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EXPERIMENTAL STRENGTH ANALYSIS OF THIN-WALL TUBES LOADED BY COMBINED GRAVITATIONAL AND VARIABLE PRESSURE EFFECTS FROM INTERNAL FLUID.

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Abstract

The main topics of the paper are results of strength experiment dealing with static and dynamic loading of a thin-wall part of the penstock at hydro-electric power plant, esp. at stress concentration zone near the edge of the saddle support. Conceive results of FEM computation and its comparison with experiment are presented too.

1. INTRODUCTION

Penstocks of hydro-electric power plants presents complicated mechanical-hydraulic systems with high demand of the strength reliability. Their loading is presumably caused by the hydrostatic pressure, but also important wide-spectrum dynamic effects induced by an operation and changes of the turbogenerator regimes are present. Perhaps the most complicated situation characterises the pumped storage power plants as consequence of both turbine and pump character of pressure pulsating.

During the reconstruction of PVE Štěchovice in years 1991–1996, when complete change of the machine part was realised (i.e. 2 separate turbines 2x20 MW and appropriate pumps were substituted by the one reversal machine 50 MW) was made the decision to preserve the original double-penstock with remarkable money saving. The penstock is composed from two practically identical pipe-lines with variable both diameter and wall thickness after dimensioning demands (DN=1700, t=34 mm at the bottom, DN = 2000, t=10 mm at the top of the pipeline).

For verification of operational reliability the extensive experimental stress and vibration analyses as a part of pre-complex and complex tests was realised. From numerous pieces of recognition the sphere dealing with very interesting behaviour of thin-wall tubes with a small angle to horizontal line together with the comparison of FEM solution were elected for presentation.

2. DESCRIPTION OF THE OBJECT AND AN EXPERIMENTAL EQUIPMENT APPLIED.

The experimental strength and dynamic analysis were carried out on the section about 40 m long cylindrical shell with diameter 2000 mm and wall thickness approx. 10 mm during all possible operating regimes. The tube in this section is fixed into massive concrete blocks on both sides and supported on 6 concrete saddles with 120° central angle, the longitudal stresses are eliminated by gland expansion-joint (compensator) situated under higher block.

Periodicity of the structure allows to reduce the measurement into 2 sections, the first of which lies in the centre between supports (measurement of radial displacements in 4 points) and the second in vicinity of the saddle (measurement of radial displacements in 3 points and strain gauge measurement), positions of gauges are schematically shown in Fig.1. The radial displacements were measured by tip extensometers based on strain-gauge principle (range ±7 mm) against a firm tubular scaffolding fixed on earth foundation.

Respecting the necessity of winter strain gauge installation point-welded strain gauges marked P-9-A (R=120Ω, k=1,95±2%, active measuring length 9 mm), were prepared . One delta-rosette at the near vicinity of the saddle corner and one single in circumferential direction in the plane of the saddle symmetry were applied (see Fig.1). Signals of the all gauges mentioned above were conditioned by DC amplifiers TECHLAB-3T for input to measuring card TEDIA CSA-1208 with 12-bit A-D converter inserted in notebook CardStar 100S with 486 DX2 processor. Program INMES for measurement, data recording and processing (statistical parameters evaluation, FFT analysis and waveform graphical outputs) was utilised.

3. RESULTS OF STATIC AND DYNAMIC MEASUREMENTS

A) Penstock Water Filling

The information from this action is highly interesting because it have enabled an explanation to some phenomena of thin tube part vibrations which were observed and studied sooner (1949-1951 Prof. Budinský, later institutes SVÚTT and SVÚM to 1957).

Principle of the problem can be described as action of internal pressure on the tube with "ovalised" cross section, while this shape is caused by gravitational action of the water filling. The highest ovalisation arises at the moment when the measured section is fully filled by the water, but later is decreased by increased internal pressure. The relation of the radial displacements on the pressure is non-linear, theoretically asymptotic to circular shape under infinite pressure.

An example of radial displacement changes time-records in the section between supports is presented in Fig.2. Notation of the places and displacement signs respect the Fig.1, pitch of horizontal lines is 1 mm. The steps near the end of filling correspond to quick pressure increment (about 0,14 MPa) which arises after filling the penstock to restrictive valve.

Very interesting is the result that deflection of the bottom surface line of tube cylinder is directed up. This surprising and seemingly illogical result can de explained by the ovalisation effect and it vas confirmed by simultaneously realised FEM computation (RNDr R. Svoboda, CSc, TECHLAB), the reduced result of which is presented in Fig. 3. The second surprising fact, that both vertical and horizontal radial displacements are higher at the section over the saddle than at the central section, was confirmed by the computation again. Comparison of results in Fig.2 and Fig.3 proves the very good agreement of both methods in displacement evaluation.

Apparently worse agreement was obtained in comparison of stress values at saddle support vicinity where theoretical results were approx. twice higher to the experimental one. the main reason seems to be an unreal considering of boundary condition for the saddle support as absolutely rigid fixation. The real case had 2 or 3 mm gaps between the tube and saddle edge as probable consequence of historical shakedown and so boundary condition are not so severe at present. Nevertheless, the FEM results were utilised for the stress concentration extrapolation and estimation of stress values on internal surface of the tube.

B) Dynamic Effects of Operation Regimes.

The relation of ovality change on internal pressure explains arise of intensive vibrations at some operation regimes, namely at transitions between them. All observed cases can be characterised as forced vibration which are nearly exactly connected with pressure pulsation. This fact determines the deformation mode of the section which was in all cases of the same type, as during filling of the penstock, i.e. there was linear relation between strain and all radial displacements. Both tubes vibrated mutually in phase, vertical displacements were in phase to the internal pressure, horizontal were opposite to it. Complete results and fatigue life evaluation is made in report [1], for lack of space only one representing example can be presented here. Fig. 4 shows the plot of strain from gauge 4 (at the centre of saddle) during regular stopping of the turbine from 100% power. The detail from this plot with the maximal amplitudes and dominant frequency 2,2 Hz as a consequence flow restriction by inlet distributor is presented in Fig.5. After full close of the flow only slow pulsation at frequency about 0,012 Hz arises as response to compensation tank level swinging.

4. Conclusions

Presented work have enabled to describe mode and quantity of vibrations in the top part of the penstock and to identify the reasons of their origin. The stress analysis confirmed admissibility of loading at all recommended regimes and so contributed to overcome some doubts based on penstock behaviour observations without an exact approach.

From the point of view the good agreement of experimental displacement results with FEM solution by program PMD (VAMET, s.r.o.) even in unexpected details is remarkable.

The grasp of vibration origin enables to propose a way of its complete removal, which can be perhaps realised on some new work. The principle of the solution is based on the initial shape of a tube, the cross section of which should be in polar co-ordinates opposite to the diagram in Fig.3. In such case the gravitational ovalisation will tend to circular section, which cannot be changed by any further pressure pulsations.

Literature:

[1] P. Jaroš, L. Korec, R. Svoboda, J. Šimek: Pevnostní měření na přivaděči PVE Štěchovice (technická zpráva TECHLAB, s.r.o., č. 96–104, 1996)

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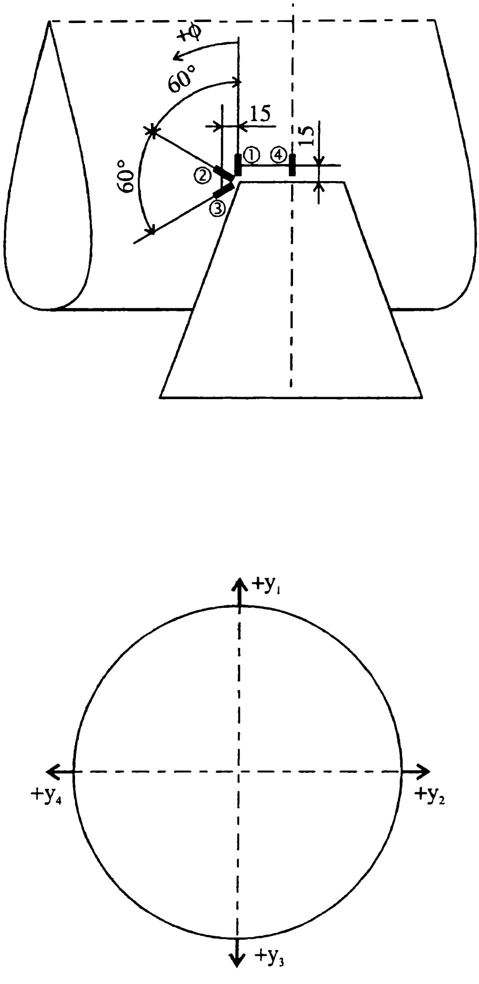
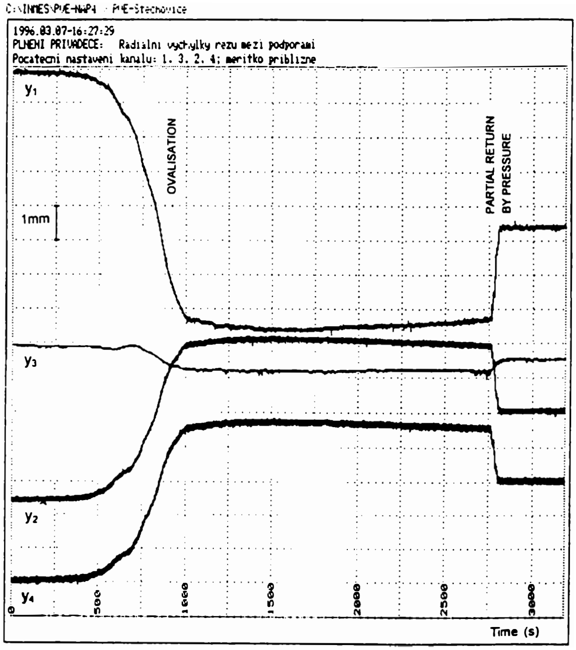


Fig. 1. Strain gauge positions, points of displacement measurement and its signs



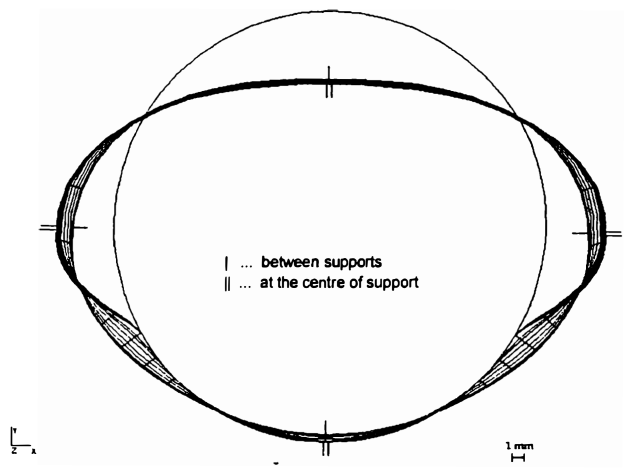
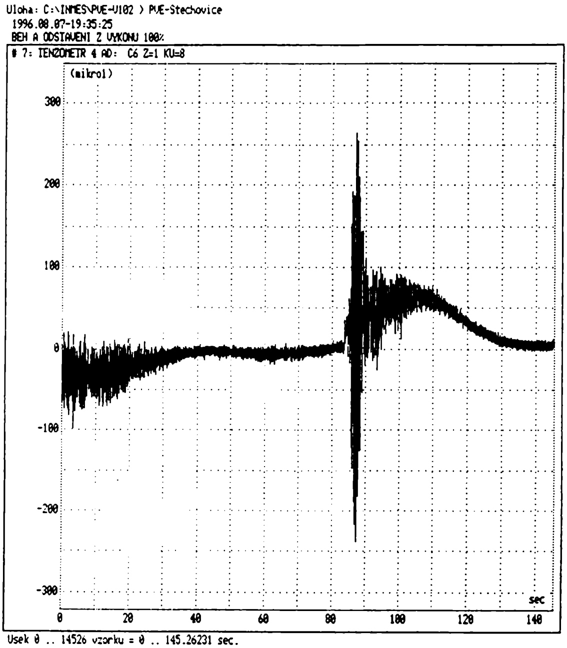


Fig.2. a) Time record of radial displacements during filling of the penstock by water
b) FEM solution of the same problem (the notation in agreement with Fig.1)



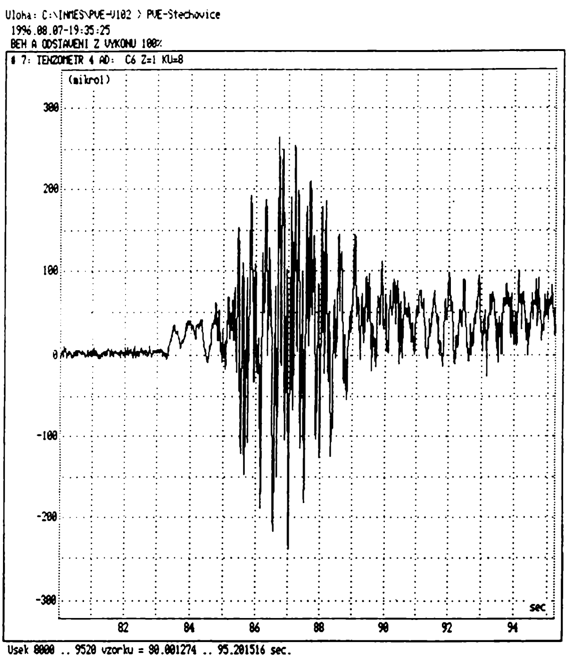


Fig.3 Strain from gauge 4 during regular stop of turbine; the whole process and its detail