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RECONSTRUCTION OF DAMAGED ROTOR SPOKE IN RHPP BAJINA BAŠTA - PART II: WELDING

REKONSTRUKCIJA OŠTEĆENOG OKLOPA ROTORA U RHE BAJINA BAŠTA - DEO II: ZAVARIVANJE

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Keywords
- rotor shell
- cracks
- reconstruction
- welding

Abstract

During the rehabilitation of the Reversable Hydro Power Plant 'Bajina Basta' in 2025, cracks were discovered in rotor spoke ribs. Through an analysis of rotor spokes it was determined that cracking was caused by unexpected weight overloading. It was also concluded that cracks cannot be grooved and surface welded due to limited space. Thus, a different approach had to be taken, leading to the reconstruction of the rotor spoke. To do so, it was necessary to strengthen the rotor by new additional spoke ribs that were welded with the existing, damaged ones, and rotor spoke.

Ključne reči
- oklop rotora
- prsline
- rekonstrukcija
- zavarivanje

Izvod

Tokom rehabilitacije Reverzibilne hidroelektrane „Bajina Bašta" 2025. godine, otkrivene su prsline u nosećim gredama oklopa rotora. Analizom naponskog stanja oklopa rotora utvrđeno je da su prsline uzrokovane neočekivanim preopterećenjem usled težine. Takođe je zaključeno da se prsline ne mogu izvaditi i površinski zavariti zbog veoma ograničenog prostora. Stoga je morao biti usvojen drugačiji pristup, što je dovelo do rekonstrukcije oklopa rotora. U tom cilju oklop rotora je ojačan novim dodatnim gredama, koje su spojene zavarivanjem sa naprslim gredama i oklopom.

INTRODUCTION

Cracks appeared on the rotor of unit R2 in RHE 'Bajina Bašta' at the points of support on the lower overhang of the beam, due to high stress concentration, spreading radially across the outer surface, Fig. 1, as shown with all necessary details /1/.

Due to geometric limitations, the repair of cracks was not possible, and so the rotor was reconstructed by installing new supporting beams that were joined by welding with the cracked beams and also by screws (not analysed here) with the rotor spoke, /1/. In this way, existing beams with cracks are relieved, and the new beams take over the load. The new beams were joined with cracked beams and the rotor casing into one unit by means of 4 welded joints, and the part of the rotor casing at reconstruction is shown in Fig. 2:

F1.1 - overhead horizontal weld new beam - old beam,
F1.2 - vertical weld new beam-old beam,
F1.3 - overhead horizontal weld new beam-rotor,
F1.4 - vertical weld new beam-rotor.

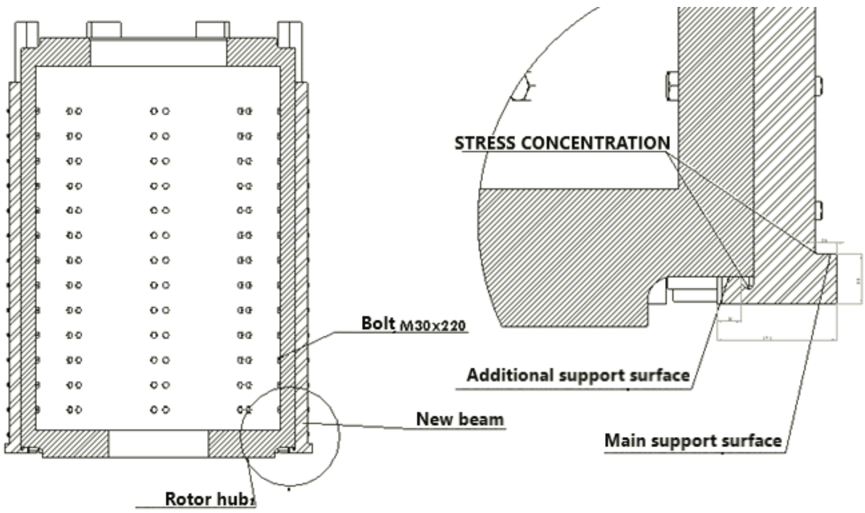

Figure 1. Rotor spoke, supporting beams and stress concentration area.

a)

b)

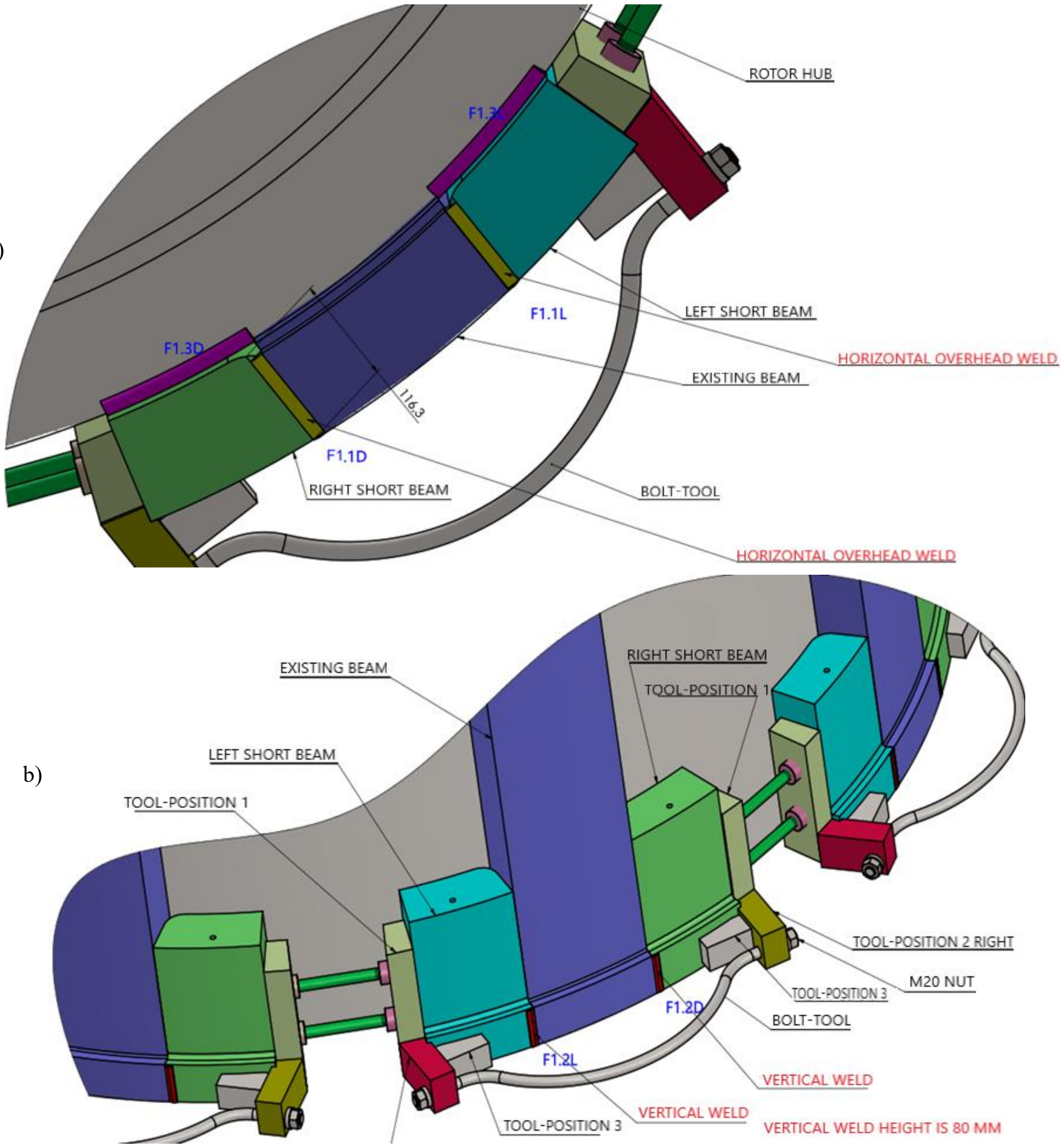

Figure 2. Isometric presentation of reconstructed part of rotor spoke: a) view from above; b) view in front.

BASE METAL

Material of existing beams is carbon structural steel JIS G3106 Grade SM 41 A/B, /2/, with minimal yield stress 235 MPa and contents of S and P up to 0.035 %. Material of new beams is steel S355 J2 with increased Mn content, up to 1.65 %, minimal yield stress 355 MPa, minimal impact toughness 27 J at -20 °C (sheet thickness 3-150 mm). Steel S355 J2 is quality, fully or double tempered steel, Si > 0.1 % and Al 0.02 %, to enable nitrogen removal. The equivalent value of C, obtained by batch analysis, is $C_{eq} = 0.32$. Base metal (BM) thickness is d = 120 mm, which along with the increased Mn content caused a need for preheating and intermediate pass heating. The preheating temperature is calculated according to the SRPS EN 1011-2 standard /3/, taking into account the influence of chemical composition, thickness of OM, diffused hydrogen content (HD) and heat input Q during welding, /4/:

- $T_p = T_{p,Ceq} + T_{p,d} + T_{p,HD} + T_{p,Q}$
- $T_{p,Ceq} = 750 \cdot C_{eq} - 150 = 750 \cdot 0.32 - 150 = 90$ °C
- $T_{p,d} = 160\tanh(d/35) - 110 = 160\tanh(120/35) - 110 = 50$ °C
- $T_{p,HD} = 62 \cdot H_D \cdot 0.35 - 100 = 62 \cdot 5 \cdot 0.35 - 100 = 8.5$, H_D is diffused hydrogen content (H_D = 5 ml/100 gr)
- $T_{p,Qfiller} = (53 \cdot C_{eq} - 32) \cdot Q - 53 \cdot C_{eq} + 32 = (53 \cdot 0.32 - 32) \cdot 1.0 - 53 \cdot 0.32 + 32 = 0$, Q is heat input (Q = 1 kJ/mm)
- $T_{p,Qroot} = (53 \cdot 0.32 - 32)0.78 - 53 \cdot 0.32 + 32 = 3.4$ °C
- $T_{p\,(filler\ pass)} = 82.5 + 49.6 + 8.5 + 0 = 141$ °C
- $T_{p\,(root\ pass)} = 82.5 + 49.6 + 8.5 + 3.4 = 145$ °C
- $T_p = 150$ °C is adopted in both cases.

WELDING PROCEDURE

Taking into account the requirement for the highest possible quality of the welded joint, as little heat input as possible, and limited space during welding, the 141-GTAW (TIG) process is adopted according to EN ISO 4063 /5/, with inert gas I1 (Ar 99.999) according to EN ISO 14175 /6/.

In the case of welding the new beam for the rotor (joint F1.4), due to the impossibility of entering the TIG torch into a very narrow space, the electric arc process with a coated electrode (111 - MMAW) is adopted. Due to the higher heat input in this welding procedure, reduced electrode oscillation and higher welding speed are used.

In TIG welding, direct current of direct polarity is used to transfer most of the heat to the weld joint (approximately 2/3), while at the same time reducing the rounding of the electrode tip, which is important in the case of ½ V groove, Fig. 3. The EN ISO 21952-A: W MoSi wire, trade name BÖHLER DMO-IG, diameter Ø2.0, is used for root pass and Ø2.4 for filling pass. As an electrode, the tungsten with the addition of thorium oxide WT 20 (red) is used, with a diameter of 2.4 mm, that must be sharpened so that the length of the conical tip is 4-6 mm. The electrode tip is pulled out of the nozzle about 2-4 mm. The wire was added to the front of melt (not directly in the middle of the arc, i.e., not under the electrode) and inserted so that its tip contacts the melt. Sequence of passes and welding parameters are shown in Fig. 3b and Table 1, respectively, as an example of all welding procedures in this reconstruction procedure.

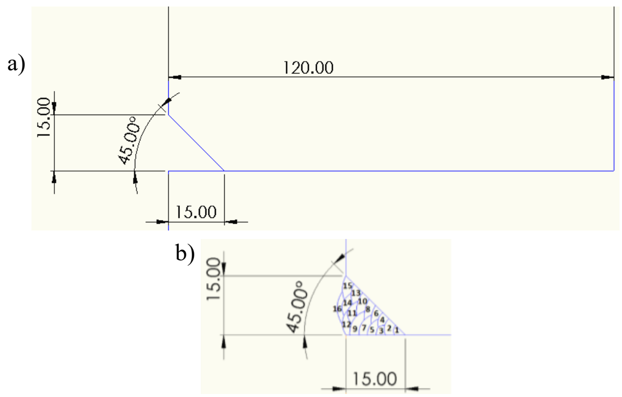

Figure 3. a) Welding groove; and b) sequence of passes.

Table 1. Parameters for the 141 welding procedure.

Pass no.	Filler metal diameter	Current	Amperage (A)	Voltage (V)	Welding speed (mm/min)	Heat input (kJ/mm)
1 (root)	2.0 mm	DC-	110-140	10.5-12.5	100-120	0.78
2-n (filler)	2.4 mm	DC-	115-155	15-17	115-145	1.00
cover	2.4 mm	DC-	115-145	14-16	115-145	0.90

For the welding procedure 111, direct current of reversed polarity is used, and the coated electrode EN ISO 2560-A:E 42 5 B42 H5, trade name BÖHLER FOX EV 50 Ø2.5 /7/, i.e., low-hydrogen coated electrode of the basic type. This electrode must be dried at 100 °C/1h + 300-350 °C/2h or 400 °C/1h or 250 ºC/4h. Since the coating is hygroscopic, it is necessary to keep the electrode in quivers at a temperature 100-150 °C before use.

WELDING SEQUENCE (Fig. 4)

I Simultaneously weld F1 (F1.1-F1.3) and F2 (F2.1-F2.3), fill up to approx. 10 mm joint height

Welder No. 1

- 1st step - weld the root pass of the overhead horizontal weld F1.1L - position PE l = 120 mm
- 2nd step - weld the root pass of the vertical weld F1.2L - position PF l = 80 mm
- 3rd step - weld the filling pass of the overhead horizontal weld F1.1L - position PE l = 120 mm
- 4th step - weld the filling pass of the vertical weld F1.2L - position PF l = 80 mm
- 5th step - weld the corner horizontal weld F1.3L - position PD l = 200 mm
- 6th step - weld the final passes of the overhead horizontal weld F1.1L - position PE l = 120 mm
- 7th step - weld the final passes of the vertical weld F1.2L - position PF l = 80 mm

Welder No. 2

- 1st step - weld the root pass of the overhead horizontal weld F2.1D - position PE l = 120 mm
- 2nd step - weld the root pass of the vertical weld F2.2D - position PF l = 80 mm
- 3rd step - weld the filling pass of the overhead horizontal weld F2.1D - position PE l = 120 mm
- 4th step - weld the filling pass of the vertical weld F2.2D - position PF l = 80 mm
- 5th step - weld corner horizontal weld F2.3D - position PD l = 200 mm
- 6th step - weld the final passes of the overhead horizontal weld F2.1D - position PE l = 120 mm
- 7th step - weld the final passes of the vertical weld F2.2D - position PF l = 80 mm.

Repeat the same welding sequence on the right (welder 1) or left beam (welder 2).

II Simultaneously weld welds F3 and F4 in the same order as welding F1 and F2

III Simultaneously weld welds F5 and F6 in the same order as for welding F1 and F2

IV Simultaneously weld welds F7 and F8 in the same order as welding F1 and F2

After all welds F1-F8, weld vertical corner weld F1.4, FW a7Δx260

V Simultaneously weld F1.4 and F2.4:

Welder 1

- 1st step - weld F1.4 L using the upward technique from 3 passes with a Ø2.5 electrode
- Step 2 - weld F1.4 D

Welder 2

- 1st step - weld F2.4 D using the 3-pass upward technique with a Ø2.5 electrode
- Step 2 - weld F1.4 D

VI Simultaneously weld F3.4 and F4.4 in the same order as when welding F1.4 and F2.4

VII Simultaneously weld welds F5.4 and F6.4 in the same order as welding F1.4 and F2.4

VIII Simultaneously weld welds F7.4 and F8.4 in the same order as for welding F1.4 and F2.4

Welding should be performed without time interruptions. Do not remove the tool for fixing and clamping new beams until it has completely cooled down, 24 hours after welding F1.1; F1.2; F1.3-F8.1; F8.2; F8.3. Grind the welds to the plane of the base material, taking care of controlled grinding and heat input.

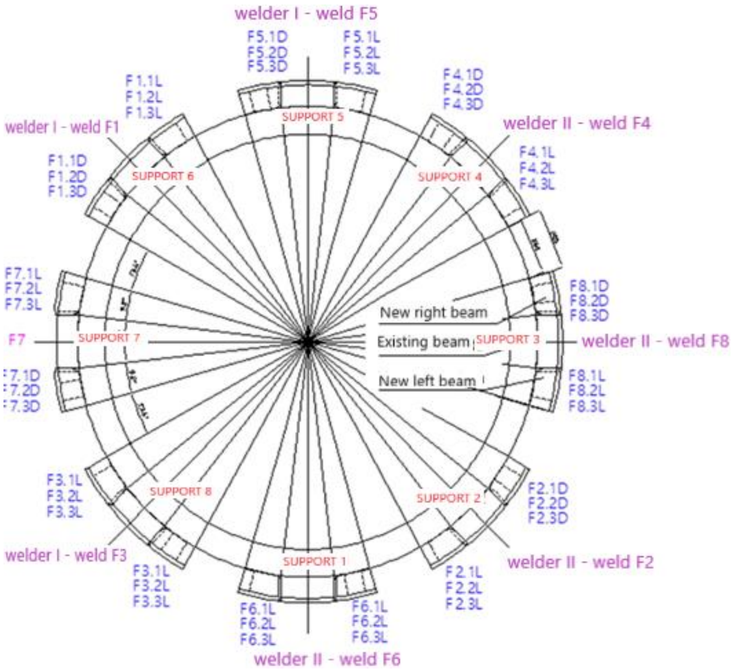

Figure 4. Welding sequence.

THERMAL CYCLE OF PREHEATING AND WELDING

Preheating is done according to standard EN ISO 13916, /8/. Electrical resistance preheating with heaters, placed on the workpiece near the weld, is used. Heaters, together with the workpiece, are insulated to minimise the release of heat. Preheating is on the outside of a heater, on both sides of the groove, never directly on the side of seam. Preheating is gradual, at a rate of around 100 °C/1h.

Temperature equalisation time is 2 min for every 25 mm of BM thickness. Temperatures are measured at a distance of 50 mm from the edge of the groove (SRPS ISO 13916) by thermocouples. The intermediate temperature in the welding zone did not exceed 250 °C, measured at the seam or BM, as close as possible to the seam. The temperature of the intermediate layer is equal to or slightly higher than preheating temperature.

After welding, welds are protected with ceramic cloth, cooled gradually to 100 °C and kept at 100 °C for about 60 min. Only when the finished position has reached the temperature of the external environment the ceramic cloth was removed. The whole thermal cycle is shown in Fig. 5.

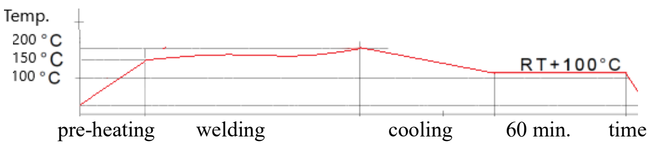

Figure 5. Thermal cycle during pre-heating.

CONCLUSIONS

Reconstruction of the damaged rotor spoke in the RHE ‘Bajina Bašta’ is successfully carried out by installing new supporting elements in the form of short beams, joined with the existing cracked beams and rotor spoke by welding and screws. Detailed stress analysis enabled the selection of the optimal variant of the reconstruction, which also represents an improvement of the basic design of rotor assembly.

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