Assessment of integrity and service life of the upper ring of turbine runner guide vane apparatus at hydro power plant ’Đerdap 1’

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During the rehabilitation of the hydroelectric generating set A6 at hydro power plant ’Djerdap 1’, state analysis and integrity assessment were carried out for all vital components and structures. After the completion of non-destructive and destructive tests carried out on parent material and welded joints of the structure of the upper ring of guide vane apparatus as part of vertical Kaplan turbine runner, it was decided that it should be replaced with a new one, because parent material and welded joints were degraded beyond repair. Existing upper ring of guide vane apparatus was made of steel St 3, in accordance with GOST standard. New upper ring of guide vane apparatus was manufactured through the use of steel S 235, in accordance with DIN standard. During ultrasonic testing 6 mm high lack of root penetration was detected at the load carrying welded joint along the entire circumference of the guide vane apparatus. It should be noted that there is no possibility of restoring the welded joint, because the occurrence of deformations at the structure has to be avoided. In this paper the results of the check of load carrying capacity of welded joints are presented, taking into account all weakened cross-sections. Determination of load carrying capacity and fatigue strength were carried out in the usual way, as well as the stress state analysis performed through the use of finite element method in order to determine the influence of undercuts. Assessment of integrity and service life of the guide vane apparatus based on the influence of cracks on stress distribution and fracture mechanics parameters was also carried out.

Keywords: *hydro turbine, upper ring of the guide vane apparatus, welded joint, crack, integrity assessment.*

1. INTRODUCTION

Vertical Kaplan turbines, manufactured in Russia, are installed in 6 hydroelectric generating units at “Djerdap 1”, with nominal power of 200 MW [1]. In figure 1 the cross-section of the turbine is shown, while in figure 2 the model of the upper ring of guide vane apparatus is presented. Loads on the upper ring of guide vane apparatus occur during manufacturing and assembly (residual stresses), and in the process of performing functional tasks during exploitation (stationary and dynamic loads). Because of the structural solution and inability of performing periodic inspections and state analyses, projected service life of the turbine and upper ring of guide vane apparatus was 40 years.

During the rehabilitation of the hydroelectric generating set A6 at hydro power plant ’Djerdap 1’, state analysis and integrity assessment were carried out for all vital components and structures. After the completion of non-destructive and destructive tests carried out on parent material and welded joints of the structure of the upper ring of guide vane apparatus as part of vertical Kaplan turbine runner it was decided that it should be replaced with a new one, because parent material and welded joints were degraded beyond repair [2]. Existing upper ring of guide vane apparatus was made of steel St 3, in accordance with GOST standard.

New upper ring of guide vane apparatus was manufactured in DSD NOELL gmbh, factory specialized for hydro-mechanical steel equipment for navigational shipping, barrages and waterpower plants. It was manufactured through the use of steel S 235, in accordance with DIN standard. During ultrasonic testing 6 mm high lack of root penetration was detected at the carrying welded joint, along the entire circumference of the guide vane apparatus. It should be noted that there is no possibility of restoring the welded joint, because the occurrence of deformations at the structure has to be avoided.

Researches carried out all over the world, which deal with integrity and reliability of turbine and hydromechanical equipment with respect to material degradation, are mostly linked with fatigue corrosion, cavitation and vibrations. There are practically no papers which deal with welded joints and structures as

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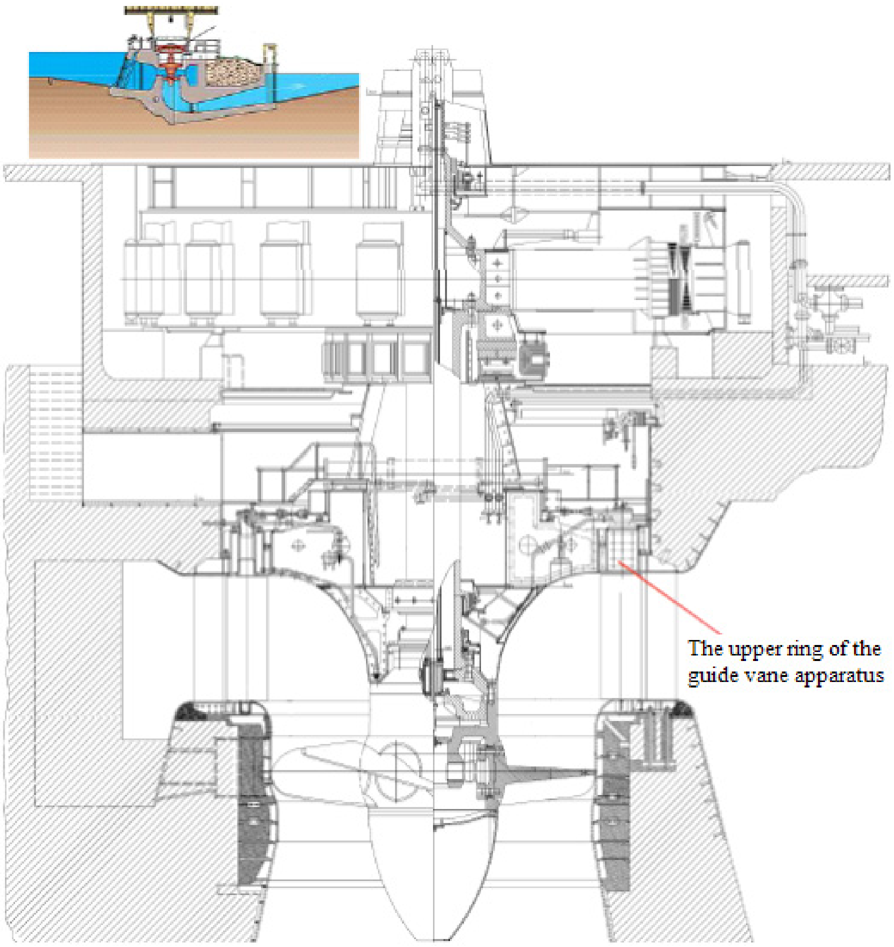

Figure 1. Appearance of the vertical Kaplan turbine, nominal power 200 MW

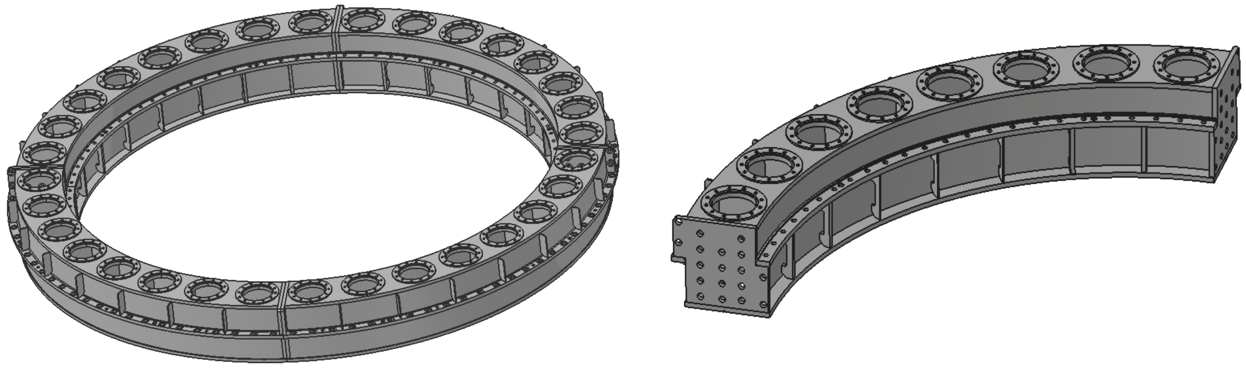

Figure 2. Appearance of the model of the upper ring of guide vane apparatus

Table 1. Chemical composition of steel of which new upper ring of guide vane apparatus was made, mass %

Steel designation	C	Si	Mn	P	S	C_{eq}
S 235	max 0.22	max 0.266	max 1.334	max 0.015	max 0.007	max 0.45

Table 2. Mechanical properties of steel of which new upper ring of guide vane apparatus was made

Steel designation and sheet metal thickness	YS $[N/mm^2]$	TS $[N/mm^2]$	TS (z direction), $[N/mm^2]$	$A_{5,65}$ [%]
S 235, thickness 40 – 100 mm	min 215	min 360	27	min 22

Table 3. Impact energy (V2 notch) for steel of which new upper ring of guide vane apparatus was made

Steel designation and sheet metal thickness	T, $[^0C]$	KV_2, [J]
S 235, thickness 40 – 100 mm, longitudinal direction	+20	27

wholes. Researches carried out on serbian hydro power plants were modest in range. Researches which were used for this particular analysis are listed in literature [3-8].

New upper ring of guide vane apparatus was manufactured in DSD NOELL gmbh, factory specialized for hydro-mechanical steel equipment for navigational shipping, barrages and waterpower plants. It was manufactured through the use of steel S 235, in accordance with DIN standard [9]. Results of tests that refer to determination of material properties are presented in tables 1- 3.

2. LOAD ANALYSIS AND CALCULATION OF THE STRESS STATE OF THE WELDED STRUCTURE

During ultrasonic testing of the upper ring of guide vane apparatus 6 mm high lack of root penetration was detected at the load carrying welded joint, along the entire circumference of the guide vane apparatus. It should be noted that there is no possibility of restoring the welded joint, because the occurrence of deformations at the structure has to be avoided.

2.1 Loads That Occur on the Upper Ring of Guide Vane Apparatus

Permanent and transferable loads that occur at the inner and outer diameter of the upper ring of guide vane apparatus (Di = 9.870 mm, Do = 12.240 mm), figure 3, have the following values:

- overall force from the turbine: $F_1 = 19.618$ [kN],
- overall force from the axle-pin: $F_2 = 540$ [kN],
- overall force from the ring: $F_3 = 840$ [kN],
- continuous line load at the internal diameter of the upper ring:

$$q_1 = \frac{F_1}{D_i \cdot \pi} = 632.69[\mathrm{kN/m}], \qquad (1)$$

- continuous line load at the external diameter of the upper ring:

$$q_2 = \frac{F_1 + F_2 + F_3}{D_o \cdot \pi} = 546.07[\mathrm{kN/m}]. \qquad (1)$$

On the basis of the fact that q_1 is greater than q_2, it can be concluded that the load that occurs at the internal diameter of the upper ring is valid for the calculation.

2.2 Numerical calculation of stresses that occur at the welded joint with lack of root penetration

Through the use of finite element method the numerical calculation of stresses that occur at the welded joint with lack of root penetration for new upper ring of guide vane apparatus in normal and disturbed mode of turbine operation was carried out. Calculation results are presented in figure 4.

For welded joint with 6 mm high lack of root penetration (figures 3 and 4), values of moment of inertia (I_y) and values of section modulus (W_{ys}, W_{yu}) were calculated for predetermined loads. Performed analyses and calculations showed that the integrity of the upper ring of guide vane apparatus is not threatened, because values of shearing stress for the overall length of the welded joint with the existing lack of root penetration does not exceed 12% of equivalent stresses for various loading modes.

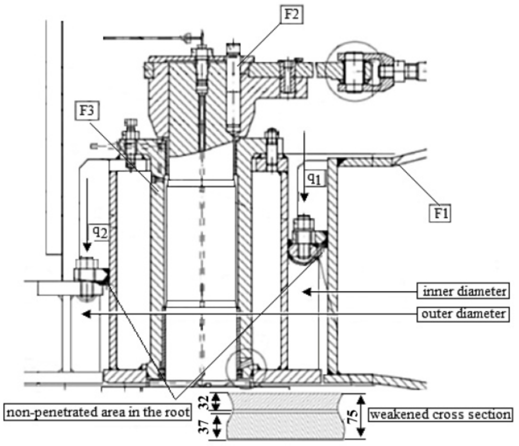

Figure 3. Appearance of loads that occur during service and non-penetrated welded joints

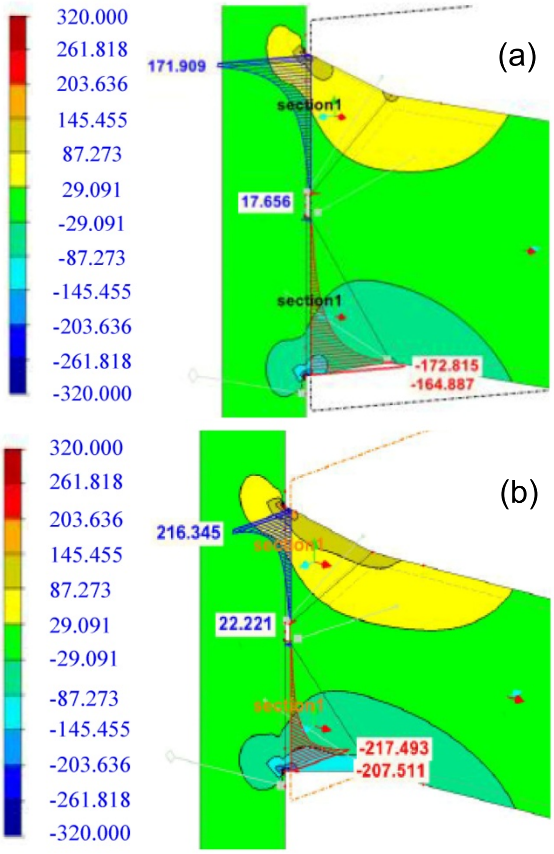

Figure 4. Appearance of distribution of von Misses stresses [MPa] at the welded joint with lack of root penetration for new upper ring of guide vane apparatus in (a) normal and (b) disturbed mode of turbine operation

3. ASSESSMENT OF SERVICE LIFE BASED ON FRACTURE MECHANICS PARAMETERS

Behaviour of cracked material during the action of the changeable load is defined by parameters which are being obtained by monitoring the growth of the fatigue crack, and those are fatigue crack growth rate (da/dN) and minimum critical stress intensity factor at which there is no crack growth, or in other words fatigue threshold (ΔK_{th}), figure 5. The area of stable growth of the fatigue crack is defined by Paris-Erdogan equation [10], which is applicable for all metals and alloys (equation 3), taking into account the analysis of stress state and deformations and linear elastic fracture mechanics theory.

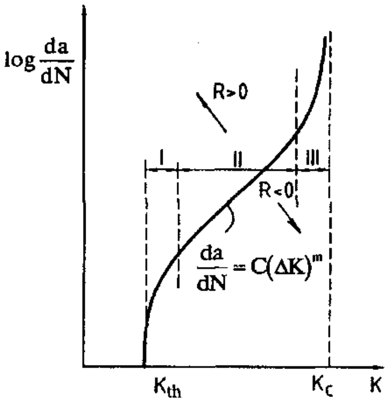

Figure 5. Typical appearance of the fatigue crack growth rate curve

$$\frac{da}{dN} = C \cdot \left(\Delta K\right)^m \qquad (3)$$

Critical stress intensity factor K_{Ic} for edge crack is being obtained from equation (4):

$$K_{Ic} = Y\sigma\sqrt{a_c} \qquad (4)$$

where: K_{Ic} = 30 [MPa•m$^{1/2}$] – minimum allowed value of stress intensity factor for temperatures below 0°C, steel S235 [9], Y = 1.12 – parameter that depends on structural element geometry and crack shape [10], $\sigma_{\max}$ = 22.2 MPa – maximum stress in disturbed mode of turbine operation (figure 4b), a_c - critical length of edge crack.

Critical length of the edge crack could be obtained from the following equation:

$$a_c = \left(\frac{K_{Ic}}{Y\sigma_{\max}}\right)^2 = \left(\frac{30MPa \cdot m^{1/2}}{1.12 \cdot 22.2MPa}\right)^2 = 6,7\text{mm}, \qquad (5)$$

which is higher than 6 mm, obtained as the lack of root penetration.

4. CONCLUSION

All relevant analyses that refer to boundary values of load carrying capacity, integrity assessment and service life were carried out taking into account the weakened cross-section at the location of the welded joint. Lack of root penetration a = 6 mm is negligible in the calculation when it comes to overall geometric size of the cross-section, but anyway demanded conditions were met. By comparing the stress state in the weakened and non-weakened cross-section it was determined that stresses in various cross-sections are almost identical. Results of performed analyses showed that lack of root penetration does not affect the load carrying capacity of the upper ring of guide vane apparatus.

ACKNOWLEDGMENT

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