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Repair Welding Methodology for the Glasses of the Kaplan Turbine Runner at the Hydro Power Plant Djerdap 1

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Abstract. Vertical Kaplan turbines, manufactured in Russia and with nominal power of 200 MW, have been installed in 6 hydroelectric generating units at hydro power plant Djerdap 1. Hydroelectric generating sets have been designed for the service life of 40 years due to structural solutions and limited possibilities of performing periodic inspections and state analyses.

During the rehabilitation of the hydroelectric generating sets, non-destructive tests were performed on all components and structures in order to complete state analysis. In this paper the damages and methodology of repair welding for damaged glasses, which are the integral part of the kinematic system of runner blades, are presented.

Introduction

Vertical Kaplan turbines, manufactured in Russia and with nominal power of 200 MW, have been installed in 6 hydroelectric generating units at hydro power plant Djerdap 1 more than 40 years ago. Kaplan turbines fulfill their function through the six blade runner.

Hydroelectric generating sets have been designed for the service life of 40 years due to structural solutions and limited possibilities of performing periodic inspections and state analyses.

During the rehabilitation of the hydroelectric generating sets non-destructive tests were performed on all components and structures in order to complete state analysis. In this paper the damages and methodology of repair welding for damaged glasses, which are the integral part of the kinematic system of runner blades (internal designation as set A1), are presented (figure 1). The role of a glass is to transfer the force from the servomotor piston through the connecting rod coupled with the crank onto the sleeve, which enables the displacement of the runner blade and alteration of the rotation angle of the blade, depending on the turbine regulation system parameters. The need for blade rotation is derived from the requirements for the optimization of the efficiency factor due to the alteration of power, stretch and water flow. Likewise, the role of glasses is to guide the piston and the piston rod, maintaining the predefined mutual clearance.

Runner glasses were formed by welding together the cylindrical forgings and necks made of steel 15XM [2]. At the neck of the glass M25x4 threads were created, which enabled the establishment of the connection with the piston by nuts.

Every glass of the six is, during turbine operation under usual working conditions, subjected to the force F_{oc} = 2.21 MN, while maximum force by which the piston acts on the glasses is F_{max} = 3.38 MN. For given force values, responding stresses are σ_{oc} = 122 MPa and σ_{max} = 159 MPa, figure 2.

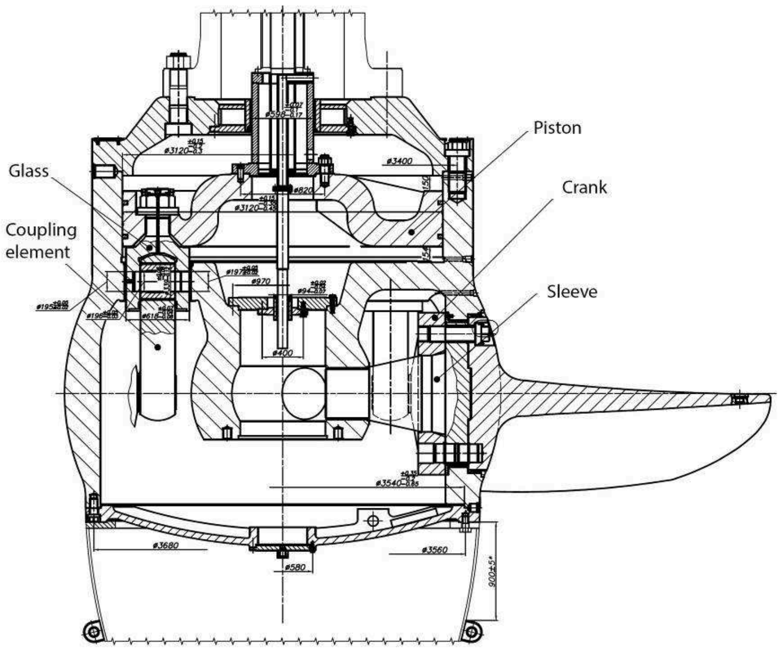

Figure 1. Glass with constitutive elements of the kinematic system of a runner blade

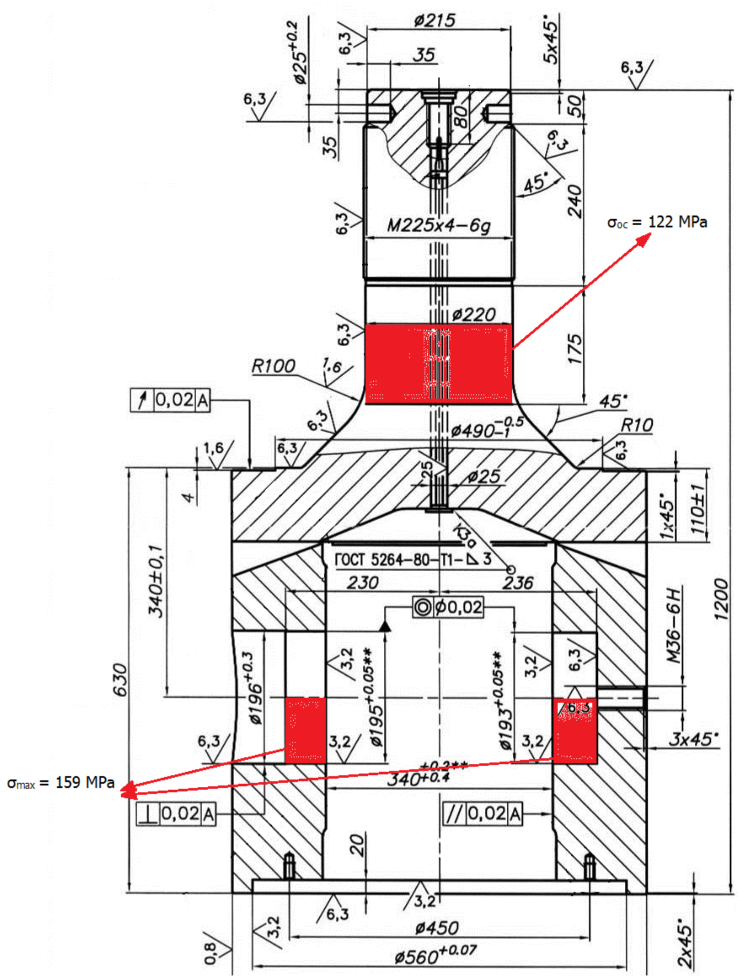

Figure 2. Appearance of a glass with basic dimensions and areas in which the stresses occur

At figure 3 characteristic mechanical damages that occur at the front of the neck of runner glass (internal no.5) during the assembly and disassembly are presented. For the repair of defects that occur at the body of runner glasses due to corrosion, erosion and/or cavitation during the exploitation of the turbine of the hydroelectric generating set A1, which were detected by non-destructive tests, the preparation of surfaces for the repair welding / surface welding by fine grinding was carried out, figure 4.

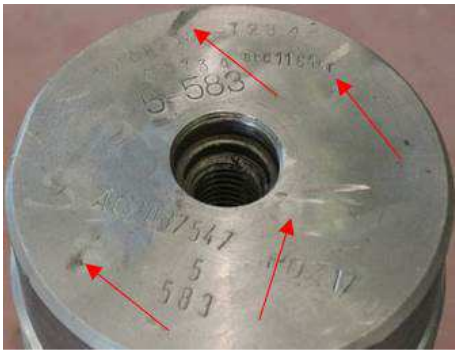

Figure 3. Characteristic mechanical damages at the front of the neck of runner glass

Figure 4. Preparation of surfaces for the repair (body of the glass nr. 5)

Repair Methodology for Damaged Surfaces of the Neck and Body of Turbine Runner Glasses of the Hydroelectric Generating Set A1

This methodology refers to works carried out during the repair of damaged surfaces of the neck and body of turbine runner glasses of the hydroelectric generating set A1.

Properties of parent material. Chemical composition and mechanical properties of steel 15XM of which the forgings were made, in accordance with standard GOST 4543-71 [2], are presented in tables 1 and 2.

Table 1. Chemical composition, values in [%]

Steel	GOST	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
15XM	4543-71	0,11-0,18	0,17-037	0,40-0,7	$\leq$ 0,035	$\leq$ 0,035	0,80-1,1	0.30-071	0,40-0,55	$\leq$ 0,30

Table 2. Mechanical properties, values for normalized and annealed state of material

Steel	GOST	Yield strength YS [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A [%]	Contraction Z [%]	Impact strength KCU [KJ/m^2]	Hardness [HB]
15XM	4543-71	min 440	min 650	min 21	min 45	118	179

Weldability analysis. Weldability of steel components and structures can be operational, metallurgical and structural. Ability of steel to be joined by welding (technological procedure for metal fusion) is determined by material equivalent CEV, which is being calculated on the basis of the chemical composition. Formulae for the obtainment of CEV are as follows:

– According to the International Institute of Welding (IIW)

$$CEV = C + \frac{M_n}{6} + \frac{C_r + M_o + V}{5} + \frac{N_i + C_u}{15} \text{ [\%]} \quad (1)$$

– Ito-Bessyo

$$CEV = C + \frac{S_i}{30} + \frac{(M_n + C_u + C_r)}{20} + \frac{N_i}{60} + \frac{M_o + V}{15} + 5B \text{ [\%]} \quad (2)$$

– HCS (Hot Cracking Sensitivity)

$$HCS = \frac{100C\left(S + P + \frac{S_i}{25} + \frac{N_i}{100}\right)}{(3M_n + Cr + Mo + V)} \text{ [\%]} \quad (3)$$

• Hot Cracking Sensitivity formula revealed that the material is not prone to hot cracking, because the obtained value for HCS is less than 4,5 (boundary value for the occurrence of hot cracking for steels with tensile strength less than 700 N/mm^2);
• For the chemical composition of steel presented in table 1 and with the content of hydrogen in weld metal H = 6 [ml/100 gr.], preheating at 100 [ºC] is sufficient;
• Critical cooling rate at which purely martensite structure, which would cause cold cracking, occurs in the heat-affected zone, should be less than 32 ºC/sec, which means that no decelerated cooling is necessary;

From the above mentioned it can be concluded that weldability of steel 15XM is satisfactory. It is necessary to perform preheating at 100ºC if welding is being carried out with filler material of the same kind [3, 4].

Selection of welding process. Through the analysis of parameters on which the selection of repair welding procedure depends (weldability of material, energetic possibilities of the welding procedure, geometric complexity of the structure, economic indicators) it was determined that it is most suitable to apply the procedure 111.

Selection of filler material. Due to limited possibilities of performing preheating and heat treatment after repair welding / surface welding, rutile based electrode OK 67.70 ESAB (Sweden) [5] was chosen. Chemical composition of pure weld metal is presented in table 3, while mechanical properties of pure weld metal are presented in table 4.

Table 3. Chemical composition, values in [%]

Electrode	C	Si	Mn	Mo
OK 67. 70	0.10	0.50	0.80	0.50

Table 4. Mechanical properties of pure weld metal

Electrode	Yield stress YS0.2% [N/mm^2]	Tensile strength R_m [N/mm^2]	Elongation A5 [%]	Impact energy $KV_{300/2}$ [J/cm^2]
OK 67. 70	> 450	530 - 630	> 22	> 47 (- 20 ^{0}C)

Procedure of preparation works for defect reparation. Procedure of preparation works for reparation of defects detected at runner glasses by repair welding / surface welding predicts the following:

- Provision of means of protection at work;
- Marking of areas with defects;
- Grinding of areas with defects by angle grinders until total elimination of defects;

- Final examination of areas where grinding was carried out through the application of magnetic particle inspection;
- Rounding of sharp edges as a part of preparation for repair welding / surface welding, figure 5;
- Determination of location, width, length, depth, and volume of eliminated material for areas where grinding was performed;
- Degreasing, drying and cleaning of areas where grinding was performed.

Sequence of execution of repair welding/surface welding. Repair welding / surface welding was executed at runner glasses in the following order:

- Welding / surface welding was executed with the application of rutile based filler material, along with treatment of every deposited layer with the pneumatic hammer with the rounded top (R = 4 – 5 mm);
- Number of deposited layers depends on the depth and shape of the grinded area, figure 6;
- Levelling of deposited filler material with parent material was executed by straight grinders;
- Machining of areas where grinding was performed was executed by serrated polishing discs, in order to obtain suitable quality of surface preparation for non-destructive tests;
- Repair welds / surface welds were examined by visual and magnetic particle inspection;
- Welding / surface welding process was repeated whenever it was necessary;
- Layers 1-9 were deposited by Ø3, 2 mm electrode, the rest by Ø4 mm electrode.

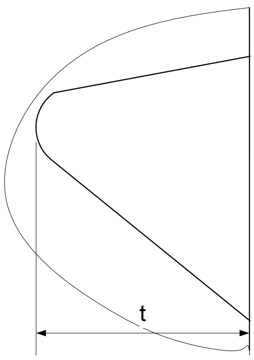

Figure 5. Shape of the area where grinding was performed (t = 5-40 mm)

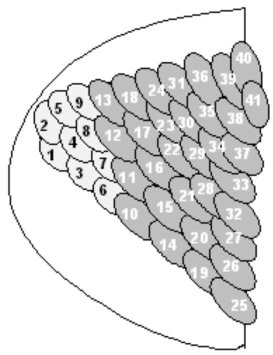

Figure 6. Appearance of a weld with the welding sequence

Results and Discussion

After the repair of defects at runner glasses non-destructive tests were performed at repair welds / surface welds. By visual inspection, which was performed in accordance with the standard EN 970 [6], and magnetic particle inspection, which was performed in accordance with the standard EN ISO 17638 [7], and taking into account the acceptance criteria defined in the standard EN 5817 [8], it was determined that repair welding/surface welding was executed successfully, which enables safe operation of runner glasses until next turbine rehabilitation, which is scheduled to be executed in approximately 40 years.

Conclusion

Successfulness of the executed methodology for the repair of defects detected at runner glasses of the hydroelectric generating set A1 was confirmed by the manufacturer of the equipment, company Power Machines from Saint Petersburg, because they gave the permission for runner glasses to be in service until next turbine rehabilitation, which is scheduled to be executed in approximately 40 years.

It should also be noted that significant financial gain was accomplished, because the manufacture of two new glasses would cost approximately 180.000 € (mass of a runner glass is approximately 927 kg), not taking into account the time necessary for their manufacture (2-3 months), which would cause the reduction in energy production during that period, while the repair of two glasses was executed in 4 days.

Presented methodology for repair welding/surface welding is also applicable for the repair of other components and structures of turbine and hydromechanical equipment, exposed to various causes of damage occurrence during operation.

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