

## ANALYSIS OF CURRENT STATE AND INTEGRITY EVALUATION OF THE PIPELINE AT HYDRO POWER PLANT 'PIROT'

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*Key words: hydroelectric generating set, crack, repair technology, pipeline integrity*

### 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 m. Pipes have been made of S275J2G3 steel. [1] Pipe wall is 22 mm thick. Maximum pressure of 2.5 MPa occurs in front of the turbine cover. [2]

Pipeline has been designed and built without anchor blocks at curvatures, which is rarity elsewhere. Geodetic measurements have been conducted permanently from the day the assembly was finished and pipeline was put into service, both when pipeline is empty and unloaded by hydrostatic pressure and when it is full. Analysis of obtained data regards the movements along the pipeline route showed that from year 2003 there are significantly higher differences in movements comparing the situations when the pipeline is full and when it is empty in comparison with the previous period.

Those differences primarily refers to tangential movements of vertices marked with numbers 6, 7 and 8, which, compared to the period until year 2002, are in the range from 3 mm for vertex 8 to 5 mm for vertex 6. Apart from geodetic measurements, the measurement of pipe diameter in 2 directions is also being carried out permanently. Those data show that from year 2003. the diameter in horizontal direction started to increase significantly, while at the same time the diameter in vertical direction started to decrease less significantly.

This paper contains the analysis of current state and integrity evaluation of the pipeline as a whole on the basis of results of non - destructive tests performed on the vital butt - welded joint in the curvature area at chainage 1+263 m (visual testing, magnetic particle testing, penetrant testing, ultrasonic testing, radiographic testing, metallographic replication testing).

## 1. INTRODUCTION

Hydro power plant 'Pirot' is located in the near proximity of town Pirot and uses the power of Visocka river at the profile of the dam 'Zavoj'. It has been built in 1990. as 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 (figure 1), manufactured in Czech Republic, tunnel and a sunken pipeline with overall length of 2.030 m and diameter that ranges from 3.000 to 3.500 m. [1]

Maximum pressure of 2.5 MPa occurs in front of the turbine cover. Pipes have been made of 22 mm thick S275J2G3 steel sheet metal [2]. Chemical composition and mechanical properties of this steel are presented in Tables 1 and 2.

Pipeline has been designed and built without anchor blocks at curvatures, which is a rarity elsewhere. In order to perform the analysis of current state and integrity evaluation of the pipeline as a whole, non - destructive tests were performed on the vital butt-welded joint in the curvature area at chainage 1+263 m.

In that area of the pipeline, according to the design documentation, the angle of the vertical curvature is  $7,18^{\circ}$ , while the angle of the horizontal curvature is  $9,82^{\circ}$ . The pipeline diameter changes from 3.500 mm to 3.340 mm.

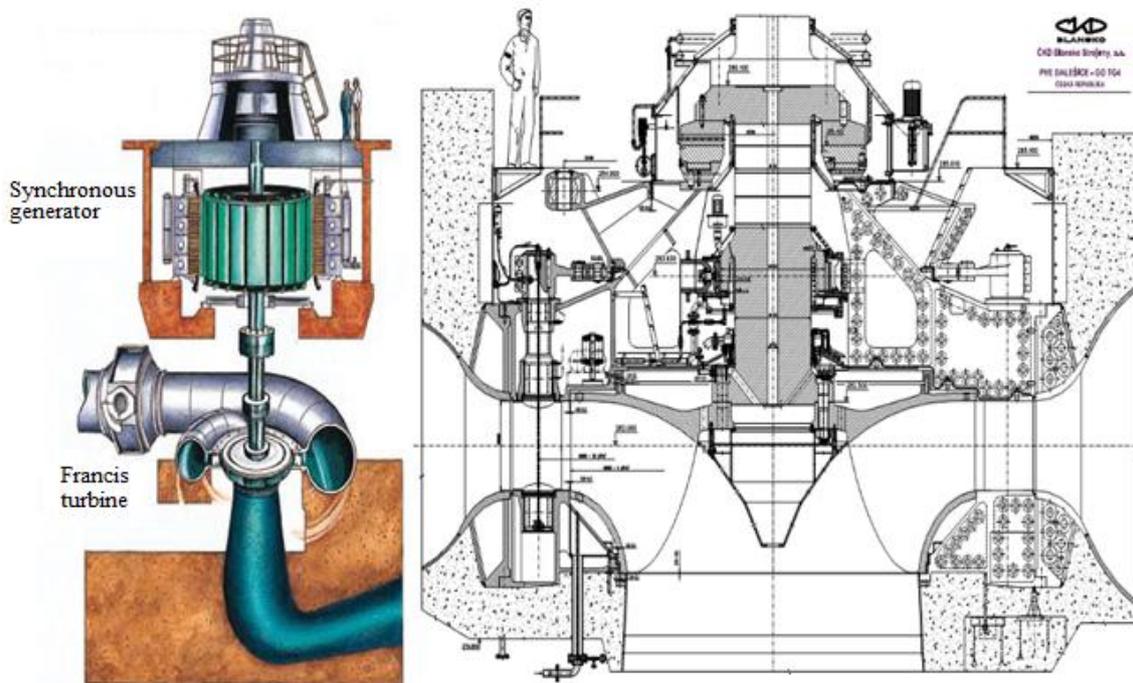
*Table 1. Chemical composition (values in [%] )*

Material	C	Si	Mn	Cu	S	P
S275J2G3	0.210	–	1.600	0.060	0.035	0.045

*Table 2. Mechanical properties, values for normalized and annealed condition*

Material	Yield strength YS <sub>0.2</sub> [N/mm <sup>2</sup> ]	Tensile strength TS [N/mm <sup>2</sup> ]	Elongation A5 [%]	Impact energy KV <sub>300/2</sub> [J/cm <sup>2</sup> ]
S275J2G3	min 275	430 – 560	21 - 23	27 (- 20 °C)

In figure 2 the uncovering of the pipeline segment is shown, while figure 3 show the preparation of the pipeline segment for non - destructive testing.



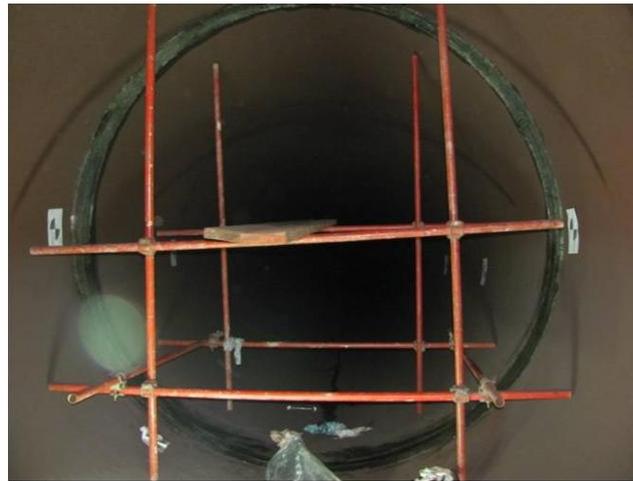
*Figure 1. Francis turbines with nominal power of 41,5 MW*



*Figure 2. Appearance of the vertical Francis turbine, with nominal power of 41.5 MW*



a) Preparation of the external pipeline surface



b) Preparation of the internal pipeline surface

*Figure 3. Appearance of preparation of the vital welded joint by grinding in order to perform NDT*

## 2. NON – DESTRUCTIVE TEST PERFORMED ON THE VITAL WELDED JOINT

In order to perform analysis of the current state and integrity evaluation of the pipeline as a whole the following non-destructive tests were performed: visual testing (VT), magnetic particle testing (MT), penetrant testing (PT), ultrasonic testing (UT), radiographic testing (RT) and metallographic replication testing.

### 2.1 Visual testing

Visual testing was performed on the vital butt-welded joint, in the area of the most pronounced geometric curvature of the pipeline. Linear indications (cracks) were detected on the surface of weld metal at 5 locations in the upper zone of the external pipeline surface, along with a large number of cracks in the heat-affected zone and parent material. [3]

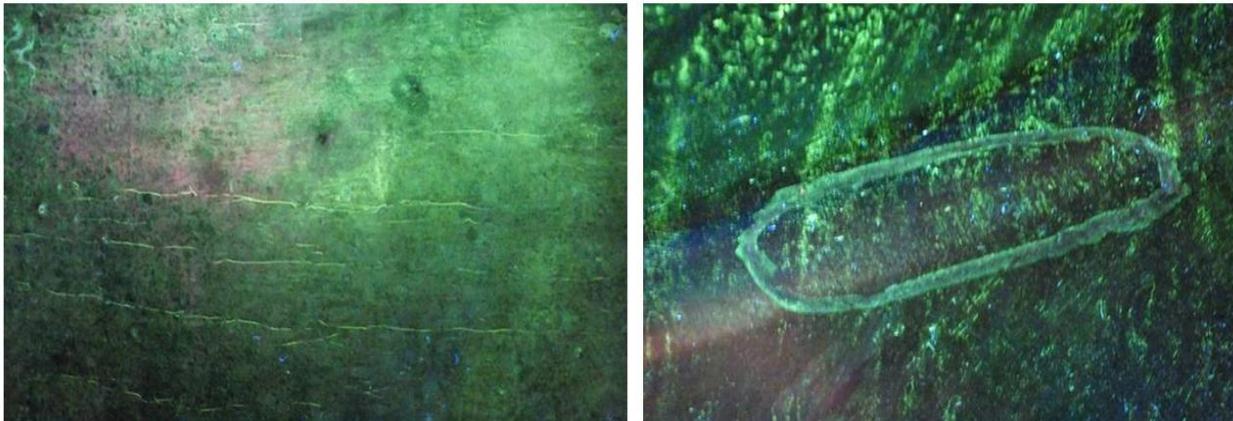
Nevertheless, in the lower zone of the internal pipeline surface the linear indications (cracks) were detected only at the surface of parent material. The deepest crack was 2,5 mm deep, while crack lengths vary. Length of the largest crack, located along the circumference of the parent material, was 540 mm (figure 4).



*Figure 4. Appearance of a segment of the examined surface of parent material along the circumference of the vital butt-welded joint*

## 2.2 Magnetic particle testing

Magnetic particle testing [4] was performed in the area of the welded joint, on the external and internal surface of the pipeline, in order to determine locations of linear indications (cracks), (figure 5).



a) Appearance of surface cracks  
on the surface of parent material

b) Appearance of surface cracks  
on the surface of weld metal

*Figure 5. Appearance of magnetic particle testing performed on the welded joint,  
at the external surface of the pipeline*

## 2.3 Penetrant testing

Magnetic particle testing was performed in the area of the welded joint, on the external and internal surface of the pipeline, in order to determine locations of linear indications (figure 6) [4].



a) Appearance of the crack at the surface  
of the heat-affected zone

b) Appearance of cracks at the surface  
of parent material

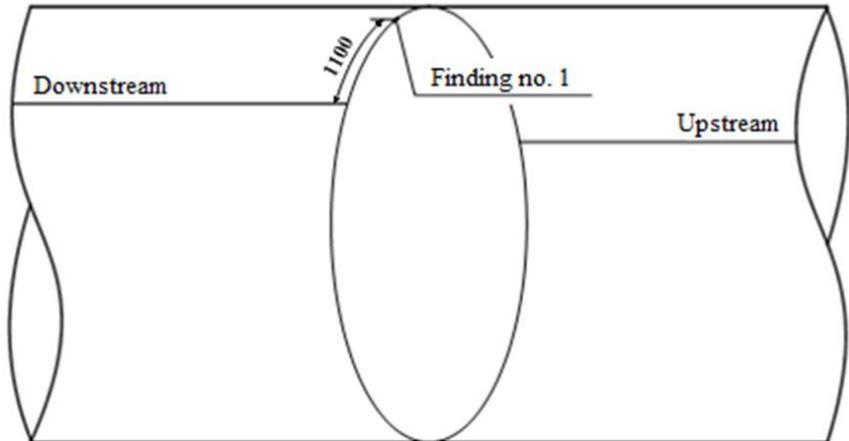
*Figure 6. Appearance of penetrant testing performed on the welded joint,  
at the external surface of the pipeline*

## 2.4 Ultrasonic testing

Ultrasonic testing was performed on parent material and weld metal [6] in order to determine depths of surface cracks. It was determined that cracks in parent material are 1,5-2,5 mm deep, while cracks in weld metal are 3,5 - 10,0 mm deep. Process of ultrasonic testing of the butt - welded joint, as well as location of the 10 mm deep surface crack are presented in figure 7.



a) Process of ultrasonic testing



b) Location of the 10 mm deep surface crack in the area of the butt - welded joint

**Figure 7.** Determination of depths of surface cracks in the area of the butt - welded joint

## 2.5 Radiographic testing

By radiographic testing a few sporadic undercuts were detected in the root area of the butt-welded joint, with lengths that range from 30 - 240 mm. [7]

## 2.6 Radiographic testing

The microstructure of the parent material of the pipeline was determined by metallographic replication testing. Examination was performed on the metallographic microscope "METAVAL", manufactured by "Carl Zeiss", Jena, through the application of the bright - field technique, which could be carried out after the surface was properly prepared (cleaning, degreasing, series of fine grinding operations, final polishing, rinsing, metallographic etching by 4% nital). [8].

Test results showed that the microstructure of the surface layer is ferrite-pearlite with small non-metallic inclusions and corrosion products present, as well as 12 - 15 mm long macrocracks. Test results also showed that the microstructure of weld metal is coarse grained ferrite-pearlite with small non-metallic inclusions and corrosion products present, as well as 30-35 mm long macrocracks. Characteristic test results are presented in figure 8.



a) Replication process

b) Microstructure of parent material

c) A crack in parent material

d) Microstructure of weld metal

e) A crack in weld metal

**Figure 8.** Appearance of characteristic results of metallographic replication testing

### 3. TECHNOLOGY FOR THE REPAIR OF CRACKED AREAS AT THE SURFACE MATERIAL OF PARENT AND WELD METAL

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.

Cracks at the surface of parent material were eliminated by fine grinding, while repair welding/surface welding had to be performed in areas at the surface of weld metal where cracks were detected after the grinding was finished through the utilization of welding procedure 111 with electrode EVB 50 (Jesenice electrodes), classified in accordance with the adequate standard [9]. Chemical composition of weld metal is presented in table 3, while mechanical properties are presented in table 4.

In figure 9 repair of the area where longest and deepest crack was detected is shown. During and after the repair of cracked areas visual and magnetic particle/penetrant testing were performed.

*Table 3. Chemical composition, values in [%]*

Electrode	C	Si	Mn
EVB 50	0.08	0.60	1.0

*Table 4. Mechanical properties of pure weld metal*

Electrode	Yield strength YS0.2% [N/mm <sup>2</sup> ]	Tensile strength TS [N/mm <sup>2</sup> ]	Elongation A5 [%]	Impact energy KV <sub>300/2</sub> [J/cm <sup>2</sup> ]
EVB Mo	> 440	510 – 610	> 24	47 (- 20 °C)



a) Appearance of the repair of a cracked area



b) An area prepared for surface welding

*Figure 9. Appearance of the preparation for surface welding*

### 4. EVALUATION OF PIPELINE INTEGRITY AS A WHOLE

According to Directive for pressure equipment [10], for design and integrity evaluation during service the calculation methods based on empirical formulae, analytical procedures and fracture

mechanics should be used. The analytical calculation of pipeline strength was performed on the basis of results of non-destructive tests and after the repair by fine grinding and welding/surface welding was carried out.

Calculation of shell and dished ends strength in relation to internal pressure has been carried out through the use of standard EN 13445-3 [11].

According to the documentation of the manufacturer, basic technical properties of the pipeline are as follows:

yield strength of shell and dished end material from room temperature:  $Y_{S0.2} = 275$  MPa

tensile strength of shell and dished end material from room temperature:  $T_s = 430$  MPa

outer diameter of the shell:  $D_o = 3\ 340$  mm

inner diameter of the shell:  $D_i = 3\ 308$  mm

nominal thickness of shell and dished end sheet metal:  $t_o = 22$  mm

operating pressure at change 1 + 263 m:  $p = 1,26$  MPa

welded joint coefficient:  $z = 0.8$

$$\frac{D_o}{D_i} = \frac{3340}{3308} = 1.01 < 1.2 - \text{this condition proves the applicability of standard} \quad (1)$$

#### 4.1 Calculation of the pipeline strength in relation to internal pressure

Calculation of strength in relation to internal pressure (equation 2) proved that thickness of the cylindrical section of the shell is sufficient, i.e. the calculated value doesn't exceed the measured one from paragraph 2.4.1. Required thickness is being obtained as follows:

$$s = \frac{D_o \cdot p}{2 \cdot f \cdot z + p} + \delta_e + c = \frac{3340 \cdot 1.26}{2 \cdot 137,5 \cdot 0,8 + 1,26} + 0,8 + 1,0 = 20,8 \text{ mm} < 22 \text{ mm} \quad (2)$$

In equation (2), according to standard [11], value 0,8 is the addition for permissible deviation of material thickness, while value 1,0 is the addition for corrosion damage. Coefficient of strength  $f$  is being calculated as follows:

$$f = \min \left( \frac{R_{p0.2}}{1,5}; \frac{R_m}{2,4} \right) = \min \left( \frac{275}{1,5}; \frac{430}{2,4} \right) = (137,5 ; 180) = 137,5 \quad (3)$$

Considering that cracks at the surface of parent material haven't been removed completely by fine grinding, the calculation of strength of the pipeline as a whole (calculation of the minimum necessary sheet metal thickness) was carried out for minimum values of yield strength and tensile strength for material S275J2G3, as well as validity coefficient of the welded joint predicted for quality class "C".

## 5. CONCLUSION

Integrity of structures is a relatively new scientific and engineering discipline, which in a broader sense encompasses state analysis and behaviour diagnostics, evaluation of service life and structure rehabilitation which means that, apart from the usual situation when it's needed to evaluate the structural integrity when a defect is detected by non-destructive testing, this discipline also comprises the analysis of the structural stress state.

It was determined that the integrity of the pipeline structure as a whole is not in jeopardy taking into account the analysis of the condition of the vital welded joint and strength calculation, as well as minimum necessary sheet metal thickness.

## ACKNOWLEDGEMENT

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