REPAIR OF DAMAGES DETECTED AT THE SHAFT AND VENTILATION RING VANES OF THE HYDROELECTRIC GENERATING SET A2 GENERATOR AT THE HYDRO POWER PLANT ’PIROT’

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Key words: *hydroelectric generating set, turbine shaft, ventilator ring vane, damage repair*

Abstract:

Hydro power plant ’Pirot’, which was built in 1990, is an accumulation-derivative power plant, which consists of 2 above-ground vertical hydroelectric generating sets that contain Francis turbines with nominal power of 41,5 MW, manufactured in Czech Republic, a tunnel and a sunken pipeline with overall length of 2.030 m and diameter that ranges from 3 000 to 3 500 mm. Pipeline, made of 22 mm thick pipes, has been designed and built without anchor blocks at curvatures, which is a rarity elsewhere. Maximum pressure of 2.5 MPa occurs in front of the turbine cover.

This paper contains the analysis of the state of the generator shaft on which the mechanical damages were detected, as well as the analysis of the state of vanes of the upper and lower ventilation ring designed for air cooling of the generator rotor where corrosion, erosion and, most of all, cavitation damages were detected, based on results of non-destructive testing (visual testing, penetrant testing, ultrasonic testing). Procedures for the rehabilitation of damaged components without disassembling them were defined. The execution of these procedures helped in saving approximately 100 000 €.

Taking into account the period of time necessary to perform complete disassembling of components, as well as the period of time needed to perform reassembling, which is directly linked with the amount of energy the hydroelectric generating set A2 would produce during that period, the overall save would mount up to approximately 500.000 €.

1. INTRODUCTION

Hydro power plant ’Pirot’ which was built in 1990., is an accumulation-derivative power plant, which consists of 2 above-ground vertical hydroelectric generating sets that contain Francis turbines with nominal power of 41,5 MW, manufactured in Czech Republic, a tunnel and a sunken pipeline with overall length of 2.030 m and diameter that ranges from 3 000 to 3500 mm. Pipeline, made of 22 mm thick pipes, has been designed and built without anchor blocks at curvatures, which is a rarity elsewhere. Maximum pressure of 2.5 MPa occurs in front of the turbine cover.

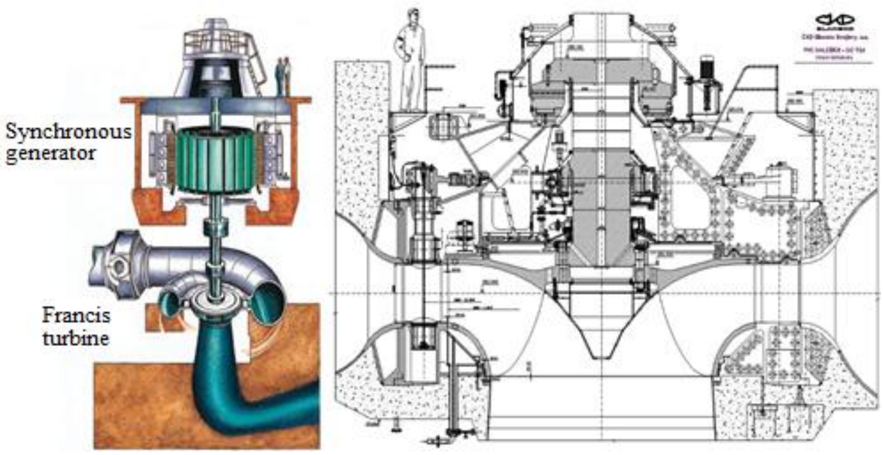
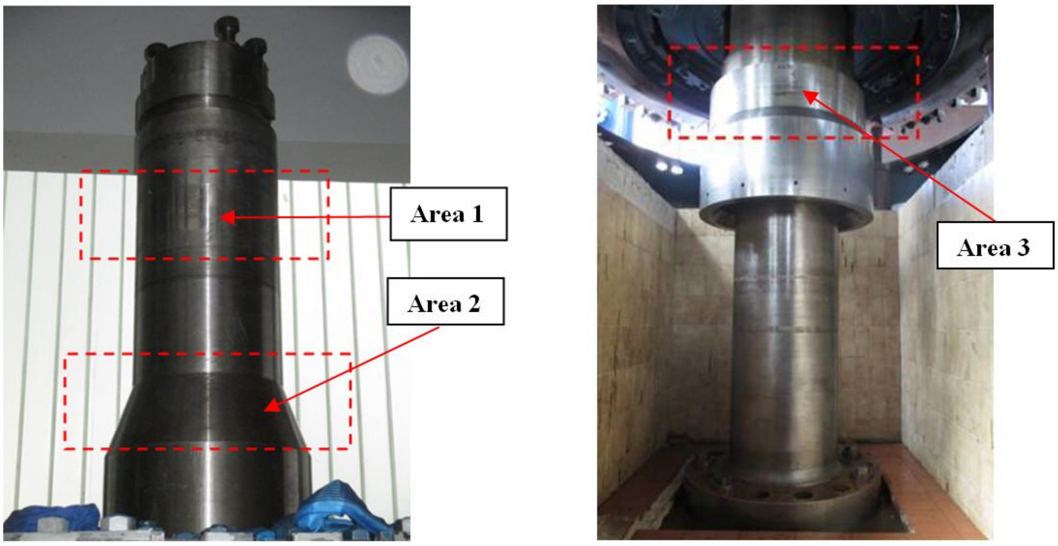


Figure 1. *Appearance of the vertical Francis turbine, with nominal power of 41.5 MW*

In figures 2 and 3 the mechanical damages detected at the upper and lower section of the generator shaft are shown. By dimensional checks it was determined that damages at the shaft are not more than 2 mm deep.

Damages detected at the vanes of upper and lower ventilation ring for air cooling of the generator rotor are shown in figure 4. Corrosion, erosion and, most of all, cavitation damages at vanes, up to 1 mm deep, were detected by penetrant testing, figure 5.



a) Appearance of mechanical damages detected at the upper section of the generator shaft

b) Appearance of mechanical damages detected at the lower section of the generator shaft

Figure 2*. Appearance of mechanical damages detected at the upper and lower section of the generator shaft*

a) Appearance of mechanical damages in area 1

b) Appearance of mechanical amages in area 2

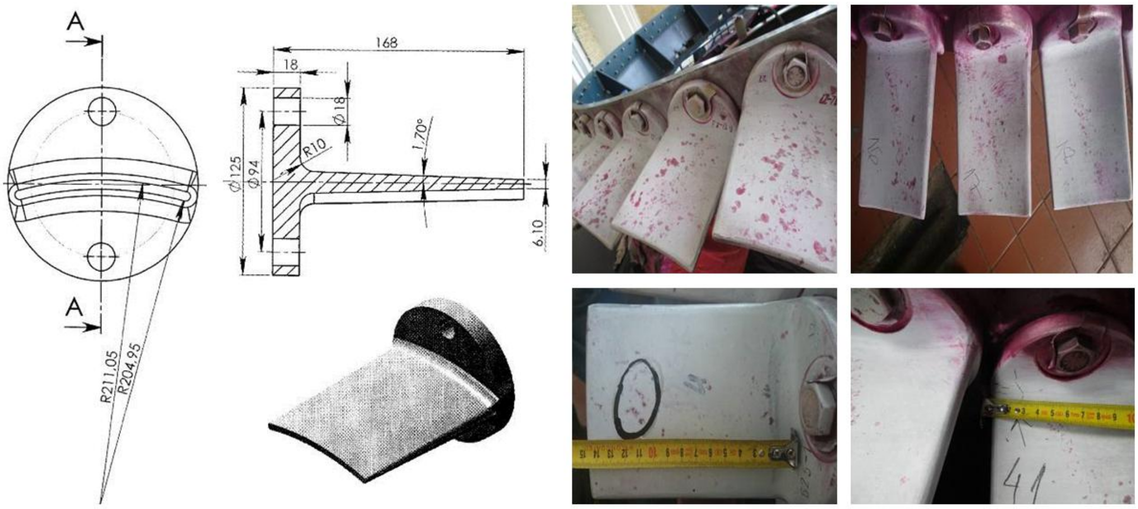
c) Appearance of mechanical damages in area 3

Figure 3*. Detailed appearance of damages detected at the upper and lower section of the generator shaft*

a) Upper row of ventilation ring vanes

a) Lower row of ventilation ring vanes

Figure 4. *Appearance of mechanical damages detected at the upper and lower row of ventilation ring vanes*



a) Upper and lower ventilation ring vane

b) Upper ventilation ring vane

c) Lower ventilation ring vanes

***Figure 5**. Corrosion and cavitation damages detected at the upper and lower ventilation ring vanes*

2. REPAIR OF DAMAGES DETECTED AT THE SHAFT AND VENTILATION RING VANES FOR AIR COOLING OF GENERATOR ROTOR

The procedures for rehabilitation of the generator shaft and vanes of the upper and lower ventilation ring for air cooling of the generator rotor without complete disassembly are presented below .[2]

Repair of area with mechanical damages at the generator shaft

On the basis of the analytical and numerical calculation of the generator shaft with mechanical damages it was determined that its repair could be performed only by fine grinding.

Repair of ventilation ring vanes for air cooling of the generator rotor

Vanes of the upper and lower ventilation ring for air cooling of the generator rotor were manufactured by casting the stainless steel with 13% of chrome and 1% of nickel. Chemical composition required in Technical conditions, as well as chemical composition of vane material are presented in table 1, while mechanical properties are presented in table 2.

***Table 1**. Chemical composition, values in [%]*

Chemical composition	C	Cr	Ni	Mn	Si	P	S	Cu
Technical conditions	≤ 0,15	11,5-14	0,7-1,2	0,5-0,9	≤ 0,60	≤ 0,035	≤ 0,015	≤ 0,50
Vane material	0,13	13,85	1,13	0,78	0,41	0,025	0,018	0,10

***Table 2**. Mechanical properties*

Mechanical properties	Yield strength YS [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A5 [%]	Contraction Z [%]	Impact energy $KCU_{300/2}$ [J/cm^2]
Technical conditions	390	550	15,0	50,0	50 (- 20^{0}C)
Vane material	522	701	20,2	60,8	53/70/76

After the detection of corrosion, erosion and, most of all, cavitation damages at the vanes of the upper and lower ventilation ring for air cooling of the generator rotor, general opinion regarding the cause of the aforementioned degradation of vane material during service and general recommendation regarding the damage repair through the application of welding / surface welding technology were obtained.

2.2.1 Selection of the procedure for repair welding / surface Wwelding

The applicability of the welding procedure 111 was determined through the analysis of parameters on which the repair welding/surface welding procedure depends (weldability of material, energetic possibilities of welding procedures, geometric complexity of the structure, economic parameters). Due to limited capability of performing pre-heating and heat treatment after repair welding/surface welding, the optimal solution is to use the basic coated electrode.

2.2.2 Selection of filler material

Selection of filler material (electrode) was carried out on the basis of weldability of steel with 13,85% of chrome and 1,13% of nickel, dimensions and location of damaged areas due to corrosion, erosion and, most of all, cavitation, possibility of performing heat treatment, machinability of surface welds and experience of NDT staff regarding the repair of Francis turbine vanes.

Taking into account the aforementioned, the martenzite - ferrite electrode OK 68.17, manufactured by ESAB, Germany, was selected. Welds formed through the use of this electrode are resistant toward corrosion, erosion and cavitation [3].

Chemical composition of this electrode is presented in table 3, while mechanical properties of weld metal are presented in table 4.

***Table 3**. Chemical composition of electrode OK 68.17, values in [%]*

Chemical composition	C	Cr	Ni	Mn	Si	Mo	Cu
Electrode OK 68.17	0, 04	11,75	4,50	0,75	0,50	0,55	0,30

***Table 4.** Mechanical properties of electrode OK 68.17*

Mechanical property	Yield strength $YS_{0.2}$ [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A5 [%]	Impact energy $KV_{300/2}$ [J/cm^2]
Electrode OK 68.17	500	750	min 20,0	min 40 (- 20^{0}C)

2.2.3 Technology for repair of damaged vanes

Basic principles of the repair technology for welding or surface welding of ventilation ring vanes for air cooling of generator rotor contain the following;

- Areas at vanes where corrosion, erosion and (most of all) cavitation damages were detected, were locally pre-heated at 150°C after the preparation was performed by angular and frontal grinder;
- Welding/surface welding was performed through the use of electrode OK 68.17 with 2.5 mm diameter
- After welding/surface welding was performed, vanes were additionally heated at 150°C for an hour; then isolated from both sides and slowly air-cooled;
- After the repair of areas where mechanical damages were detected by welding/surface welding was performed, welds were finely grinded by angular and frontal grinders in order to obtain adequate geometry and surface roughness.

3. CONCLUSION

Successfulness of the repair methodology carried out in areas where damages were detected has been acknowledged by the equipment manufacturer ”ČKD Blansko” from Czech Republic.

It should also be noted that significant financial effect was achieved, because the avoidance of complete disassembling helped to save approximately 100 000 €. Taking into account the period of time necessary to perform complete disassembling of components, as well as the period of time needed to perform reassembling, which is directly linked with the amount of energy the hydroelectric generating set A2 would produce during that period, overall save would mount up to 500 000 €.

Acknowledgement

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4. REFERENCES

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[3]OK 68.17, E 13 4 R 3 2, Coated electrode designed for the welding of stainless-steel castings of the 13Cr4NiMo type, ESAB, Czech Republic.