M. Arsić, M33 2. 2. 2018.

MACEDONIAN UNION OF METALLURGISTS

VIII[th] International Metallurgical Congress

METALLURGY, MATERIALS AND ENVIRONMENT

PROCEEDINGS

30[th] May – 3[ht] June 2018

Ohrid, Republic of Macedonia

Edited by:

Sveto Cvetkovski & Goran Načevski

VIIIth International Metallurgical Congress,
(Metallurgy, Materials and Environment)
organized by

Macedonian union of metallurgists

under the auspices of the

Ss. Cyril and Methodius University in Skopje
Faculty of Technology and Metallurgy
Economic Chamber of Macedonia
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Contents

REPAIR OF DAMAGED SURFACES AT THE VITAL SECTION OF THE REGULATORY MECHANISM OF THE HYDRO TURBINE GUIDE VANE APPARATUS

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Abstract

Vertical Kaplan turbines were installed in 6 hydroelectric generating sets at "Djerdap 1", nominal power 178 MW, that were made in Russia. During the refurbishment of the hydroelectric generating set A1 at the hydro power plant Djerdap 1, experimental non-destructive tests on all of its components were performed in order to determine the state of the turbine as a whole. During the testing the damages and cracks were detected on internal surfaces of cranks and sleeves of guide vane apparatus vanes, which were caused by turbine shaft vibrations. Cranks and sleeves were made of cast steel 25L, in accordance with the standard GOST 977.

The repair methodology for damaged internal surfaces of cranks of guide vane apparatus vanes is presented in this paper. It was necessary, due to the structural solution used for the design of cranks and sleeves and their function during exploitation, to define a large number of details, carefully reconsider them and carry out all activities with extreme care in order to enable the safe operation and continuous use of cranks. Overlooking, underestimation or incorrect perception of important details could cause significant problems during turbine operation.

Key words: hydro turbine, crank, sleeve, damages, repair tehnology

Introduction

Vertical Kaplan turbines are installed in 6 hydroelectric generating sets at "Djerdap 1", nominal power 200 MW, that were made in Russia, Fig. 1 [1]. They have been designed for the service life of 40 years due to the structural solution, or in other words because of the impossibility of performing periodic inspections and state analyses. Position of cranks and guide vane apparatus vanes is shown in Fig. 2, while dimensions of a crank. Cranks and vane sleeves, Fig. 3, were made of cast steel 25L, in accordance with the standard GOST 977 [2].

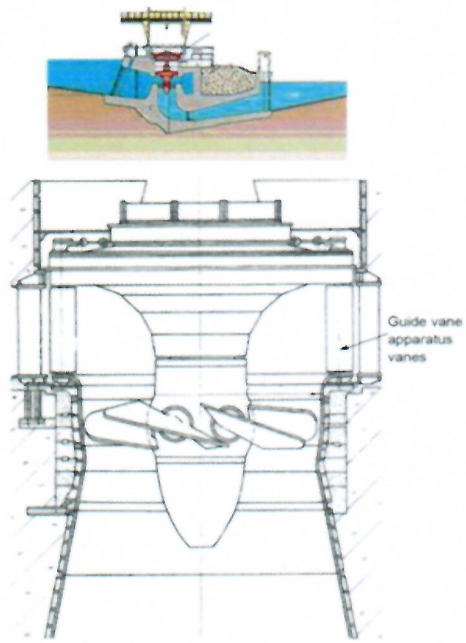
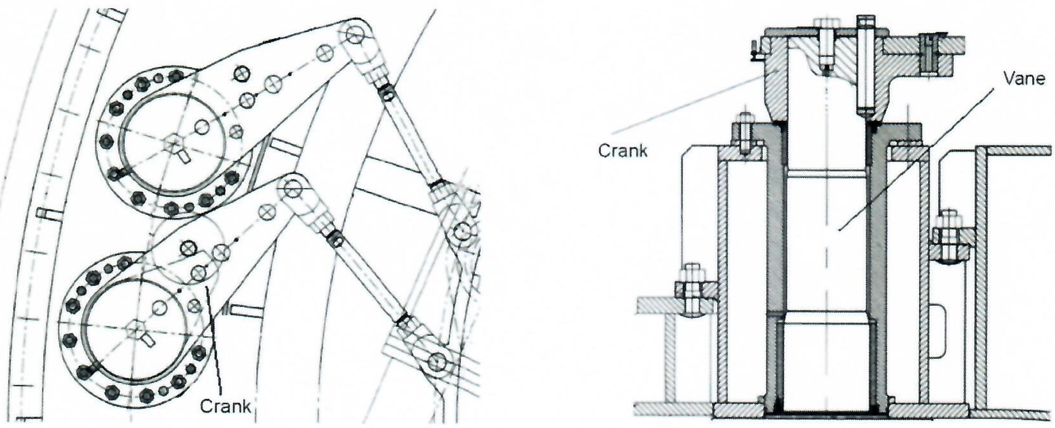


Fig. 1 Appearance of the operating part of the vertical Kaplan turbine, nominal power 178 MW



a) Crank with the regulatory mechanism

b) Crank with the vane

Fig. 2 Position of cranks and guide vane apparatus vanes

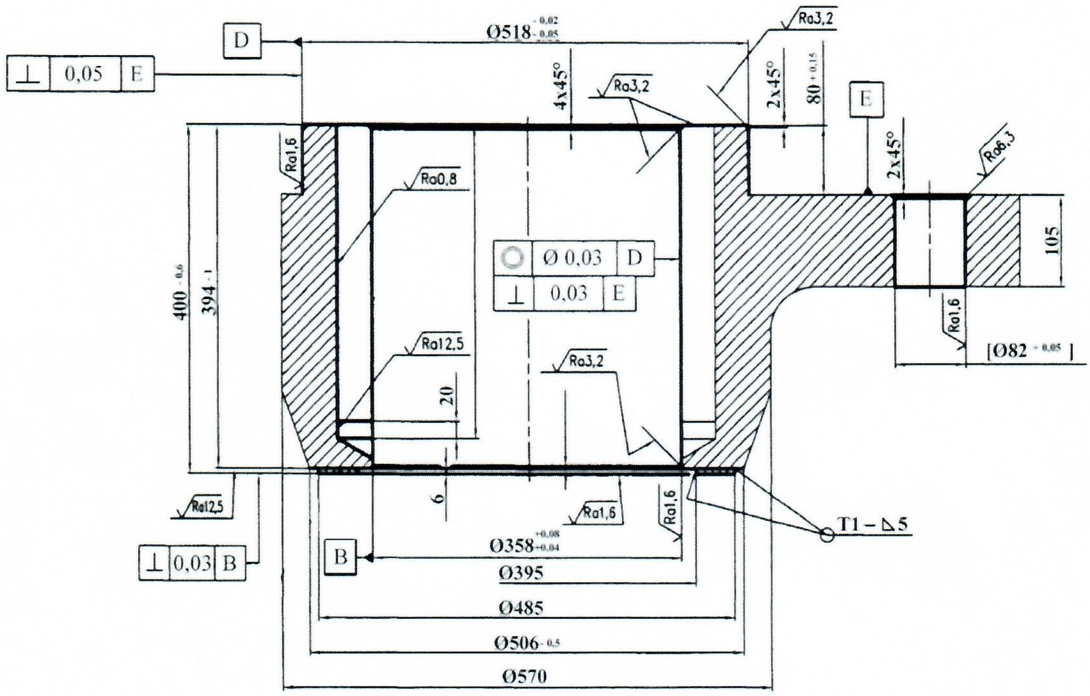


Fig. 3 Dimensions of a crank

Experimental

Non-destructive tests were performed in order to enable the determination of the current state of internal surfaces of cranks and sleeves. Defects positioned along the circumference of cranks were measured by micrometer and detected through the application of penetrant testing (PT) or magnetic particle testing (MT), while defects within the material were detected through the application of ultrasonic testing (UT). Characteristic damages on one of the cranks and on the sleeves are shown in Fig. 4.

a) Damages detected by PT

b) Cracks detected by MT and UT

Fig. 4 Appearance of defects positioned along the circumference of the internal area and semi-opening

Tehology for the Repair of Defects on Internal Surfaces of Cranks and Guide Vane Apparatus Vanes

This technology refers to the activities performed during the repair of cranks and sleeves, on which it was necessary to grind out linear indications and perform welding/surface welding on the internal surfaces of crank hubs, as well as on the surfaces of sleeves.

Chemical composition and mechanical properties of cast steel 25L, of which the cranks and vanes were made, are presented in Tables 1 and 2 (according to standard GOST 977-75).

Table 1 Chemical composition, values in [%]

Material	C	Si	Mn	Cr	Ni	Cu	S	P
25L	0.22-0.30	0.20-0.52	0.35-0.90	< 0.30	< 0.30	< 0.30	max 0.045	max 0.04

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

Material	Yield stress $R_{0.2}$ [N/mm^2]	Tensile strength R_m [N/mm^2]	Elongation A5 [%]	Contraction Z (%)	Impact energy KCU [J/cm^2]
25L	min 305	min 520	min 21	min 27	min 62

According to the formula for maximum values of chemical elements presented in table 1, the calculated value of material equivalent C_e is higher than 0.45 (limit value of good weldability). According to Ito-Bessyo (equation 2), material equivalent C_e is higher than 0.3 (limit value of good weldability), which indicates the proneness of the material to cold cracking. Therefore it was necessary to perform the repair procedure in areas of cranks and vanes where defects were detected, including the preheating and controlled cooling.

$$Ce = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 > 0.45 \quad (1)$$

$$Ce = C + Si/30 + (Mn + Cu + Cr)/20 + Mo/15 + Ni/60 + V/10 + 5B > 0.30 \quad (2)$$

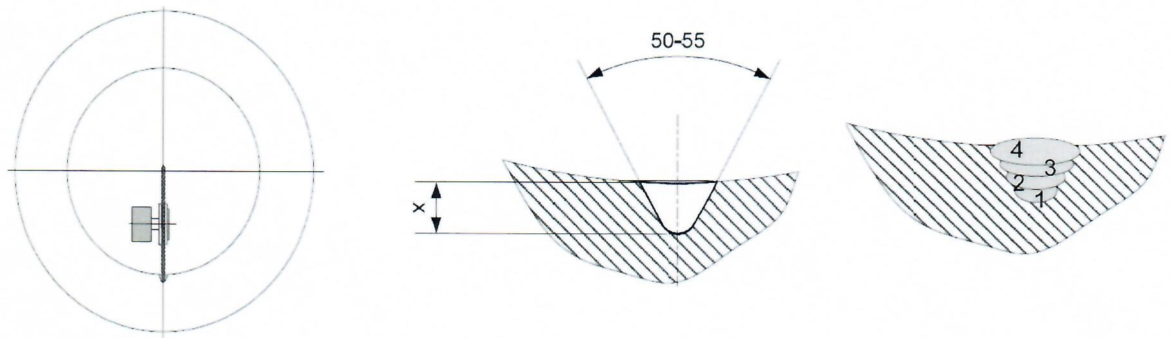
Through the application of the formula for hot cracking sensitivity, it was determined that the material is not prone to hot cracking (equation 4), because the obtained value for hot cracking sensitivity is lower or equal to 4 (boundary value for the occurrence of hot cracks at steels with the value of tensile strength $R_m < 700$ N/mm^2).

$$HCS = 100C\,(S+P+Si/25+Ni/100)\,/\,(3Mn+Cr+Mo+V) \leq 4.0 \quad (3)$$

Regardless of chemical composition (table 1), crank hub thickness (d = 105 mm) and damaged vane sleeves at diameters Ø 240 mm, Ø 360 mm and Ø 400 mm, due to their structural solution, preheating was carried out by inductors in order to reach the temperature of 150 °C, as suggested in russian literature for cast steel 25L. Calculations showed that much larger preheating temperatures were needed due to the thickness of cranks and diameters of sleeves.

The first step was to eliminate detected cracks by grinding. Visual testing and magnetic particle testing (or dye-penetrant testing) were performed continuously during their elimination. After the grinding, the preparation of grooves was performed, and finally welding/surface welding was carried out, Fig 5.

Based on parameters that influence the selection of welding pocedure (weldability of base material, energetic characteristics of the welding procedure, geometric complexity of the structure, comparative economic analysis), welding was carried out through the use of the coated electrode EVB 50 (Elektrode Jesenice d.o.o.) and utilization of procedure 111. Preheating to 150°C was performed through the use of induction heaters, as suggested in russian literature. Preheating temperature inspection was performed by IC thermometers, [4].



a) Elimination of defects by grinding b) Groove preparation c) Weld layer sequence

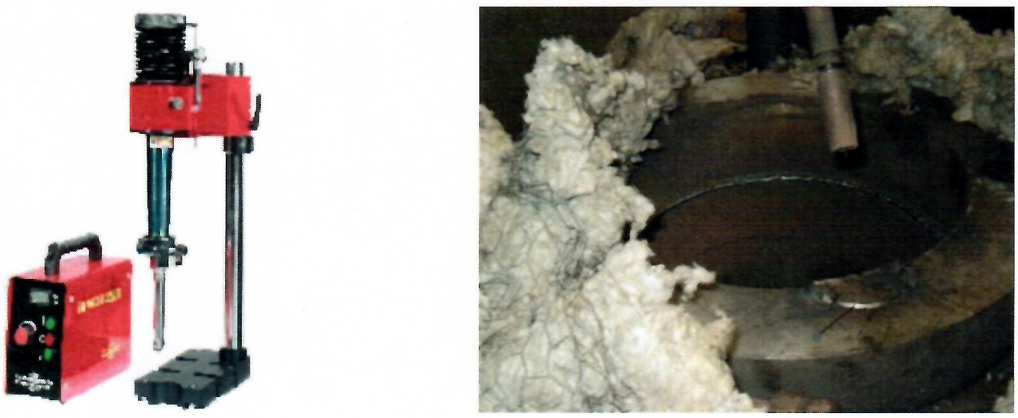
Fig. 5 Elimination of defects, groove preparation and welding process

Surface welding was performed through the use of ID WELD 2501 device on internal surfaces of crank hubs and utilization of procedure 131, by TIG Mo wire, 1.2 mm in diameter (Elektrode Jesenice d.o.o.) according to standard EN 1668 [5], and with the use of protection gas M21 according to standard EN 439 [6], Fig. 6.

The repairing of defects that occurred on the semi-opening for the two-part wedge has been performed using the same device and TIG Mo wire, 2.5 mm in diameter, figure 2. In order to achieve the continuity of the surface during the welding, 5 mm thick plates were temporarily attached, and afterwards grinded away.

Optimum surface welding parameters, determined through a series of tests performed on components made of same material and of similar thickness, are as follows [4]:

- number of revolutions during surface welding: 0.5-1 r/min,
- surface welding: continuous, I = 200 A,
- current source: any standard source for MIG/MAG welding process,
- voltage: U = 20 – 30 V,
- flux of the protection gas: 10 – 20 l/min.



a) Device ID Weld 2501 b) Welding performed at the surface of the opening

Fig. 5 Device for welding at the surface of the opening (ID Weld 2501)

In order to reduce the level of residual stresses and eliminate the possibility of occurrence of deformations after welding/repair welding and finish machining, cranks have been heat-treated through the use of technology with the following parameters [4]:

- heating rate max 40 °C/h until reaching the temperature of 300 °C,
- 2h holding time at the reached temperature of 300 °C,
- continuation of heating at the heating rate of 40 °C/h until reaching the temperature of 580 ± 10 °C, prescribed
- not less than 5h holding time at the reached temperature of 580 ± 10 °C, time starts counting when the temperature is reached at all thermometers in the furnace,
- cooling rate not higher than 40 °C/h until reaching the temperature of 250 °C, further cooling under the isolation layer.

Heat treatment diagram is shown in Fig 6.

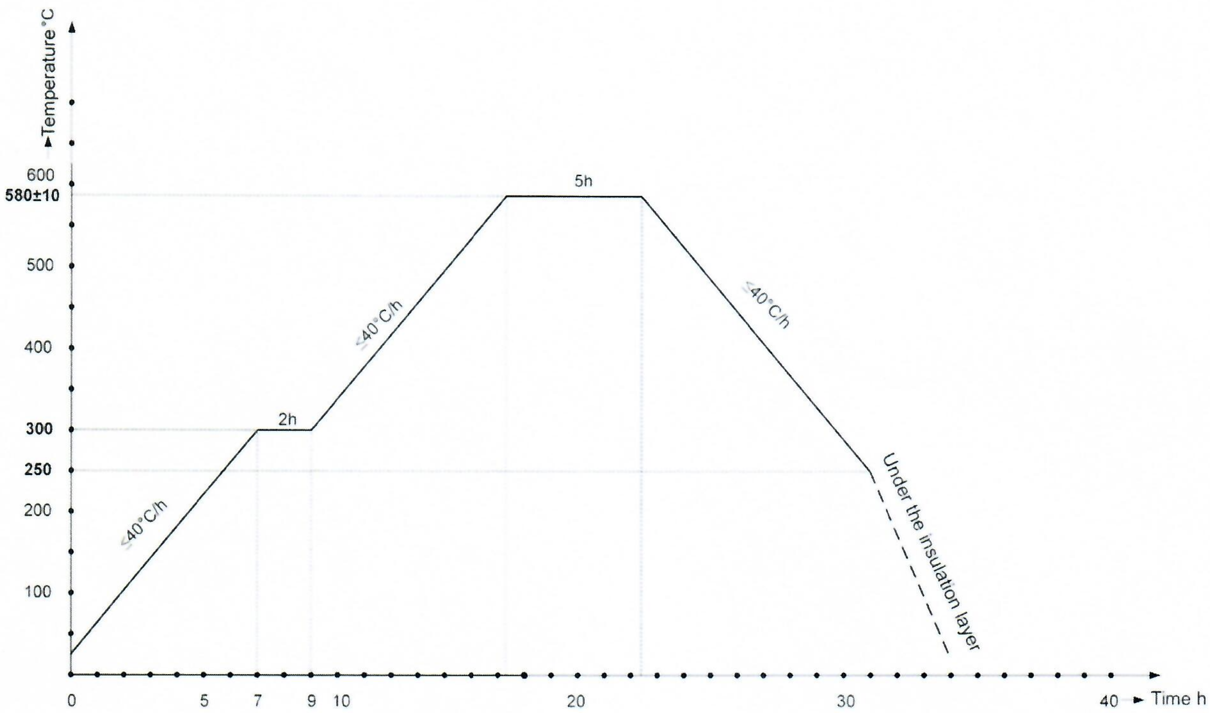


Fig. 6 Heat treatment diagram

Results and Discussion

After performed welding in areas at internal surfaces of crank hubs inspection of quality of performed repairs has been carried out.

All cracks on cranks were detected through magnetic particle testing (MT) or penetrant testing (PT), while internal surfaces during and after the finish machining were inspected by the magnetic particle testing method or the penetrant testing method, while dimensions of damaged areas have been measured by a micrometer. Size of damages detected on vane sleeves has been determined through visual testing and measured by micrometer. In cases when defects were detected at crank hubs and vane sleeves, the welding procedure was repeated after every machining phase. It should be noted that after the finalization of every phase the surface has been inspected by the magnetic particle testing method or penetrant testing method.

Inspection of heat treatment quality has been carried out by measuring the hardness of weld metal which should, by technical conditions, range from 130 – 240 HB. Also, a test has been performed in order to determine whether the hardness of base material of the crank after the heat treatment was within the required range for given base material.

Successfulness of performed repair methodologies for damages detected at internal surfaces of crank hubs and sleeves of guide vane apparatus vanes from turbine A1 at the hydro power plant 'Đerdap 1' has been confirmed by the equipment manufacturer „Силовые машины" from Saint Petersburg, because they guaranteed that the equipment can be used safely until the next refurbishment, or to put it differently for the next 40 years.

Also, it can be concluded that utilized technologies are applicable for the reparation of other components and structures of turbine and hydromechanical equipment made of cast steel 25L.

Acknowledgement

Authors wish to thank the Ministry of Education, Science and Technological Development of Serbia for supporting projects TR 35002.

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