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Use of Non-Destructive Tests for the Assessment of Integrity and Service Life of Hydro-Mechanical Equipment

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Abstract. Technical diagnostics of hydromechanical equipment, is based on testing procedures including the history of the exploitation with expert knowledge of structures and operating conditions, as well as, on the analysis of results performed by experts with appropriate experience and knowledge in design, exploitation, maintenance, reliability, fracture mechanics etc. Degradation of properties of the material and/or welded joints of hydro-mechanical equipment is being caused by the simultaneous influence of a large number of factors. First of all, it is thought of technological, metallurgical, structural and conditions of exploitation. In this paper, the selection of methodology for the rehabilitation of hydro-mechanical equipment is presented based on the previously conducted assessment of state of equipment using the nondestructive testing methods. Repair welding, repair of damaged surfaces by cold metallization, corrections of existing structural solutions of metallic components in order to improve their technical characteristics and extend the service life are presented.

Introduction

Stresses occur at hydromechanical equipment during the process of production, assembly of equipment and during exploitation (stationary and non-stationary dynamic loads). With the addition of unpredictable influence of corrosion, erosion and cavitation during exploitation, it's easily understandable that stressing of certain components and equipment as a whole can not be fully presented by a model in which the parameters are being altered uniformly under working conditions.

Integrity of structures is a relatively recent scientific and engineering discipline, which in a broader sense embraces condition analysis and behavioral diagnostics, service life assessment and rehabilitation of structures which means that, beside the usual procedure that refers to assessment of structural integrity and includes detection of defects by non-destructive testing, this discipline also comprises the analysis of stress state of the crackless structure.That's the way to define the stress-strain fields, which enables the identification of critical components of analyzed structures even before the defects appear. Basic components of vertical Kaplan turbines of hydroelectric generating sets at 'Djerdap 1', with nominal turbine power of 178 MW, are marked in Fig. 1. It should be noted that many of stated components exist at horizontal Kaplan turbines of hydroelectric generating sets at 'Djerdap 2', with nominal turbine power of 28 MW, Fig. 2. The same is true when it comes to Francis turbines.

Experimental Non-Destructive Tests

Hydropower plants are interested in providing every possible means of protecting hydromechanical equipment when it comes to degradation of parent material and/or welded joints at components and structures, caused by stresses and unpredictable influence of corrosion, erosion and cavitation or their combined effect. It's important to note that, on one hand, the researches regarding the modern structural materials resistable to above mentioned influences are being conducted, while on the other hand the researches regarding modern technological procedures and materials for reparation and preventive protection of equipment which is already in service are being carried out.

In this paper the results of visual testing (VT), penetrant testing (PT) and magnetic particle testing (MT) in order to detect the surface defects, as well as results of ultrasonic testing in order to detect internal defects within welded joints (WJ), or, to put it differently, within weld metal (WM), heat affected zone (HAZ) and parent material (PM) have enabled the determination of causes of degradation of parent material and/or welded joints. The results obtained by applying a wide range of non-destructive methods were used to assess level and causes of degradation and to determine the repair methodology for the hydromechanical equipment at hydropower plants ’Djerdap 1’ and ’Djerdap 2’.

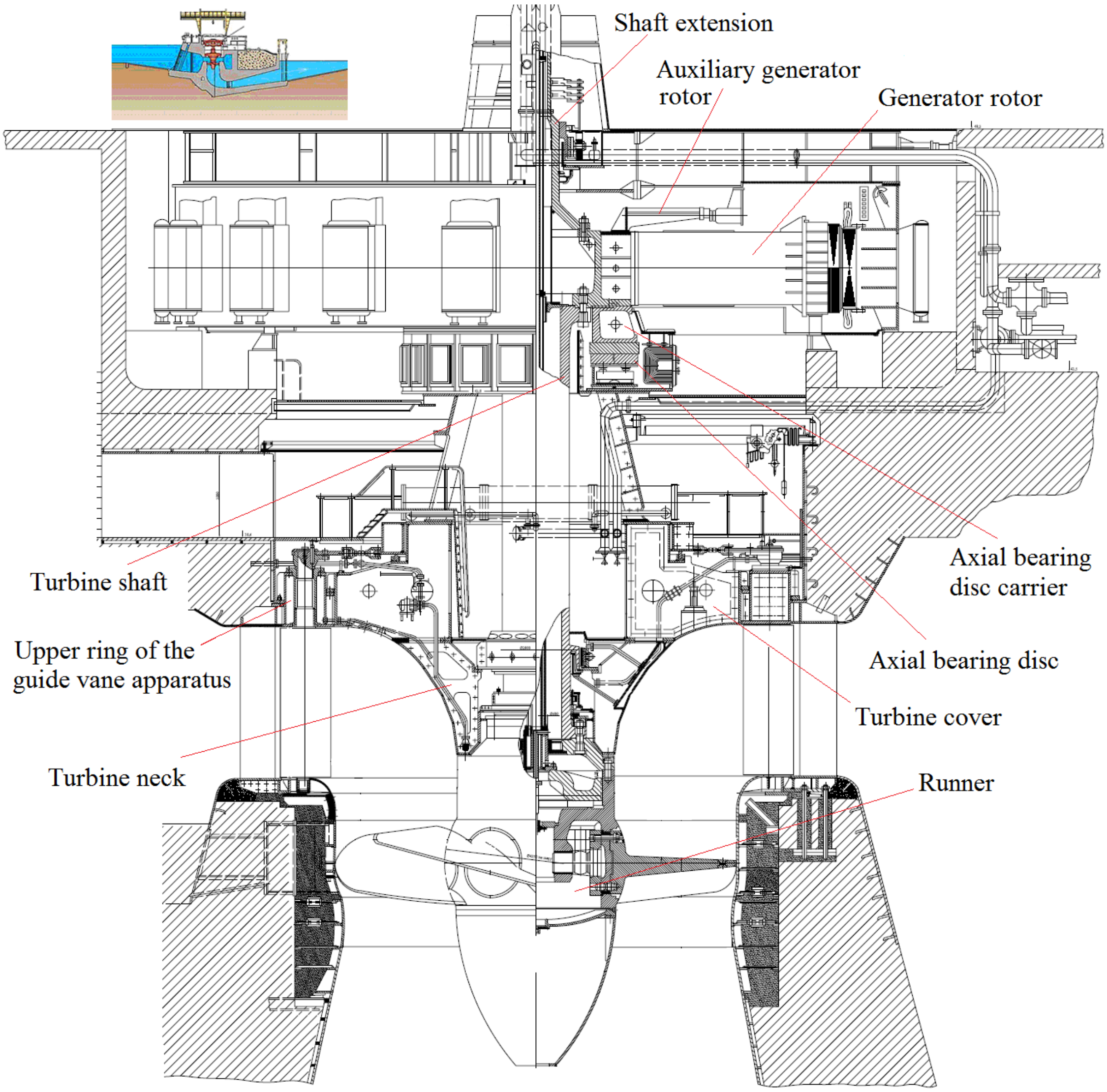


Figure 1. Appearance of the vertical Kaplan turbine, nominal power 178 MW (’Djerdap 1’)

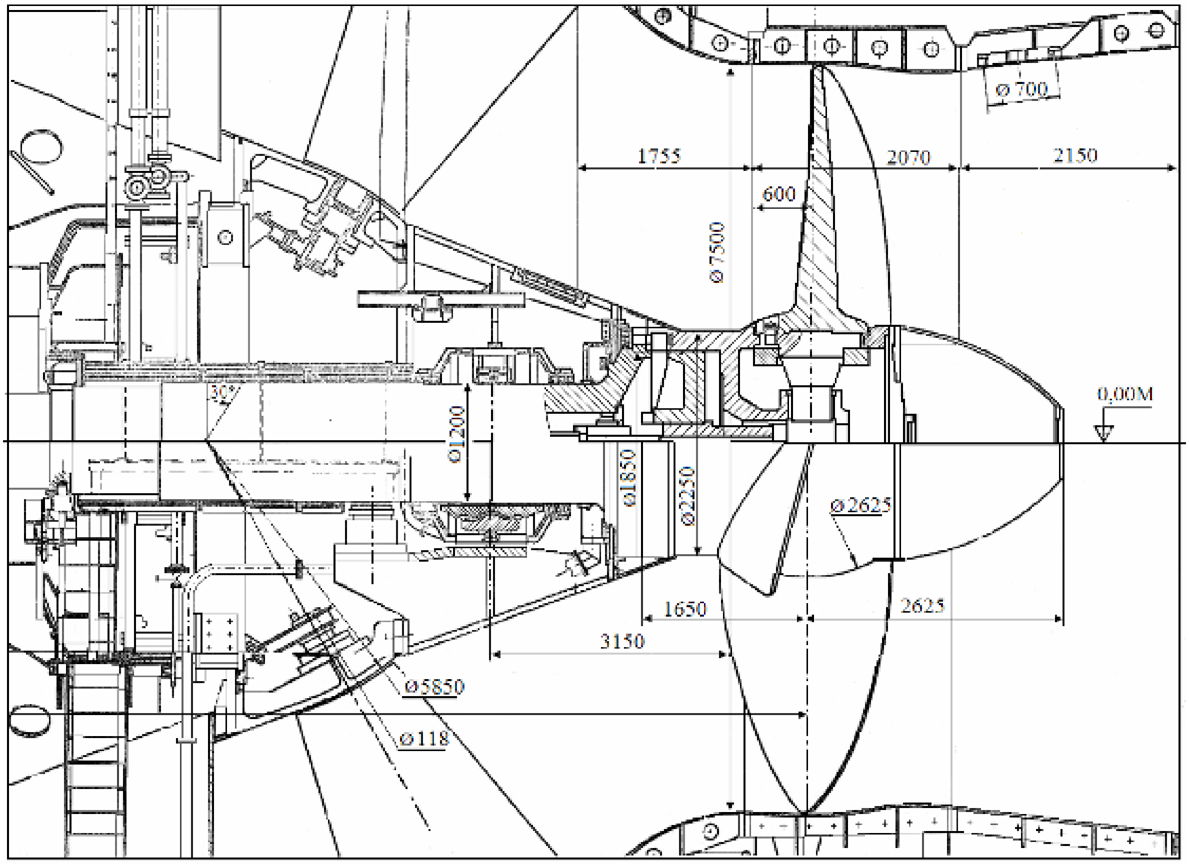


Figure 2. Appearance of a horizontal Kaplan turbine, nominal power 28 MW ('Djerdap 2')

Fracture and damaging of turbine shaft at hydropower plant Djerdap 2

After more than 20 years of operation, at 1 of 10 hydroelectric generating unit turbine shafts a through-thickness crack and fracture were detected, Fig. 3, while at other turbine shafts cracks (damages) were detected and repaired through the use of an adequate repair welding technology, Fig. 4. Cylindrical section of the shaft was made of steel 20 SL, while flange was made of cast steel 20 GSL, in accordance with GOST 977/88.

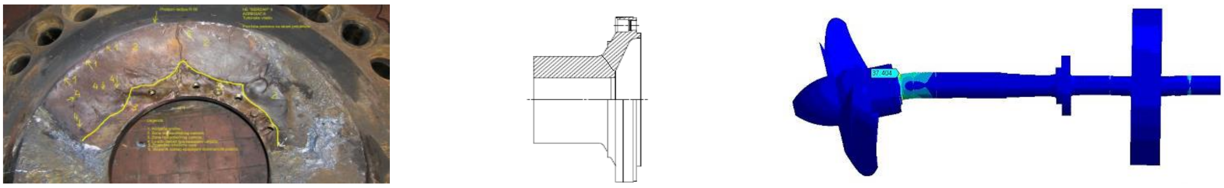


Figure 3. Appearance of the fracture of the horizontal Kaplan turbine shaft, nominal power 28 MW

a) Cracks detected by PT

b) Cracks detected by MT

Figure 4. Appearance of cracks detected at turbine shafts

Testing of pipes and elbows of the regulation system at hydropower plant Djerdap 1

Purpose of these tests is to analyze the condition of welded pipes and elbows of the regulation system pipeline at the hydroelectric generating set A6 during production and exploitation, as well as to determine the influence of local wall thinning and material degradation on their integrity under combined influence of the internal pressure of turbine oil (p = 4 MPa) and planar loads, Fig. 5. Function of the regulation system, which comprises the pipeline for the supply of the turbine regulator with oil, is to open and close vanes of the guide vane apparatus and regulate the position of runner blades and their number of revolutions. Characteristic damages that occur during the production and exploitation of pipes and elbows are presented in Fig. 6. Pipes and elbows have been made of steel St 20, in accordance with GOST 977/88 (A 53 according to ASTM).

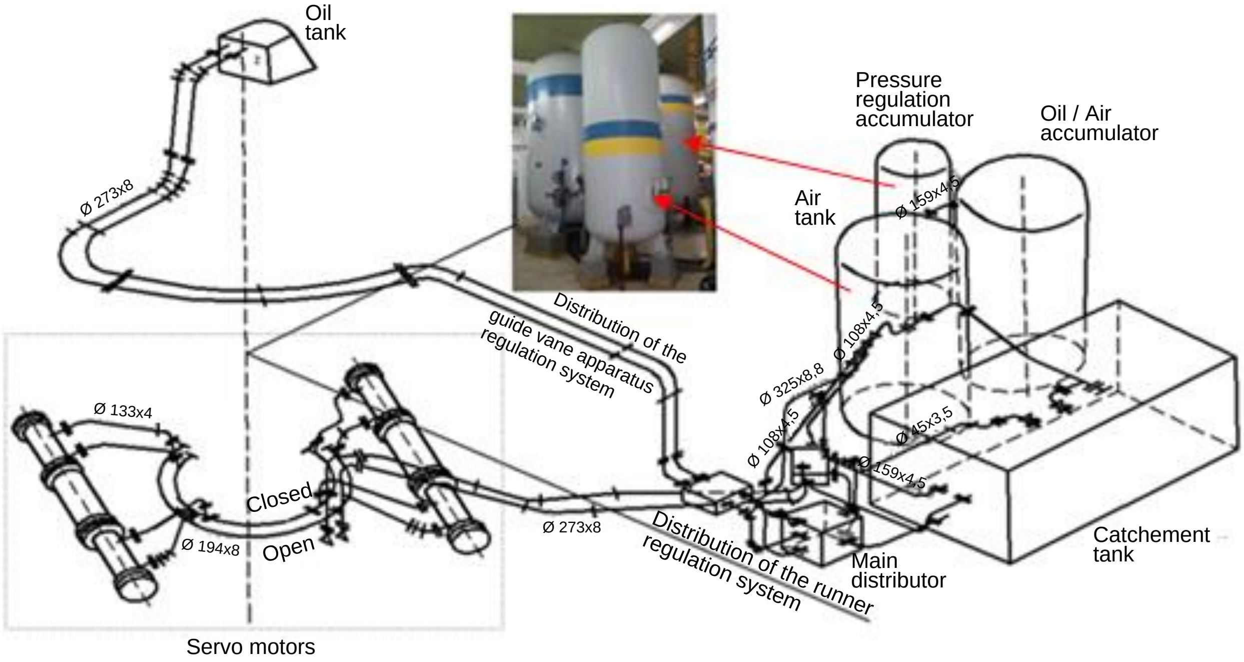
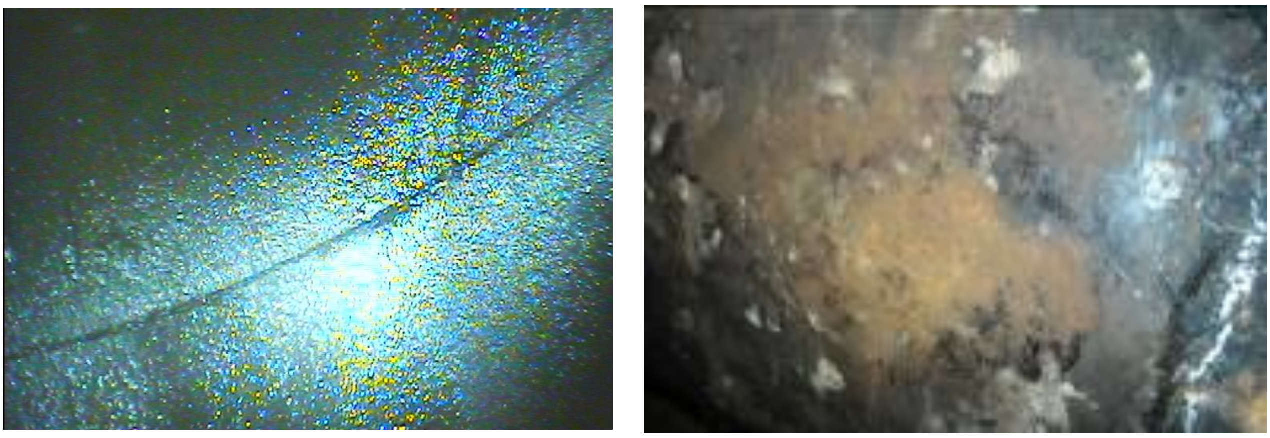


Figure 5. Appearance of the turbine regulation system



a) Incomplete root penetration – endoscopy

b) Pitting corrosion at the surface – VT

Figure 6. Appearance of characteristic damages that occur during the production and exploitation of pipes and elbows

Damages that occurred at the upper ring of the hydroelectric generating set a6 guide vane apparatus at Djerdap 1 during exploitation period

The upper ring of the turbine runner guide vane apparatus was fabricated by welding 4 segments made of steel St 3 together, in accordance with GOST 977/88, by flux-cored arc welding. Through magnetic particle testing a large number of fatigue cracks was detected at all 4 segments, while incomplete penetration and lamellar tearing (LT) and defect (D) were detected in the root area by ultrasonic testing, Fig. 7.

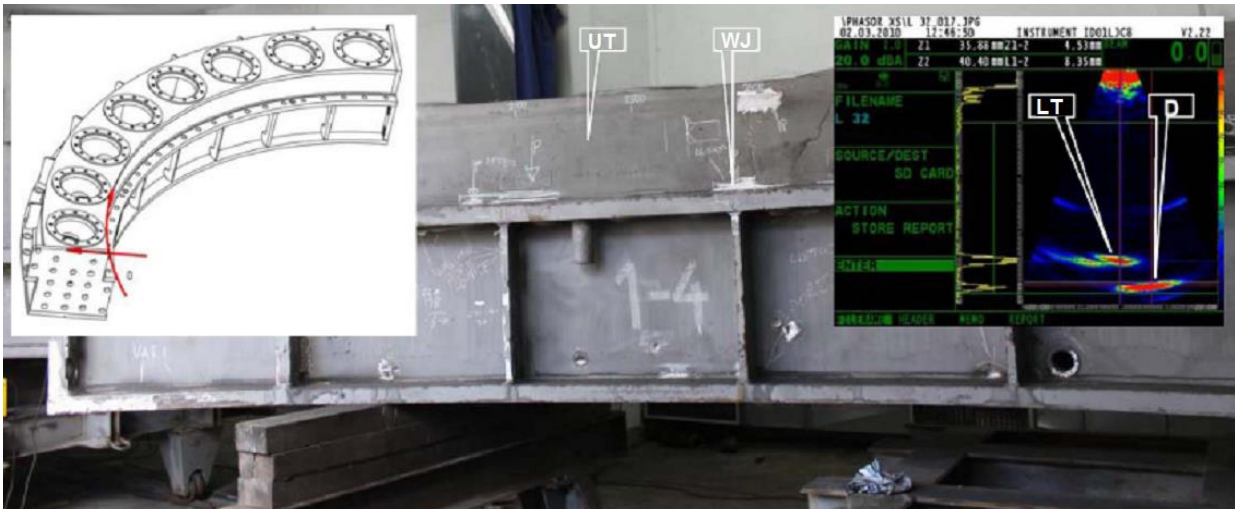


Figure 7. Display of results of ultrasonic testing performed at one of the segments

Analysis of turbine cover condition at hydropower plant Djerdap 1

Turbine cover, which weighs 118636 kg, was fabricated by welding 4 segments made of steel St 3 together, in accordance with GOST 977/88. Models and results of magnetic particle testing (MT) carried out at welded joints of a turbine cover segment are presented in Fig. 8, Fig. 9 while Fig. 10 displays echographs taken during ultrasonic testing which show lamellar tearing in the area of the welded joint.

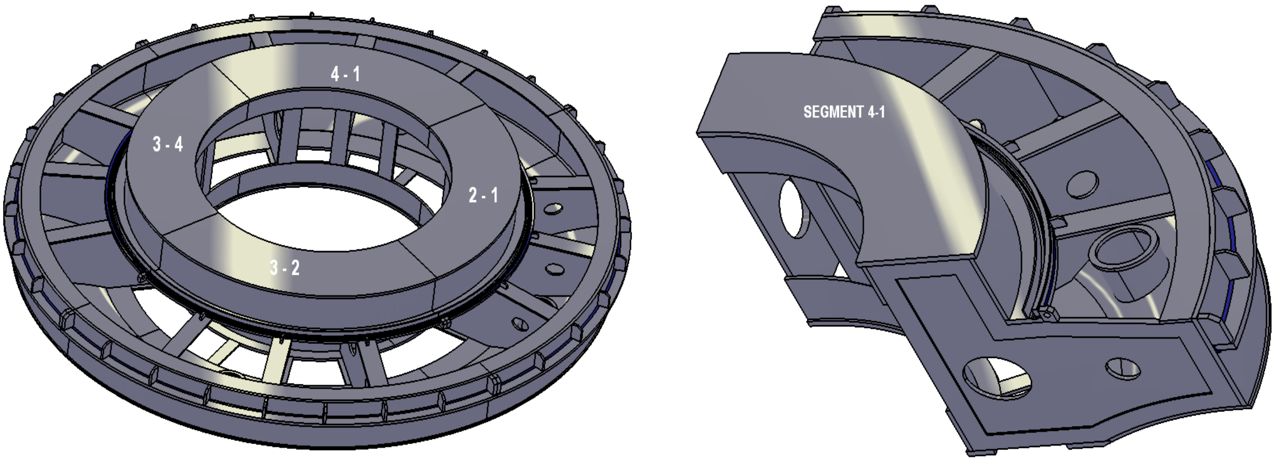
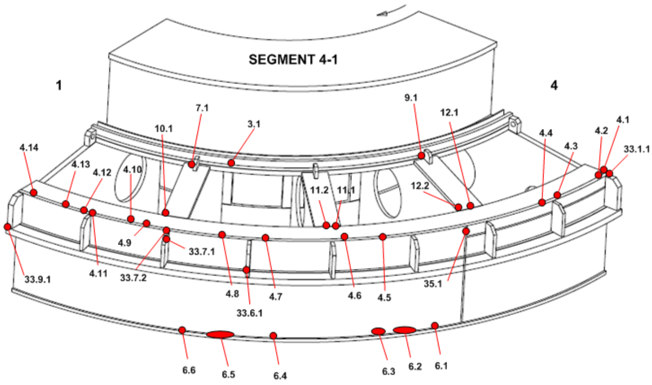
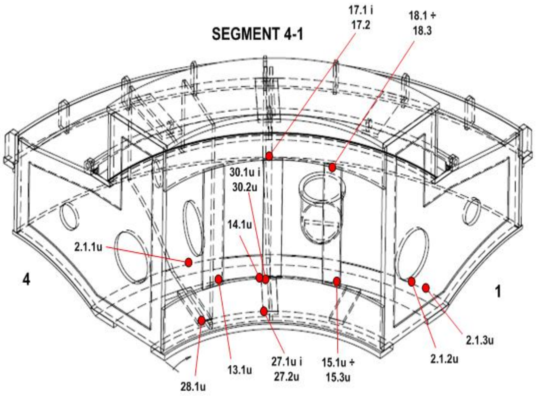


Figure 8. Model of turbine cover and segment 4-1





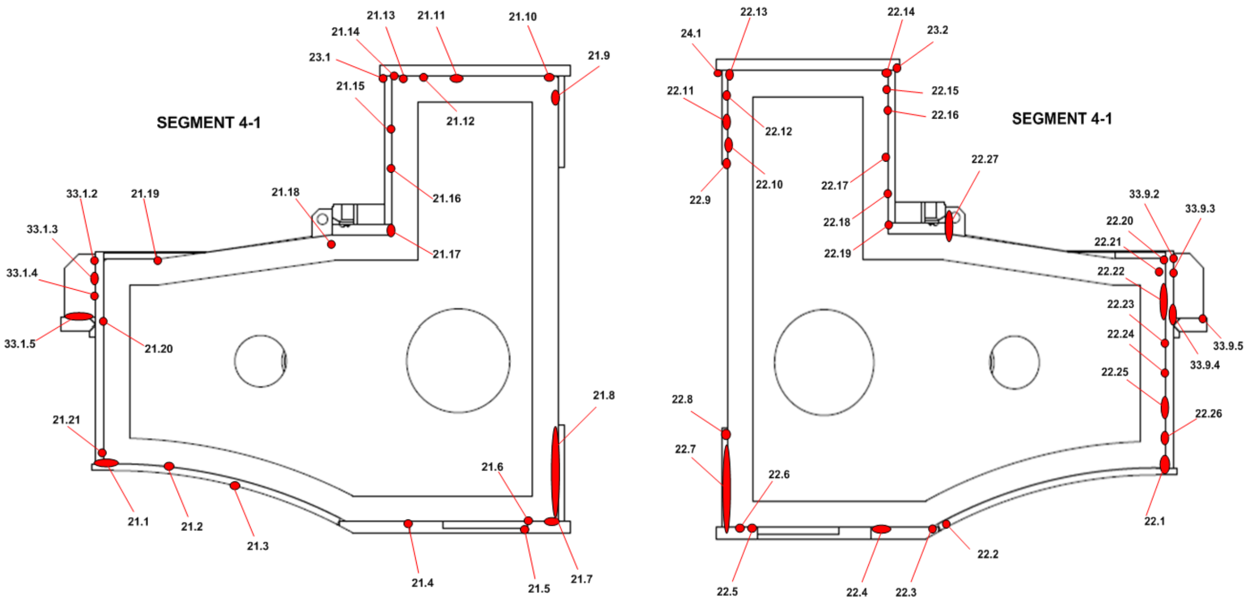


Figure 9. Results of magnetic particle testing (MT) performed at welded joints of a turbine cover segment

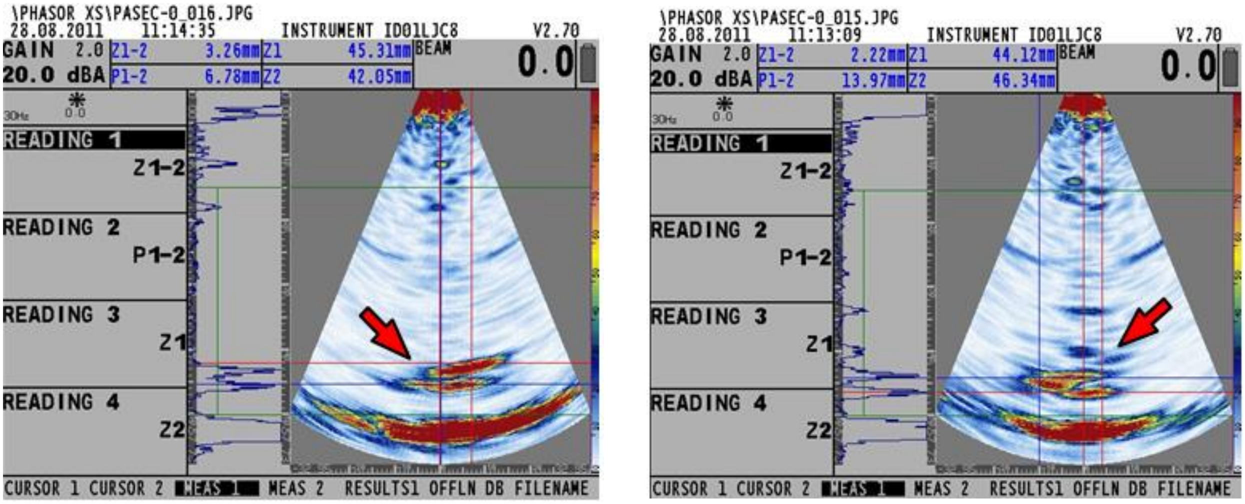


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Figure 10. Display of echographs with lamellar tearing in the area of the welded joint

Damages detected at the housing of the synchronous valve at hydropower plant Pirot

Function of the synchronous valve is to protect the runner and runner blades from the hydraulic impact of water when the turbine stops, or in other words to drain the water from the turbine when it stops working, because the water at that moment posseses such kinetic energy that it could cause the breakdown of the hydroelectric generating set as a whole. Test results showed that damages that occurred were caused by corrosion, erosion and cavitation, Fig. 11.

a) Valve housing b) Strengthening rib

Figure 11. Damages detected at the synchronous valve

Results and Discussion

It was determined that fracture and damaging of turbine shafts at HPP Djerdap 2 were caused by small transitional radii between the cylindrical part of the shaft and flange, as well as by corrosion fatigue. Transitional radius was enhanced from R=80 mm to R=100 mm through the implementation of the repair welding technology for the turbine shaft, [1].

On the basis of experimental tests the evaluation of the global deformation behaviour of welded pipes and elbows of turbine regulation system was executed, through the use of elasticity theory and three-dimensional elastic-plastic finite element analysis and depending on parameters that refer to the quality of welded joints and wall thinning, such as: type and location of defects in welded joints, decrease of wall thickness, length of section with thinned wall, circumferential angle of the elbow for different types of bending and various geometric characteristics of elbows. It was determined that the pressure which could be considered critical for the integrity of welded pipes and elbows, with defects that occur during production and exploitation, is p=10 MPa, [2].

By comprehensive researches, executed on the basis of results of non-destructive tests, it was established that there are two equally significant causes of degradation of parent material and welded joints of the upper ring of guide vane apparatus, which is a constitutive part of the turbine runner, [3]:

- degradation caused by defects that occur due to steel production technology,
- degradation caused by defects that occur due to technology of fabrication of the welded structure.

Linear indications that were detected at welded joints by magnetic particle testing are fatigue cracks that occur as a consequence of variable loading to which the turbine cover is subjected during service, while incomplete penetration of the root is a direct consequence of inadequate welding technology used during the fabrication of the structure, while lamellar tearing of parent material in the near proximity of welded joints is a direct consequence of the use of inadequate technology of steel production and flaws in the technology of fabrication of the turbine cover as a whole. Analysis of condition, integrity assessment and residual service life evaluation for the turbine cover is presented in the report, [4].

By determination of causes of degradation of parent material and welded joints of the Francis turbine synchronous valve, based on results of non-destructive tests, it was enabled to make a decision regarding the rehabilitation procedure. Taking into account the fact that damages caused by corrosion, erosion and cavitation were up to 10mm deep, repair of damages was executed by surface welding, [5].

Summary

On the basis of presented examples it can be concluded that only execution of periodic inspections at components and structures of hydromechanical equipment and databases that refer to realized inspections enable determination of condition, as well as causes of degradation of material and/or welded joints, evaluation of mutual influence of certain components, as well as determination of functionality and reliability of the system and equipment as a whole. It should also be noted that non-destructive tests are very significant when it comes to identification and making expert decisions regarding the methodology which should be used for the rehabilitation of damaged components.

Acknowledgement

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