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DAMAGE ANALYSIS AND RESTORING OF STRUCTURAL INTEGRITY OF PELTON RUNNER AFTER REPAIR WELDING: CASE STUDY

ANALIZA OŠTEĆENJA I OBNAVLJANJE INTEGRITETA RADNOG KOLA PELTON TURBINE NAKON REPARATURNOG ZAVARIVANJA: STUDIJA SLUČAJA

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- repair welding
- Pelton runner
- X3CrNiMo13-4 steel
- damage analysis

Abstract

This paper presents the repair welding technology of a Pelton runner blade, including an analysis of damage caused by cavitation. Extreme exploitation conditions resulted in crack initiation followed by its propagation to a length 200 mm, detected during regular annual maintenance, compromising Peltron turbine's structural integrity. The base material of the Pelton turbine is steel X3CrNiMo13-4, and as well as the blade geometry itself, required special attention during the process of defining the repair welding technology. An austenitic electrode was used for this purpose along with a welding technology defined in a way to counter the initiation of new cracks at the same location. Following the NDT, the Pelton runner was put back into exploitation, along with recommendations for further monitoring.

Ključne reči
- reparaturno zavarivanje
- Pelton turbina
- čelik X3CrNiMo13-4
- analiza oštećenja

Izvod

U ovom radu je prikazana tehnologija reparaturnog zavarivanja lopatice radnog kola Pelton turbine, kao i analiza oštećenja izazvana kavitacijom. Ekstremni radni uslovi doveli su do nastanka, a kasnije i do širenja prsline na lopatici, dužine 200 mm, otkrivene na redovnom godišnjem pregledu čime je narušen integritet Pelton turbine. Osnovni materijal Pelton turbine, čelik X3CrNiMo13-4, ali i sama geometrija lopatice turbine, zahtevali su posebnu pažnju prilikom definisanja tehnologije reparaturnog zavarivanja. U tu svrhu primenjena je austenitna elektroda, a definisana i sprovedena tehnologija zavarivanja treba da predupredi nastanak novih prslina na istom mestu. Nakon NDT kontrole, radno kolo Pelton turbine je vraćeno u eksploataciju uz odgovarajuće preporuke za dalji monitoring.

INTRODUCTION

Repair welding is a known standard technique used for restoring functionality of damaged constructions and machine parts caused by exploitation condition, /1-8/. Repair welding represents a complex technological discipline requiring extensive knowledge about different fields and skills. In addition to knowing about the function of each repaired part, one must also know about the material properties of these parts. The repair welding procedure consists of clearly defined steps, beginning with dismantling, followed by part cleaning, damage analysis, based on which repair welding method has to be adopted, then followed by technological procedure of determining, preparation, performing repair welding itself, NDTs examination and evaluation, and finally machining to the final measures before returning it to operation mode with a running-in period. Damage analysis and defects detection are among the most important activities that precede adequate repair welding procedure, requiring knowledge on material properties and metallurgy aspect of it, loading condition to which part/construction is exposed to. All these represent an input for the prediction of damage mechanics to be expected on the working part, thus successfully performing the conducted repair welding technology /3, 4, 6, 8-9/.

Parts of hydro-power plants are exposed to various loading condition and restoring their functionality after damage, that has been caused by these conditions, represents a very demanding task necessary for safe and reliable in operation. Various methodology of structural integrity assessment of such equipment (new, damaged or repaired) represents an integral part of any analysis and inspection. This is mainly caused by specific material properties, along with loading conditions and stress state, depending on the type of equipment, /10-13/.

The topic of research is the Pelton turbine widely used in hydropower stations with various head geometry, ranging 80-800 m. Main parts of Pelton turbine are runner, turbine case, nozzles assembly, inlet pipe, deflector, etc. The following part of this manuscript is dedicated to Pelton runner, which represents the main focus of research. The Pelton runner is assembled in the shaft of the generator, torque transmission by ping, and utilizes the dynamic power of high pressure water flow to rotate the runner forcing the rotor to operate (Fig. 1). The centre line of the jet is in the same plane as the runner while rotating. The main advantages of this type of turbine are its (i) compact construction, (ii) stable running and (iii) easy operation. It should be emphasized that the Pelton runner is subjected to extremely high stresses during exploitation condition, requiring high quality material for this purpose to be used. They are manufactured from a single piece of forging and poses high toughness along with the finest grain structure, /14/. Still, extreme loading and environmental conditions can cause damage even on high quality material (thus, the equipment of such delicate part), especially if cavitation is involved as a damage mechanism, /15-17/.

Figure 1. Pelton runner with its blades, /14/.

The first part of this paper shows analysis of damages of blade no. 5 of the Pelton turbine, mainly due to cavitation. Extreme exploitation conditions led to the initiation and propagation of a crack, discovered during regular annual maintenance, which could cause complete failure of Pelton runner. Length of this crack was 200 mm, which necessitated the repair welding of the damaged zone, i.e., blade. Base material of the Pelton turbine is X3CrNiMo13-4 steel (which will be described in more detail), and its geometry required special attention while defining the repair welding technology. For this reason, a repair welding technology using an austenitic electrode was selected and is presented here. In addition, the paper includes a method for assessing the structural integrity of the turbine, which would confirm that the conditions for restoring this part into exploitation have been met.

PARENT MATERIAL OF PELTON TURBINE RUNNER, STEEL X3CrNiMo13-4

Parent steel of Pelton turbine runner is ultra-low carbon martensitic stainless steel X3CrNiMo13-4 (EN designation 1.4313), which is a martensitic grade steel with high corrosion resistance, and good durability characteristic after appropriate heat treatment. Its mechanical properties (Table 1), such as high tensile strength, toughness, etc., are caused by high concentration of elements such as Mo and Ni in the chemical composition (Table 2). These two alloying elements have limited the need for increasing the C content to a concentration comparable to stainless austenitic grade. Ni content (~ 4 %) has significantly increased the steel's resistance to numerous corrosive environmental conditions, providing the ability for application at elevated temperature up to ~ 300 °C, still retaining the resistance to numerous corrosive environments and conditions. Due to its properties, which are superior to conventional martensitic stainless steels, it is mainly used for hydropower plant application, water turbine equipment, but it can be found in petrochemical industries, plant engineering, etc. However, its main disadvantage is poor weldability, requiring serious attention during defining welding technology, narrowing the selection to very few wires/electrodes for this purpose.

Table 1. Mechanical properties of steel X3CrNiMo13-4 (1.4313).

Re [MPa]	Rm [MPa]	A5 [%] min	Z [%] min	KV [J/cm^2] min
620	780-980	15	40	50

Table 2. Chemical composition of steel X3CrNiMo13-4 (wt.%).

C	P max	S max	Si	Cr	Mo	Mn max	Ni	N max
0.05	0.04	0.015	0.7	12-14	0.3-0.7	1.5	3.5-4.5	0.02

DAMAGE ANALYSIS AND DETECTION ON PELTON TURBINE RUNNER BLADE

To understand this particular problem regarding the cracking of the blade, this section begins with the Pelton runner blade (characteristic’s) geometry, given in Fig. 2. Notably, blade thickness is just 4 mm exposed to extreme conditions with expected cavity and high loading due to water flow causing high stress at the blade edge.

During regular annual maintenance of Pelton turbines, a large crack was detected in blade no.5, using NDT methods, namely magnetic particles. Figure 3 shows the appearance of the detected crack of length 200 mm, from both front and back sides. It was confirmed that this crack was caused by cavitation, leading to the decreasing of the blade’s thickness and crack initiation, where even at lower load level the rapid crack growth can occur. It must be noted that this case represents a considerable crack growth during a single year.

All of the above imposed the question of what should be done about this damaged runner. Taking into account its sophisticated features, this part with such damage should not be allowed to operate, where its failure could cause downtime and severe financial losses. Since it was impossible to determine with certainty whether this was a defect that occurred during design, and there was no evidence of casting defects (taking into account how Pelton runner was made) that could cause crack initiation (confirmed by NDT), it was concluded that the best course of action would be to repair weld the turbine blade using an electrode of higher toughness compared to the base material. One of the main reasons for this electrode’s type selection is better absorption of impact forces. In this way, future damage of this zone could be prevented. For this purpose, the austenitic electrode was the choice for the filler material.

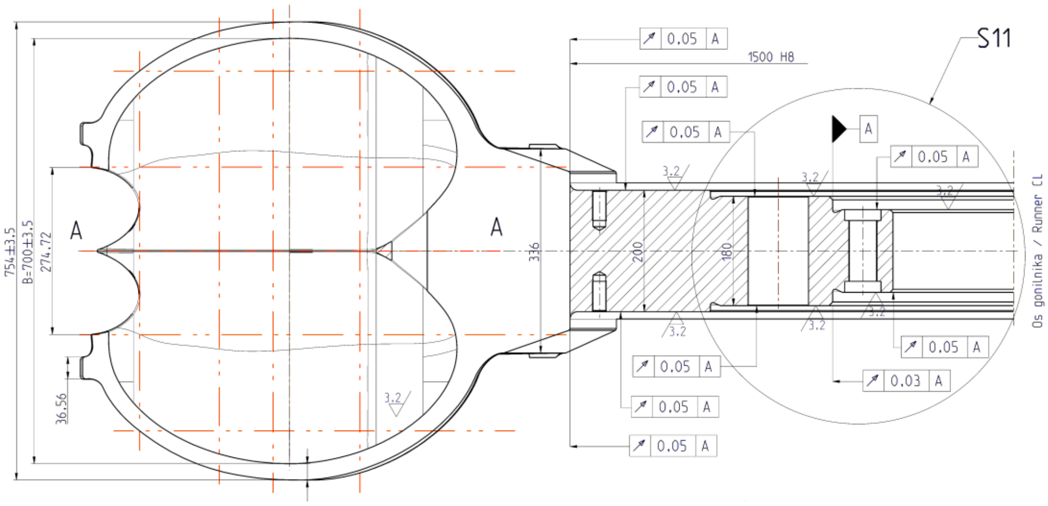

Figure 2. Geometry of Pelton runner blade.

Figure 3. Detected crack on Pelton runner’s blade, 200 mm length: front side (top); back side (bottom).

REPAIR WELDING TECHNOLOGY AND RESTORING STRUCTURAL INTEGRITY

Prior to repair welding, it was necessary to machine the U groove by grinding of the crack on the blade back side, up to approximately one half of its thickness, in the direction of the crack, Fig. 4. The so-called ‘removal’ of the crack was then performed, and penetrant testing was also done in order to examine the state of the damaged area of the blade.

Figure 4. Groove on Pelton runner blade, on the back side.

After grooving and liquid penetrant testing (on the back side), the start weld plate was placed at the beginning of the crack and the groove itself.

Present conditions imposed the need to weld on-site, within the hydro-powerplant facilities. Hence, manual arc welding procedure (MAW, also denoted as 111) was selected, using austenitic electrode with a commercial designation of INOX 29/9/R, manufactured by Elektrode Jesenice. This electrode is a ferritic-austenitic rutile electrode, mainly used for welding high-alloyed, tool- and high-manganese steels, i.e., steels with unfavourable weldability. In addition, it is meant for surface welding of inter-layers and worn-out parts. The electrode is characterised by a stable arc, and the welding process itself is without spatter, with fine droplets. Slag is easily removed, and welds are smooth and resistant to cracks and porosity. This electrode has good resistance to various corrosive environmental conditions, as well. The chemical composition and mechanical properties of this electrode are shown in Tables 3 and 4, respectively.

Table 3. Mechanical properties of INOX 29/9 R electrode /18/.

Re [MPa]	Rm [MPa]	A5 [%] min
> 500	740-840	> 20

Table 4. Chemical composition of INOX 29/9 R electrode /18/.

C	Si	Cr	Mn	Ni
0.15	≤ 0.7	29	0.9	0.9

Immediately before welding, the electrodes were dried at 300 °C for 2 hours. Due to small blade thickness, there was no need for preheating. Welding parameters are given in Table 5, whereas the welding plan is shown in Fig. 6. Interpass temperature was not greater than 200 °C. The required level of welded joint quality was B (according to EN ISO 5817 standards).

Table 5. Welding parameters.

Electrode diameter	Layer	Position *	Current [A]	Voltage [V]
Ø2.5	1-3	PC	70-85	20-22
Ø3.25	4-n	PC	100-120	20-22

* horizontal position in a vertical plane

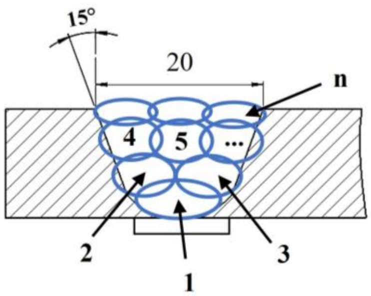

Figure 5. Filling plan for U groove of runner's blade.

After filling the groove, a 3 mm surface layer was welded above the cap weld. This was done for two reasons: (i) to avoid undercuts after grinding, and (ii) to anneal the cap pass. The appearance of the groove after repair welding is shown in Fig. 6. This was followed by making a small U groove on the blade front side, while also monitoring the damage of the surface. Welding on the front side of blade no.5 was performed in the same way as the back side. After cooling of the welded joint to ambient temperature, the start plate was removed, and the blade was ground and polished to its design geometry, from both sides. Grinding was performed to minimum surface quality of R_a = 1.6 μm. The front and back sides of the repaired blade are shown in Fig. 7.

After grinding and machining of the blade geometry to its predefined dimensions, NDT was performed using visual and penetrant methods, with a scope of 100 %. These tests did not reveal crack-like defects, pores, undercuts nor any other indications, which confirmed that the Pelton turbine in question fulfils the requirements for further exploitation.

Figure 6. Blade groove after filling on the back side.

Figure 7. Repaired section of blade no. 5 where the crack was located: back side (top), front side (bottom).

CONCLUSIONS

Damage analysis and restoration of structural integrity are crucial steps in defining the repair welding technology, as shown in the case of a Pelton turbine, including the prevention of cracks reoccurring at the location where they were initially detected. After repair welding, more frequent regular maintenance is recommended, with additional tests of the blade damaged zone, at intervals of 1000 work hours. If the results of these tests are satisfactory, maintenance intervals can be increased gradually.

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