apparatus vanes, specify a large number of details, consider them carefully and carry them out in order to improve safety, because if some of them get overlooked, underestimated or incorrectly perceived, significant problems in turbine operation may occur.This methodology refers solely to the repair of damaged welded joints between sleeves and bodies of guide vane apparatus vanes.

Introduction

Vertical Kaplan turbines, with nominal power of 178 MW and manufactured in Russia, have been installed in 6 hydroelectric generating units of hydro power plant 'Djerdap 1' [1]. They were designed for the service life of 40 years due to the structural solution, or in other words due to the impossibility to perform periodic inspections and condition analyses. In Fig. 1 the guide vane apparatus vane is shown. In Fig. 2 welded joints V40 between the upper or lower sleeve and body of the vane are displayed. The repair methodology for non-penetrated welded joints was composed on the basis of ultrasonic testing results.

Chemical Composition and Mechanical Properties of Parent Material

Chemical compositions and mechanical properties of cast steel 25L, steel forging St 25 and sheet metal MSt 3 of which the shaft sleeves and bodies of guide vane apparatus vanes were made are presented in Table 1 and Table 2, according to standards GOST 977 [2], GOST 8479 [3], GOST 1050 [4] and GOST 380-60 [5].

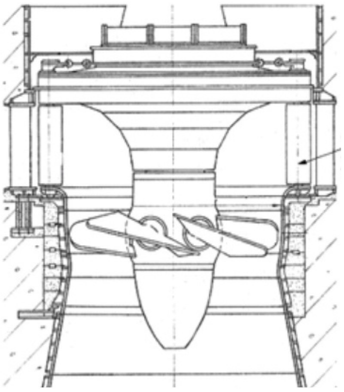

Fig. 1 Appearance of a vertical Kaplan turbine the front of the neck of runner glass

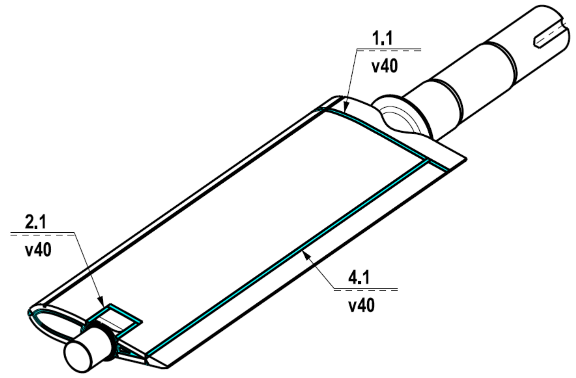

Fig. 2 Appearance of a guide vane apparatus vane with marked V40 welded joints

Table 1 Chemical composition, values in %

Material	GOST	C	Si	Mn	P	S	Cr	Ni	Cu
25L	997	0,22-0,30	0,20-0,52	0,35-0,80	≤ 0,040	≤ 0,045	< 0,30	< 0,30	< 0,30
St 25	1050	0,22-0,30	0,17-0,37	0,50-0,80	≤ 0,035	≤ 0,040	< 0,25	< 0,25	< 0,25
MSt3	380-60	0,14-0,22	0,12-0,30	0,40-0,65	≤ 0,045	≤0,055	< 0,30	< 0,30	< 0,30

Table 2 Mechanical properties of normalized and annealed material

Material	GOST	Yield strength YS [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A [%]	Contraction Z [%]	Impact energy KCU [KJ/m^2]
25L	997	305-315	520-530	21-23	27-28	62-64
St 25	8479	min 195	min 390	20	50	49
MSt3	380-60	min 206	min 509	43	-	54

Weldabilty Analysis of Parent Materials

Weldability of parent materials is limited. Taking into account that cast steel 25L is 60 mm thick, as well as that sheet metal MSt 3 is 36 mm thick, it is recommended to perform preheating and post weld heat treatment even when welding is being performed with use of filler material of the same type. According to Sepherian, preheating temperature is being calculated on the basis of the chemical composition, Table 1. For thicknesses up to 200 mm and chemical composition of cast steel 25L, necessary preheating temperature during welding is $T_p = 276$ °C.

Selection of Welding Procedure. Based on experience, the welding / surface welding process carried out through the use of filler wire (process 136) was selected due to the fact that significantly lower residual stresses compared to other welding procedures that are based on the use of filled welding electrodes occur.

Selection of filler material. Repair of non-penetrated welded joints between the sleeves and bodies of guide vane apparatus vanes by welding / surface welding was carried out through the use of filler wire Ø 1,2 mm [6]. Chemical composition and mechanical properties of weld metal formed through the use of filler wire OK E71T-1 are presented in Table 3 and Table 4.

Table 3. Chemical composition of weld metal, values in [%]

Filler wire	C	Si	Mn
OK E71T-1	0,06	0,50	1,30

Table 4. Mechanical properties of weld metal

Filler wire	Yield strength YS [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A [%]	Impact energy KV [KJ/m^2]
OK E71T-1	> 420	510-590	> 22	> 54 (- 20 ^{0}C)

Repair of Non-Penetrated Welded Joints

This methodology refers to works carried out during the repair of non-penetrated welded joints between the sleeves and bodies of guide vane apparatus vanes by welding / surface welding.

Removal of non-penetrated areas in welded joints. Appearance of a non-penetrated area in welded joint V40 is shown in Fig. 3. Grinding of the section with lowered weld metal thickness should be carried out until reaching the depth which allows easier welding of 2-2.5 mm of sheet metal thickness in root area. Multiple openings with 3 mm in diameter should be drilled in order to check this measure, Fig. 4-6. Length of the section which is being repaired is restricted to 200 mm in one passage in order to reduce the level of deformations. When it comes to longer sections, the repair should be carried out in several passages.Grinded spots should not have sharp edges and should enable accessibility for deposition of layers by welding. Grinded area should be degreased, dry and clean.

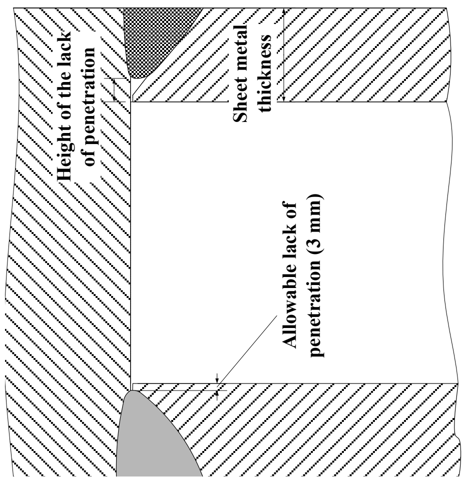

Fig. 3 Welded joints with the lack of root penetration at the side of the upper sleeve

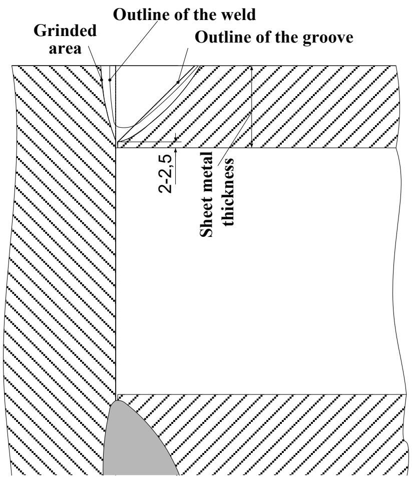

Fig. 4 Appearance of the grinded area at the side of the upper sleeve

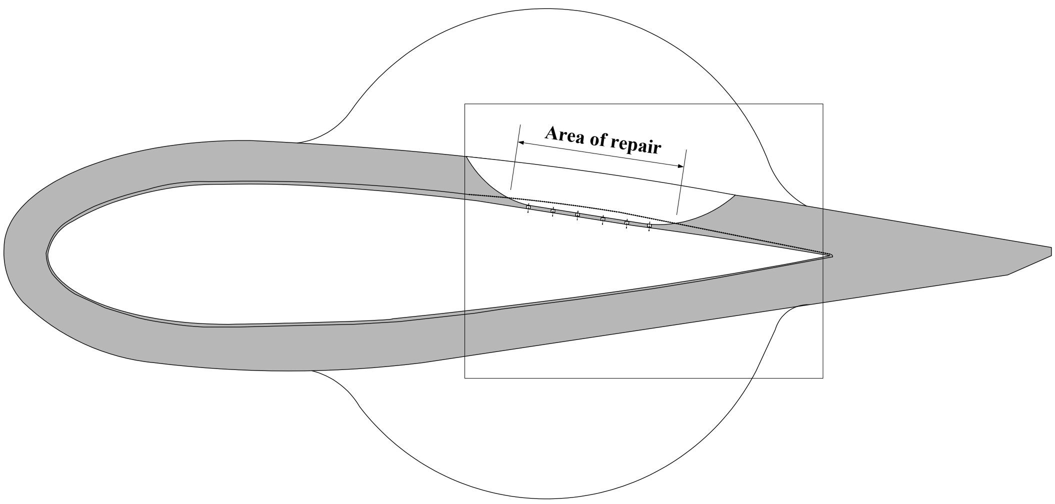

Fig. 5 Repair of sections with the lack of root penetration shorter than 200 mm

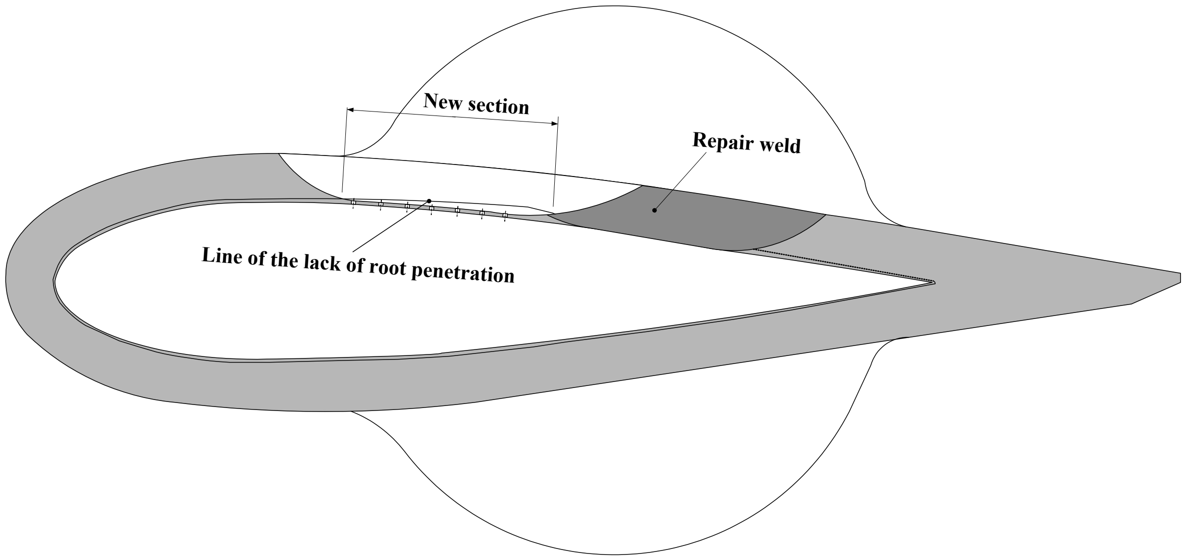

Fig. 6 Repair of sections with the lack of root penetration longer than 200 mm

Welding Process Performed in Order to Repair Areas with Lack of Root Penetration

Preheating at max 150°C was performed by using the inductors located 300 mm around the area where grinding was performed, in compliance with Russian literature for cast steel 25L. Preheating temperature was checked by IC thermometers. Welding was performed in PA position in grinded areas that were located on the same side of the vane, while welding in areas that were located symmetrically on both sides of the vane was carried out by 2 welders in PF position [7]. Welding was performed at ambient temperature greater than 5ºC, with no significant air streaming. Weld reinforcement was removed by grinding after the finish of the welding process.

Parameters of welding performed in areas of welded joints with lack of root penetration. Parameters that were used during the welding through the use of filler wire OK E71T-1 are as follows:
– Wire diameter: 1.2 mm;
– Current source: direct, polarity +, voltage 25-28V, current intensity 215-225 A;
– Protective gas: Ar mixture, composition of gas mixture in accordance with EN ISO 14175: M3-1 [8], gas consumption 12-15 l/min;
– Welding speed in horizontal position: 0.35-0.45 m/min;
– Wire feed speed in horizontal position: 9.5 m/min;
– Length of the free end of the wire: 10-12 mm;
– Distance between the contact nozzle and the welding pool: 12 mm.

Procedures that cause decrease of stresses and deformations that occur during welding. Following procedures were applied for the decrease of stresses and deformations that occur during repair welding:
– During the deposition of weld beads system that included overlaying of groove edges, with the finish layer for annealing, which was removed by grinding the face of the weld in order to even it with parent material (Fig. 7) was applied;
– Every layer was treated by pneumatic hammer with rounded top with diameter of 3 mm;
– After grinding was performed wide area (weld metal, heat affected zone and 10 mm of parent material on every side) of the repair weld was treated by pneumatic hammer with rounded top with diameter of 3-5 mm, during which overlapping of prints was required. After hammering the surface had to be polished.

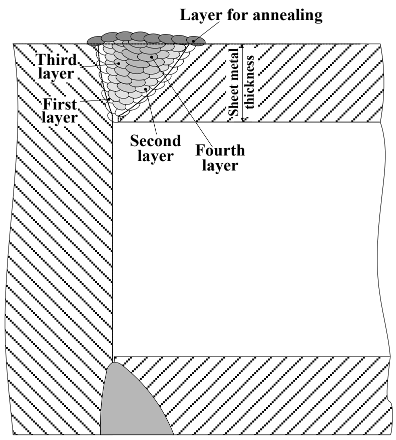

Fig. 7 Appearance of the order of deposition of weld beads along the cross-section

Heat Treatment of Repair Welds at Guide Vane Apparatus Vanes

Heat treatment was carried out only for guide vane apparatus vanes with the volume of repair welds that exceeds 3000 cm^3.

Applied parameters that refer to heat treatment, shown in Fig. 8, are as follows:

– Heating until reaching T = 300ºC±25 ºC was carried out in 1 hour;
– Heating until reaching T = 590±15 ºC was carried out with rate less than 70ºC/h;
– Keeping the temperature at 590±15 ºC was carried out in 5h;
– Cooling until reaching 250 ºC was carried out with rate less than 50ºC/h;
– Cooling below 250ºC in still air.

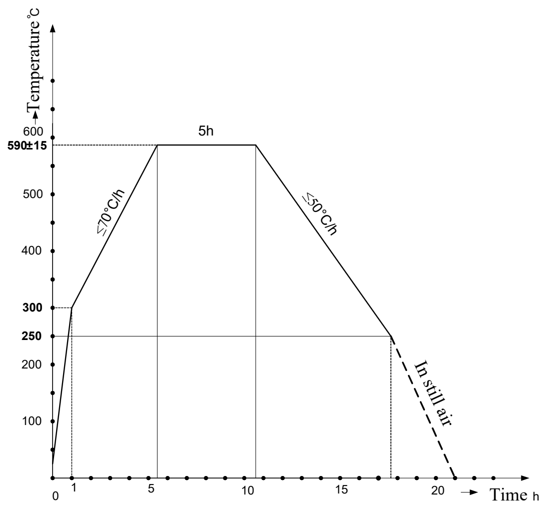

Fig. 8 Diagram that refers to heat treatment of repair welds of guide vane apparatus vanes

Testing of Repair Welds by Non-Destructive Methods

Testing of repair welds by non-destructive methods was carried out after the machining of the weld face and heat treatment were finished.

Visual testing. Visual testing (VT) was carried out before, during and after welding in compliance with standard [9] and acceptability criteria from standard [10] for quality level B.

Magnetic particle testing. Magnetic particle testing (MT) of repair welds was carried out after the machining of the weld face and heat treatment were finished, in compliance with standard [11] and acceptability criteria from standard [12] for acceptance level 2.

Ultrasonic testing. Ultrasonic testing (UT) of repair welds was carried out after the machining of the weld face and heat treatment were finished, in compliance with standard [13] and acceptability criteria from standard [14] for acceptance level 3.

Conclusion

Successfulness of applied methodology for repair of areas of welded joints where lack of root penetration was detected between sleeves and bodies of turbine guide vane apparatus vanes by welding at hydro power plant 'Djerdap 1' was confirmed by equipment manufacturer 'Power Machines' from Saint Petersburg, because they gave the guarantee for their use until next rehabilitation of the turbine.

Acknowledgement

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