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Analiza trenutnog stanja i ocena integriteta cevovoda na hidroelektrani Pirot

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Hidroelektrana Pirot, koja je izgrađena 1990 godine, je akumulaciona elektrana derivacionog tipa, koja se sastoji od dva nadzemna vertikalna agregata sa Francis turbinama nominalne snage 41,5 MW, proizvedene u Češkoj Republici, tunela i ukopanog cevovoda ukupne dužine 2030 m i prečnika od Ø 3000 mm do Ø 3500 mm. Cevovod debljine lima 22 mm je izrađen od čelika kvaliteta S275J2G3 (stara oznaka Č.0462). Maksimalni pritisak u njemu ispred turbinskog zatvarača je 2,5 MP.

Cevovod je projektovan i izgrađen bez ankernih blokova na prelomima, što pretstavlja retkost u svetu. Na cevovodu se u kontinuitetu od završetka izgradnje i puštanja u rad sprovode geodetska merenja kada je cevovod prazan i neopterećen hidrostatickim pritiskom i kada je cevovod pun. Pregledom i analizom dobijenih podataka o pomeranjima duz trase cevovoda utvrđeno je da od 2003-2004 godine postoje znatno veće razlike u pomeranjima za pun i prazan cevovod, nego u prethodnom periodu. Te razlike se prvenstveno odnose na tangencijalna pomeranja za temena oznake 6, 7 i 8, koja se u odnosu na period do 2002 godine kreću od 3 mm za teme 8 do 5 mm za teme 6. Pored geodetskih merenja u kontinuitetu se, sa unutrašnje strane cevovoda, sprovode i merenja promena horizontalnih i vertikalnih prečnika. Iz tih podataka se moze videti da u periodu 2003-2004 godine postoji i značajan trend povečanja horizontalnih, kao i manje izraženo smanjenje vertikalnih prečnika.

U radu je izvršena analiza trenutnog stanja i ocena integriteta cevovoda kao celine na osnovu rezultata ispitivanja vitalnog sučeonog zavarenog spoja metodama bez razaranja u zoni preloma na stacionaži – dužini cevovoda 1+263 m (vizuelno ispitivanje, ispitivanje magnetnim česticama, ispitivanje penetrantima, ispitivanje ultrazvukom, radiografsko ispitivanje, metalografsko ispitivanje metodom replika).

Ključne reči: hidroelektrana, prslina, tehnologija sanacije, integritet cevovoda

1.UVOD

Hidroelektrana Pirot je locirana neposredno u blizini grada Pirota i koristi vode Visocke reke na profilu brane Zavoj. Izgrađena je 1990 godine kao akumulaciona elektrana derivacionog tipa, koja se sastoji od dva nadzemna vertikalna agregata sa Francis turbinama nominalne snage 41,5 MW (sl. 1) proizvedene u Češkoj Republici [1], tunela i ukopanog cevovoda pod pritiskom ukupne dužine 2030 m i prečnika od Ø 3000 mm do Ø 3500 mm. Maksimalni pritisak u cevovodu je 2,5 MP. Cevovod debljine lima 22 mm je izrađen od čelika kvaliteta S275J2G3 (stara oznaka Č.0462) [2], za koji su hemijski sastav i mehaničke osobine date u Tab. 1 i u Tab. 2.

Tabela 1. Hemijski sastav, vrednosti u [%]

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

Tabela 2. Mehaničke osobine, vrednosti za normalizovano i otpušteno stanje

Materijal	Napon tečenja $YS_{0.2}$ [N/mm^2]	Zatezna čvrstoća TS [N/mm^2]	Izduženje A5 [%]	Energija udara $KV_{300/2}$ [J/cm^2]
S275J2G3	min 275	430–560	21-23	27 (-20^{0}C)

Cevovod je projektovan i izgrađen bez ankernih blokovana prelomima, što predstavlja retkost u svetu. U cilju analiza trenutnog stanja i ocene integriteta cevovoda kao celine izvršena su ispitivanja metodama bez razaranja vitalnog sučeonog zavarenog spoja u zoni preloma na stacionaži – dužini cevovoda 1+263 m. Na tom delu cevovoda, prema projektnoj dokumentaciji, vertikalni prelom cevovoda iznosi 7,18^0, a horizontalni 9,82^0 i prelaz cevi sa prečnika Ø 3500 mm na prečnik Ø 3340 mm. Na sl. 2 prikazano je otkopavanje, a na sl. 3 priprema cevovoda za predviđena ispitivanja.

2. ISPITIVANJA METODAMA BEZ RAZARANJA VITALNOG ZAVARENOG SPOJA

Za potrebe analize trenutnog stanja i ocene integriteta cevovoda kao celine izvršena su sledeća ispitivanja metodama bez razaranja: vizuelno ispitivanje (VT), ispitivanje magnetnim česticama (MT), ispitivanje penetrantima (PT), ispitivanje ultrazvukom (UT), radiografsko ispitivanja (RT) i metalografsko ispitivanje metodom replika.

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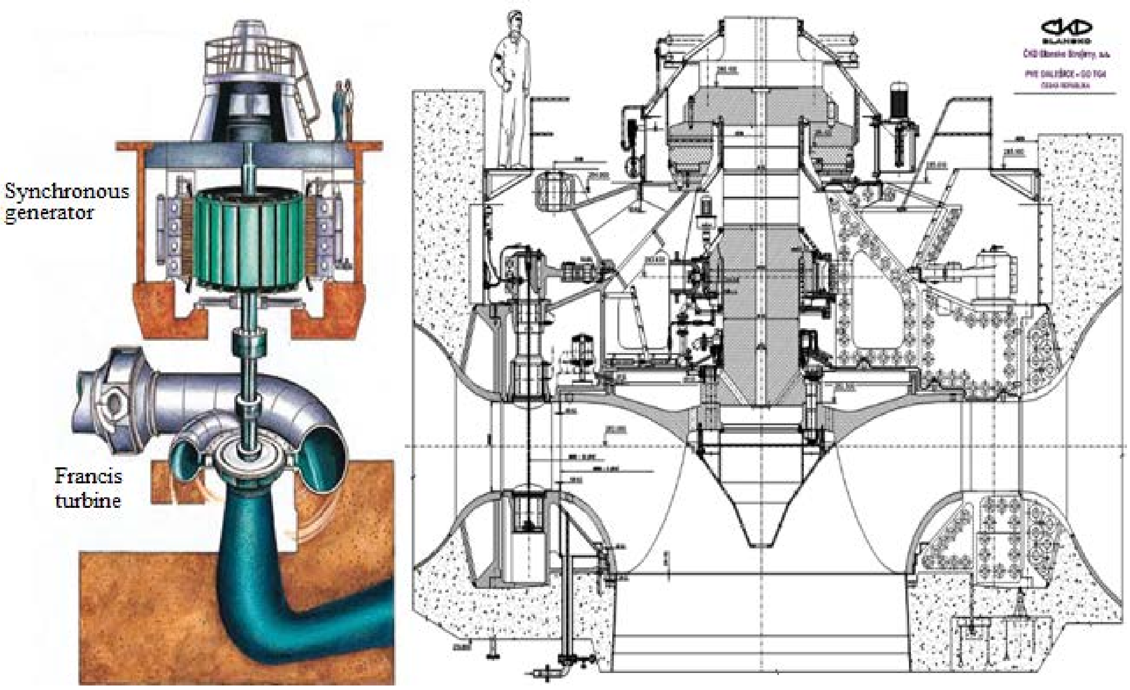


Sl.1. *Prikaz vertikalne Francis turbine, nominalne snage 41,5 MW*

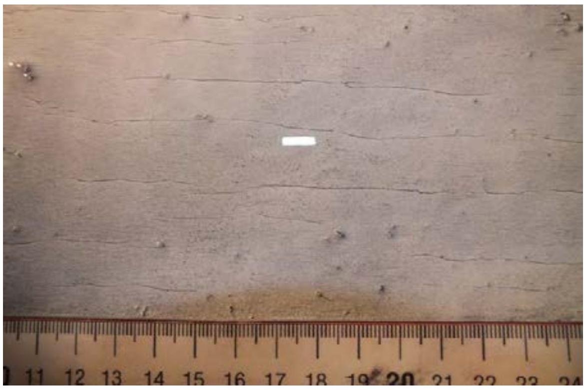
Sl.2. *Prikaz otkopavanja cevovoda*

a) Priprema brušenjem spoljašnjeg dela *b) Priprema brušenjem unutrašnjeg dela*

Sl.3. *Prikaz pripreme brušenjem vitalnog zavarenog spoja na cevovodu radi ispitivanja*

2.1 Vizuelno ispitivanje

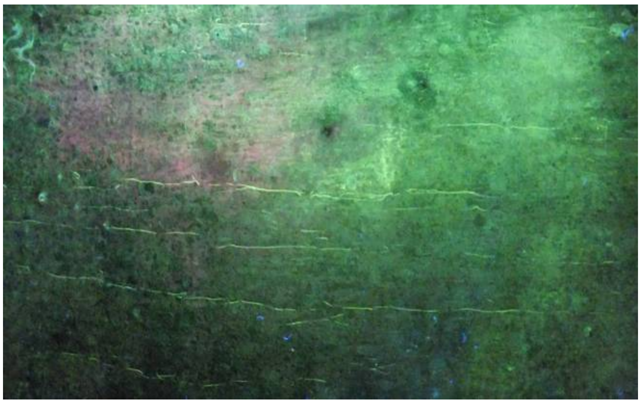
Vizuelnim ispitivanjem [3] vitalnog sučeonog zavarenog spoja (ZS) u zoni najveceg geometrijskog preloma cevovoda, u gornjoj zoni na spoljašnjoj strani cevovoda, utvrđene su površinske indikacije (prsline) u metalu šava (MŠ) na 5 mesta i veći broj prslina u zoni uticaja toplote (ZUT) i u osnovnom materijalu (OM). Međutim, u donjoj zoni sa unutrasnje strane cevovoda utvrđene su površinske indikacije (prsline) samo u OM. Najveća utvrđena dobina prsline je veličine 2,5mm, a njihove duzine variraju pri čemu je najduža utvrđena u OM po obimu ZS i iznosi 540 mm, sl. 4.



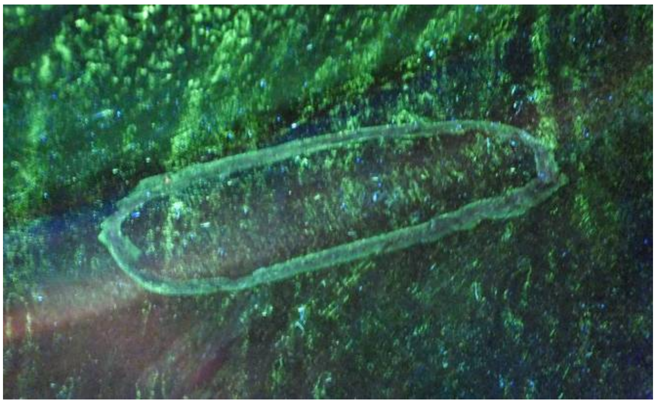
Sl.4. Prikaz jednog dela ispitane površine OM po obimu vitalnog sučeonog ZS u toj zoni cevovoda

2.2 Ispitivanje magnetnim česticama

Ispitivanja magnetnim česticama [4] ZS, sa spoljašnje i unutrašnje strane cevovoda, izvršena su da bi se proverilo postojanje površinskih prslina sl.5.



a) Prikaz površinskih prslina u OM

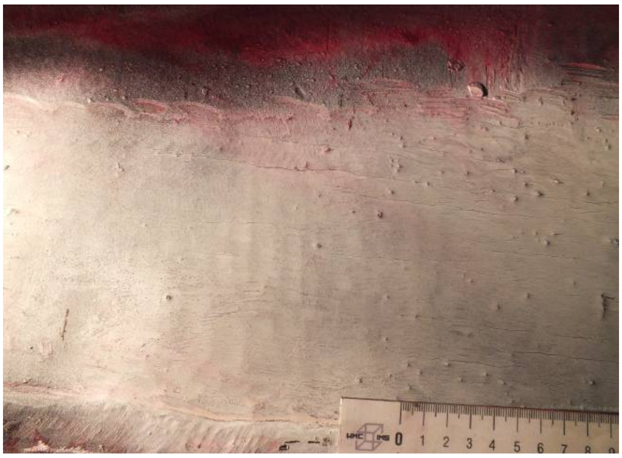


b) Prikaz površinskih prsline u MŠ

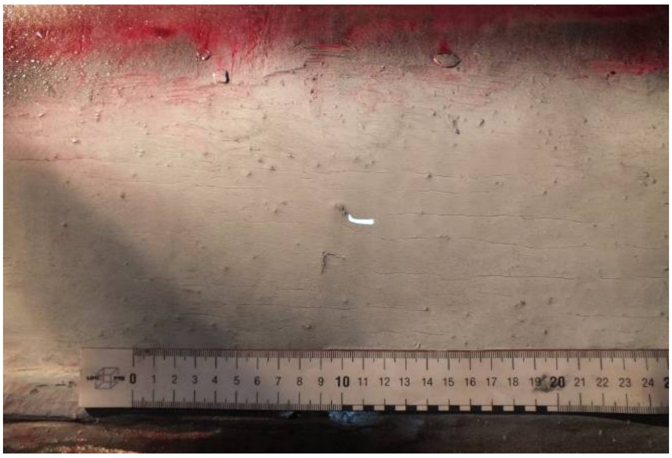
Sl.5. Prikaz ispitivanja magnetnim česticama jedne zone ZS sa spoljašnje strane cevovoda

2.3 Ispitivanje penetrantima

Ispitivanja penetrantima ZS [5], sa spoljašnje i unutrašnje strane cevovoda, izvršena su da bi se proverilo postojanje površinskih prslina, sl.6.



a) Prikaz površinske prsline u ZUT

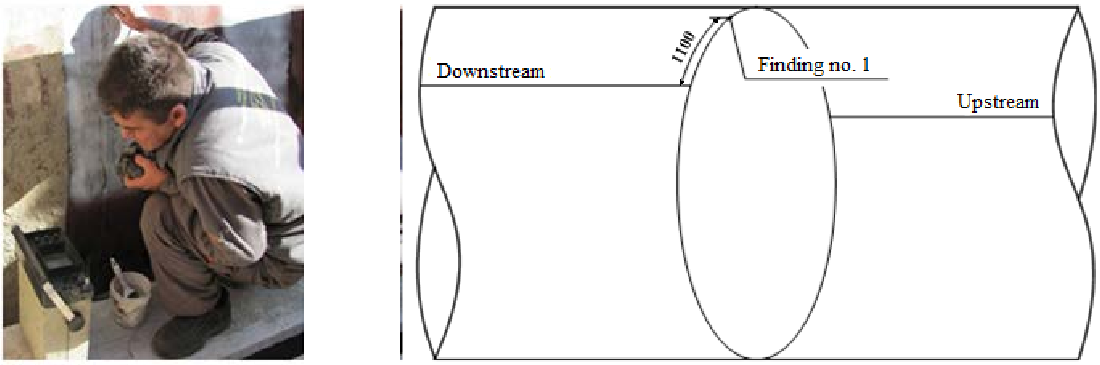


b) Prikaz površinskih prslina u OM

Sl.6. *Prikaz ispitivanja penetrantima jedne zone ZS sa spoljašnje strane cevovoda*

2.4 Ispitivanje ultrazvukom

Ispitivanja ultrazvukom OM i ZS [6], sa spoljašnje i unutrašnje strane cevovoda, izvršena su da bi se utvrdile dubine površinskih prslina. Utvrđeno je da dubine prslina u OM iznose od 1,5 mm do 2,5 mm, a dubine prslina u MŠ od 3,5 mm do 10,0 mm. Na sl. 7 prikazano je ispitivanje UT sučeono ZS cevovoda i lokacija površinske prsline sa najvećom dubinom od 10 mm.



a) Prikaz UT ispitivanje ZS *b) Lokacija jedne od površinskih prslina dubine 2,5 mm u sučeonom ZS*

Sl.7. *Prikaz ispitivanja UT dubina površinskih prslina u jednoj zoni ZS sa spoljašnje strane cevovoda*

2.5 Radiografsko ispitivanje

Radiografskim ispitivanjem [7] utvrđene su mestimične greške tipa zajeda u korenom delu sučeonog ZS, dužina: 30mm, 35 mm, 65 mm, 75 mm, 100 mm i 240 mm.

2.6 Metalografsko ispitivanje metodom replika

Metalografskim ispitivanjem metodom replika [8], utvrđeno je mikrostrukturno stanje OM cevovoda. Ispitivanje je izvršeno na metalografskom mikroskopu marke *"METAVAL"* proizvođača *"Carl Zeiss"* iz Jene (Nemačka) korišćenjem tehnike svetlog polja, nakon priprema ispitanih površina (čišćenje, odmašćivanje, niz operacija finog brušenja, završno poliranje, ispiranje, nagrizanje 4%-nim nitalom). Rezultatati ispitivanja su pokazali da je mikrostruktura površinskog sloja OM cevovoda feritno-perlitna sa prisutnim sitnim nemetalnim uključcima i produktima korozije, kao i makroprslinama dužina od 12 mm do 15 mm, a da je mikrostruktura MŠ krupnozrnasta feritno-perlitna sa prisutnim sitnim nemetalnim uključcima, produktima korozije i makroprslinama dužina od 30 mm do 35 mm. Karateristični rezultati ispitivanja prikazani su na sl. 8.

a) Uzimanje replika *b) Mikrostruktura OM* *c) Jedna od prslina u OM* *d) Mikrostruktura MŠ* *e) Prslina u ZS*

Sl.8. *Karateristični rezultati metalografskog ispitivanja (metodom replika) mikrostruktura OM i ZS*

3. TEHNOLOGIJA SANACIJE PRSLINA U OSNOVNOM MATERIJALU I ZAVARENOM SPOJU

Analizom parametara od kojih zavisi izbor postupka reparaturnog zavarivanja/navarivanja (zavarljivost materijala, energetske mogućnosti postupaka zavarivanja, geometrijska složenost konstrukcije, ekonomski pokazatelji) utvrđena je celishodnost primene postupak 111. Zbog ograničenih mogućnosti izvođenja predgrevanja i termičke obrade nakon reparaturnog zavarivanja/navarivanja, optimalno rešenje je korišćenje elektroda sa bazičnom oblogom.

Tabela 3. *Hemijski sastav, vrednosti u [%]*

Elektroda	C	Si	Mn
EVB Mo	0.08	0.60	1.0

Površinske prsline u OM sanirane su finim brušenjem, a prsline u zonama vitalnog ZS reparaturnim zavarivanjem/navarivanjem primenom postupak 111 sa elektrodom EVB 50 (Elektrode Jesenice), klasifikovan prema standardu [9]. Hemijski sastav čistog metala šava elektrode dat je u tab. 3, a mehaničke osobine u tab. 4. Na sl. 9 prikazana je priprema prsline sa najvećom dužinom i dubinom za sanaciju. U toku i posle sanacija prslina u OM i vitalnom ZS cevovoda sprovedena su ispitivanja metodama VT i MT/PT.

Tabela 4. *Mehaničke osobine čistog metala šava*

Elektroda	Napon tečenja YS0.2% [N/mm^2]	Zatezna čvrstoća TS [N/mm^2]	Izduženje A5 [%]	Energija udara $KV_{300/2}$ [J/cm^2]
EVB Mo	> 440	510 – 610	> 24	47 (-20 ^{0}C)

a) Prikaz pripreme prsline za sanaciju *b) Jedna od prslina u ZS priprmljena za sanaciju*

Sl.9. Priprema jedne od prslina u ZS sa spoljašnje strane cevovoda utvrđene ispitivanjima PT i UT

4. OCENE INTEGRITETA CEVOVODA KAO CELINE

Prema direktivi za opremu pod pritiskom [10], za projektovanje i ocenu integriteta u eksploataciji predviđene su proračunske metode zasnovane na empirijskim formulama, analitičkim postupcima i mehanici loma. Ocena integriteta cevovoda u eksploataciji na osnovu rezultata ispitivanja bez razaranja i nakon izvršene sanacije finim brušenjem i zavarivanjem/navarivanjem izvršen je analitički proračun čvrstoće cevovoda.

Proračun čvrstoće omotača i danca u odnosu na unutrašnji pritisak sproveden je u skladu sa standardom EN 13445-3 [11].

Prema dokumentaciji proizvođača, osnovne tehničke karakteristike cevovoda su sledeće:

– napon tečenja za materijal omotača i danca na sobnoj temperaturi	$YS_{0.2}$ = 275 MPa
– zatezna čvrstoća za materijal omotača i danca na sobnoj temperaturi	TS = 430 MPa
– spoljašnji prečnik omotača	D_o = 3340 mm
– unutrašnji prečnik omotača	D_i = 3308 mm
– nominalna debljina materijala omotača i danca	t_0 = 22 mm
– radni pritisak na stacionaži – dužini cevovoda 1+263 m	p = 1.26 MPa
– koeficijent zavarenog spoja	z = 0.8

$$\frac{D_o}{D_i} = \frac{3340}{3308} = 1.01 < 1.2 \text{ -uslov za primenljivost standarda} \quad (1)$$

4.1 Proračun čvrstoće cevovoda u odnosu na unutrašnji pritisak

Proračunom čvrstoće u odnosu na unutrašnji pritisak (jednačina br. 2) dokazano je da je debljina cilindričnog dela omotača dovoljna, odnosno da izračunata vrednost debljine nije veća od izmerene koja je navedena u paragrafu 2.4.1. Zahtevana debljina loma cevovoda određuje se na sledeći način:

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

U jednačini (2) prema standardu [10] vrednost 0,8 predstavlja dodatak za dozvoljeno odstupanje debljine materijala, a vrednost 1,0 dodatak za korozijska oštećenja. Za koeficijent čvrstoće *f* se uzima manja vrednost izračunata jednačinom (3):

$$f = \min\left(\frac{YS_{0.2}}{1,5}; \frac{TS}{2,4}\right) = \min\left(\frac{275}{1,5}; \frac{430}{2,4}\right) = (137,5;\ 180) \quad (3)$$

S obzirom da površinke prsline u OM nisu u potpunosti otklonjene finim brušenjem, da bi se bilo na strani sigurnosti, proračun čvrstoće cevovoda kao celine (proračun minimalno potrebne deljina lima) je izvršen za minimalne vrednosti granice tečenja i zatezne čvrsoće materijala S275J2G3, kao i za koeficijent valjanosti ZS (koeficijent oslabljenja ZS) predviđen za „C" klasu kvaliteta.

5. ZAKLJUČAK

Integritet konstrukc ija je relativno nova naučna i inženjerska disciplina, koja u širem smislu obuhvata analizu stanja i dijagnostiku ponašanja i popuštanja, procenu veka i revitalizaciju konstrukcija. To znači da, osim uobičajene situacije u kojoj treba proceniti integritet konstrukcije kada se ispitivanjem bez razaranja otkrije greška, ova disciplina obuhvata i analizu napons kog stanja konstrukcije.

Analizom stanja vitalnog ZS i proračunom čvrstoće, odnosno minimalno potre bne debljine lima, utvrđeno je da integritet konstrukcije cevovoda kao celine nije ugrožen.

ZAHVALNOST

Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Srbije na podršci za realizaciju projekata TR 35002 i TR 35008.

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Analysis of Current State and Integrity Evaluation of the Pipeline at Hydro Power Plant „PIROT“

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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. Pipe wall is 22 mm thick. Maximum pressure of 2.5 MPa occurs in front of the turbine cover.
Pipeline has been designed and built without anchor blocks at curvatures, which is a 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 regarding 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 refer 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
Keywords: hydro power plant, crack, repair technology, pipeline integrity

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 [1], a tunnel and a sunken pipeline with overall length of 2.030 m and diameter that ranges from 3.000 to 3.500 m. 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.

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 $YS_{0.2}$ [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A5 [%]	Impact energy $KV_{300/2}$ [J/cm^2]
S275J2G3	min 275	430–560	21-23	27 (-20^{0}C)

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 7,18^0, while the angle of the horizontal curvature is 9,82^0. The pipeline diameter changes from 3.500 mm to 3.340 mm. In figure 2 the uncovering of the pipeline segment is shown, while figure 3 shows the preparation of the pipeline segment for non-destructive testing.

2. Non-Destructive Tests 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.

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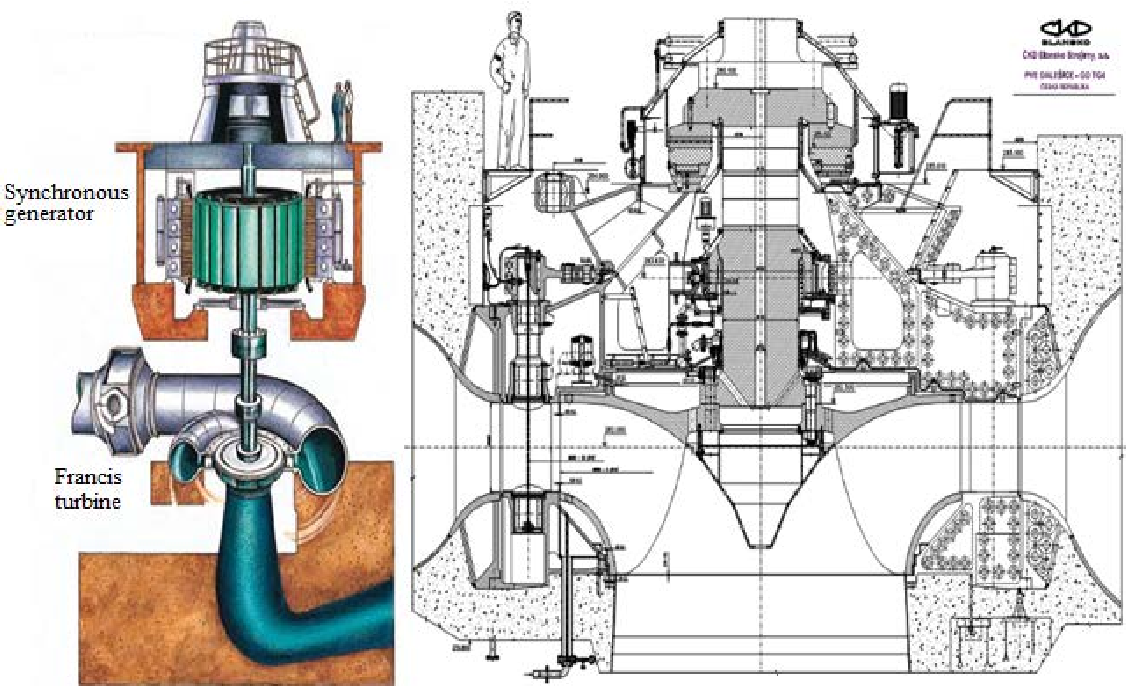


Fig.1. *Appearance of the vertical Francis turbine, with nominal power of 41.5 MW*

Fig. 2. *Appearance of the uncovered pipeline segment*

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*

2.1 Visual Testing

Visual testing [3] 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. 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).

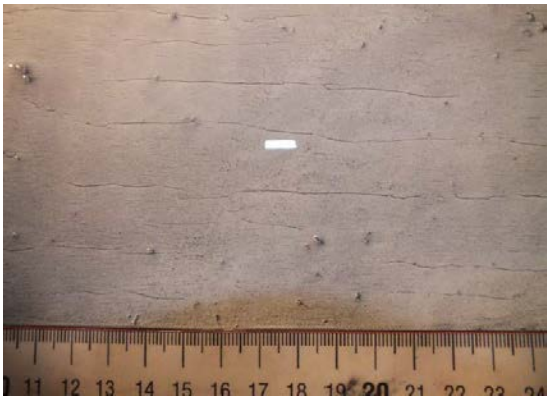
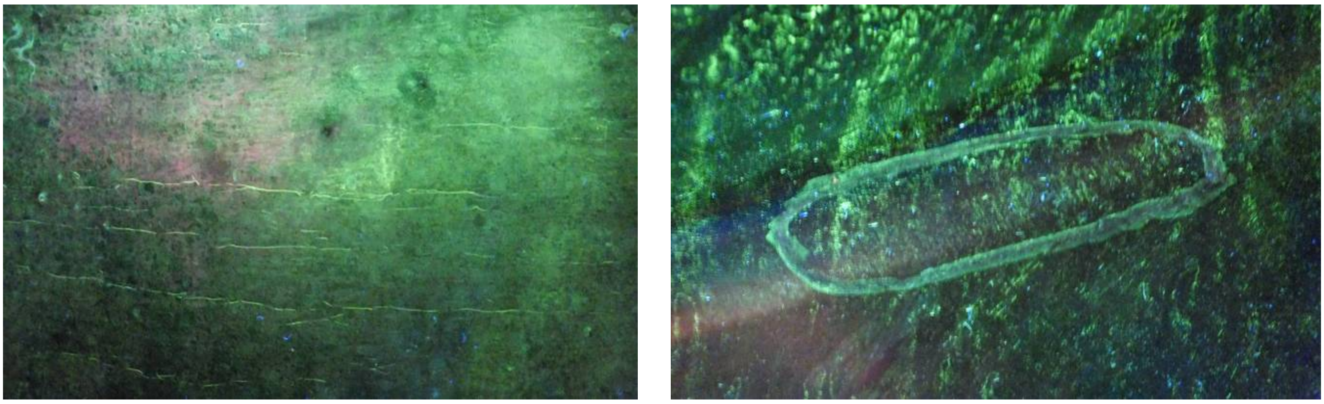


Figure 4. *Appearance of a segment of the examined surface of parent material along the circumference of the vital butt-welded joint*

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.



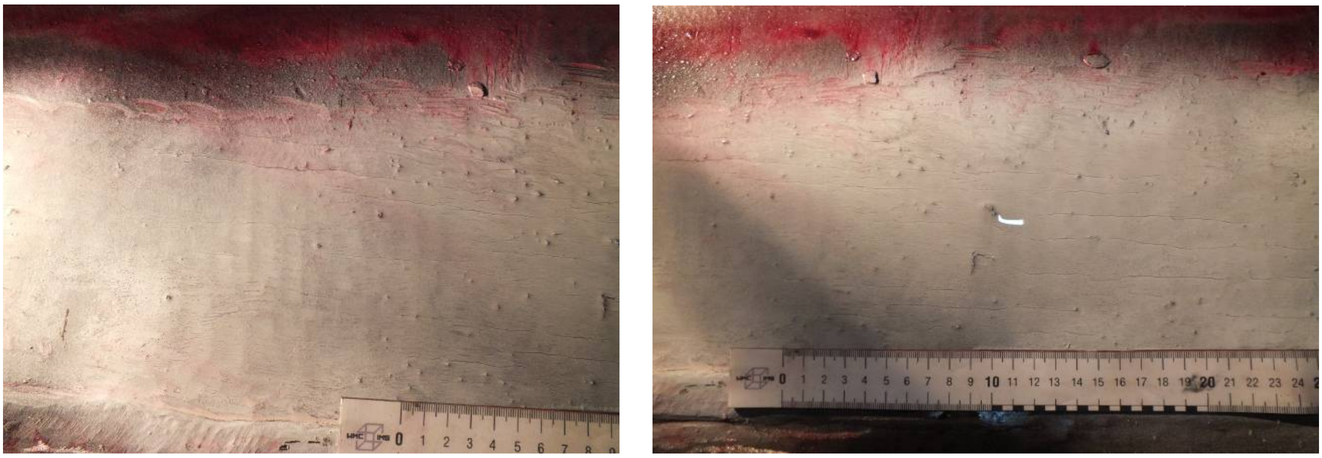
a) Appearance of surface cracks on the surface of parent

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

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

2.3 Penetrant Testing

Penetrant testing [5] 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 6.



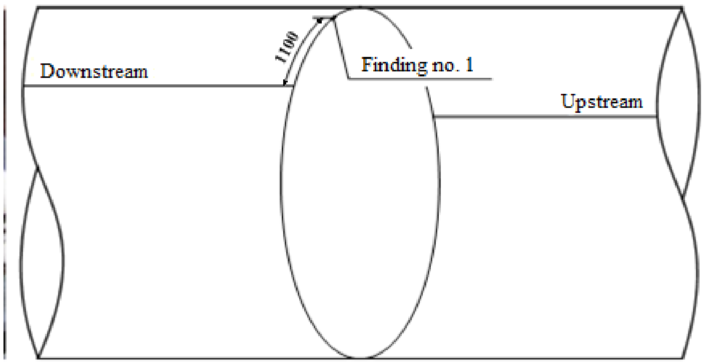
a) Appearance of surface cracks on the surface of parent

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

Figure 6. *Appearance of magnetic particle 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 [7] a few sporadical undercuts were detected in the root area of the butt-welded joint, with lengths that range from 30-240 mm.

2.6 Metallographic Replication Testing

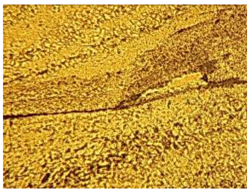
The microstructure of the parent material of the pipeline was determined by metallographic replication testing [8]. Examination was performed on the metallographic microscope "METAVAL", manufactured by "Carl Zeiss", Jena, through the application of the bright-field technique, which could be carried out after the surface was properly prepared (cleaning, degreasing, series of fine grinding operations, final polishing, rinsing, metallographic etching by 4% nital). 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 the repair of the area where the 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 Mo	0.08	0.60	1.0

Table 4. *Mechanical properties of pure weld metal*

Electrode	Yield strength YS0.2% [N/mm^2]	Tensile strength TS [N/mm^2]	Elongation A5 [%]	Impact energy $KV_{300/2}$ [J/cm^2]
EVB Mo	> 440	510 – 610	> 24	47 (-20 ^{0}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 the 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 for room temperature — $YS_{0.2} = 275$ MPa
- tensile strength of shell and dished end material for room temperature — TS = 430 MPa
- outer diameter of the shell — D_o = 3340 mm
- inner diameter of the shell — D_i = 3308 mm
- nominal thickness of shell and dished end sheet metal — $t_0 = 22$ mm
- operating pressure at chainage 1+263m — p = 1.26 MPa
- welded joint coefficient — z = 0.8

$\frac{D_o}{D_i} = \frac{3340}{3308} = 1.01 < 1.2$ - this condition proves the applicability of the standard (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 does not exceed the measured one from paragraph 2.4.1. Required thickness is being obtained as follows:

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

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:

$$\text{f} = \min\left(\frac{YS_{0.2}}{1,5}; \frac{TS}{2,4}\right) = \min\left(\frac{275}{1,5}; \frac{430}{2,4}\right) = (137,5;\ 180) \quad (3)$$

Considering that cracks at the surface of parent material have not 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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