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Application of Computational Methods and Methods of Experimental Stress Analysis for Determination of Lifespan of Pipe Yards

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BIOGRAPHICAL NOTES

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KEY WORDS
Pipe Yards, Fatigue, Experimental Stress Analysis

ABSTRACT
Compressor stations and their pipe yards are technological complexes that are loaded by dynamic loading during their operation. The result of such loading can be fatigue failure of structural member or whole system with serious consequences. One possibility of decreasing disadvantageous dynamic loading and increasing of lifespan is using vibroinsulation elements. The lifespan of structure is intimately connected to critical locations as pipe joints realized by welds. Residual lifespan is expressed on the basis of data gained by experiments according to appropriate standards.

1. Introduction

Pipe yards of compressor stations are part of technological equipment of strategic importance for the transport and distribution of gas. Gas pipelines of compressor stations are composed of complex technological net of crossing overground and underground pipes (Figs. 1 and 2) that are exposed to diverse dynamic stress phenomena. Pipe systems have to be carefully checked from the point of their reliability because their failure can threaten human lives, to cause serious ecological catastrophes and heavy economic losses.

Fig. 1: *Pipe yard of compressor station.*

Fig. 2: *Pipe yard with pipes of suction, medium pressure and discharge.*

2. Structures of pipe yards and their loading

The pipelines are typically loaded by pulsations of pressure (surging) and whistle effects. The reason of pulsations in pipe system of compressor station is non-stationary flow through some devices that is a result of unsuitable distribution of flow in pipe system and resulting increase of resistance, shifting of operation point of these devices to the boundaries of dynamic stability. The main reason of such phenomenon can be inappropriate arrangement of individual devices. Vibration of pipeline with low frequency in the level of some Hz resulting e.g. due to two steps gas boosting results to vibration of valves and for more intensive vibration during time period longer than 15 minutes it can cause damage of fittings of pipe yard. The surging is a non-stationary phenomenon that arises during operation of turbo-compressor and it is a result of flow interaction inside of pipeline system. During surging occurs periodical flow change in turbo-compressor and in connected pipe net. Non-stationary phenomena in pipeline system arise also due to so-called whistle effect that is a result of Helmholtz steady oscillations in the locations of connection of valves and closed branches, where arises disturbing flow field. Beside of this, in every pipe system occurs during its operation time-dependent loading, e.g. during starting or finishing its operation, changes of pressure from technological reasons and so on, that can lead during long-time operation to fatigue failure of material and in case of exceeding of lifespan to its damage. Assessment of fatigue lifespan of critical segment of working pipe is possible if we know the shape of investigated section, its dimensions, mechanical properties of material, real operational load, history of pipe loading and corresponding information about random loading. Pipe yards belong to the group of technological carrying structures that are designed in accordance with Standard STN EN 1993 - Eurocode 3. Design of steel structures. These Standards are used also later in the phase of strength check, for assessment of failure states and verification of safety after certain period of operation, for assessment of fatigue level, or after general overhaul. The lifespan analysis has to be accomplished for such critical elements, structural members, and critical locations that are supposed to be critical for lifespan of the whole structure. Critical are locations of pipe joining in saddles, where due to several years dynamic loading and vibrations occurred failures. Accordingly there was provided measurement and lifespan assessment of pipeline systems on two compressor stations with turbo-compressors with power 6 MW. At the investigated section of pipe yard KS 1 were used vibroinsulation elements (steel dampers) on the pipe base, Figs. 3 and 4.

Fig. 3: *Base of pipe with vibroinsulation elements.*

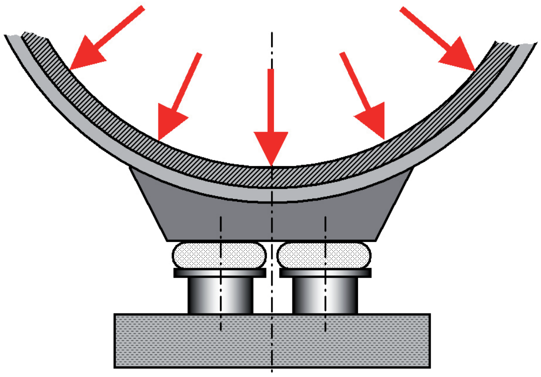

Fig. 4: *Integration of vibroinsulation elements into base of pipe.*

The pipes of pipe zard KS 2 are without of vibroinsulation elements. The main reason for using vibroinsulation was the aim to remove dynamic loading in order to decrease loading of pipeline system and at the same time to prolong its lifespan.

3. Data collecting about pipeline loading

During the investigation was applied the combined method of experimental and analztical determination of operational loading (resulting internal forces) due to random loading prosecc in the chosen location (cross-section) of pipe that was verified many times in practice. Basic principle of this method was used for datermination of internal force quantities in pipe yards. The principle was later enhanced in order to allow creation of complex view about possible dangerous loadings in locations of supports, concentrators and branches of pipe yard. At the same time were considered operational influences of random process of loading to the resulting stress and to assessment of residual lifespan of pipe yards. On the basis of this method there were realized experimental measurements on the basis of electrical resistance strain-gage method. Applied measurement chain had configuration according to Fig. 5. The measurements were realized on the discharging pipe with a branch while three cross-sections, signed as A, B, and C, Fig. 6, with applied strain-gage rosettes, separated the section of pipe with base containing elastic vibroinsulation elements on KS 1 and without Vibroinsulation element on KS 2. Strain-gage measurements were accomplished at different time periods. In Fig. 7 is a view to uncovered part of pipeline and on Fig. 8 is a detail of applied strain-gage rosettes [4], [5].

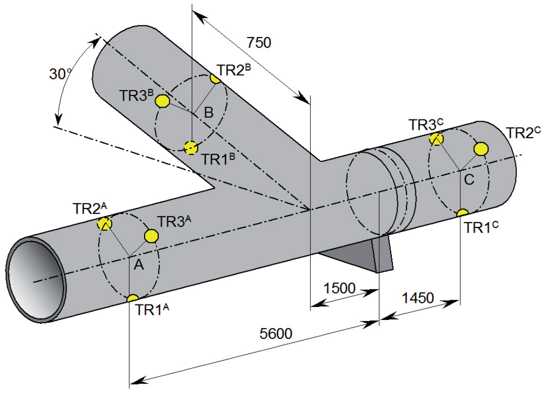

Fig. 6: *Location of strain-gages on the pipe of discharge with a branch.*

Fig. 5: *Strain-gage measurement chain.*

Fig. 7: *Uncovered part of pipeline.*

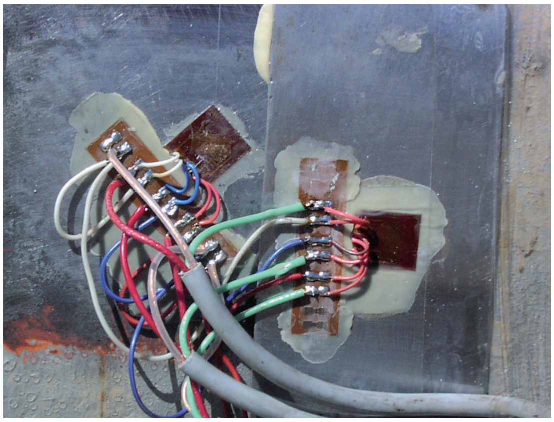

Fig. 8: *Detail of applid strain-gage rosettes.*

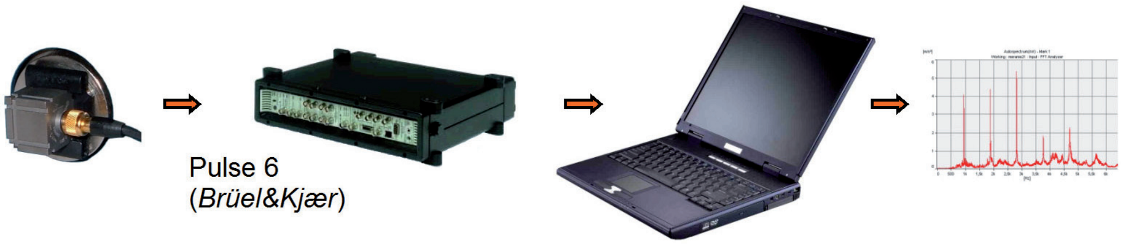

Fig. 9: *Chain for measurement of mechanical vibration.*

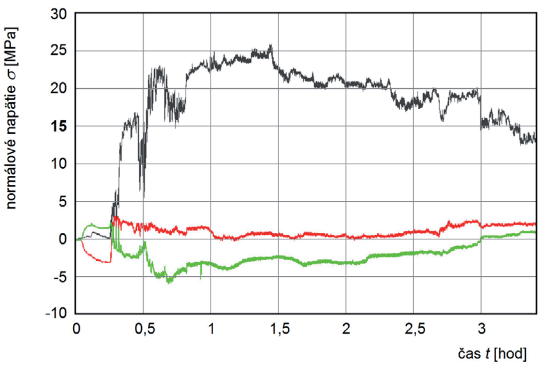

Fig. 10: *Example of charts of measured normal stresses in location A.*

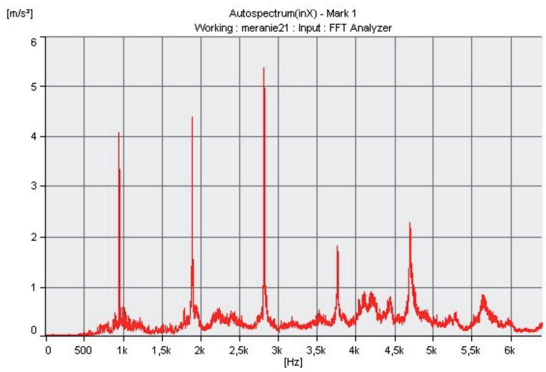

Fig. 11: *Example of chart of measured frequency dependence of accelerations on a base.*

The information about relevant stress amplitudes had to be connected with dynamical effect during operation. It was the reason why the stress changes determined by strin-gages were verified by dynamic parameters – time and frequency dependent accelerations gained from measurements of mechanical vibration by the PULSE 6. Corresponding measurement chain had configuration according to Fig. 9. Examples of gained charts are given in Fig. 10 and 11.

Strength and lifespan of investigated pipeline systems was closely tied to further critical locations of structure, e.g. joints of pipes realized by welds. In order to investigate degradation changes of material properties after long-term operation there were accomplished destructive and non-destructive analyses of material. In case of destructive analysis was taken a specimen from the critical location and consecutively it was tested according to the Standards that were valid at that time. Mechanical and technological properties of material were verified by the tensile test, by the impact test of bending under temperature 0°C and by test of brittleness under low temperatures. If possible, the results were compared with data given by producer. At the same time metallographical analysis was realized for determination of material structure [2]. If there were problems with taking specimens, the harness test with Poldi hammer was performed in order to determine standard static tensile toughness. The welded joints used in the pipeline were from the point of view of structure, hardness, fracture toughness and brittleness under low temperatures considered as meeting the requirements. Statical levels of stresses were in computations of lifespan incorporated as residual stresses. They were detected by the methods of experimental stress analysis – by the hole-drilling method based on strain-gage measurements according to Standard ASTM E837-01 using system RS 200 [3]. The measurement chain had configuration according to Fig. 12.

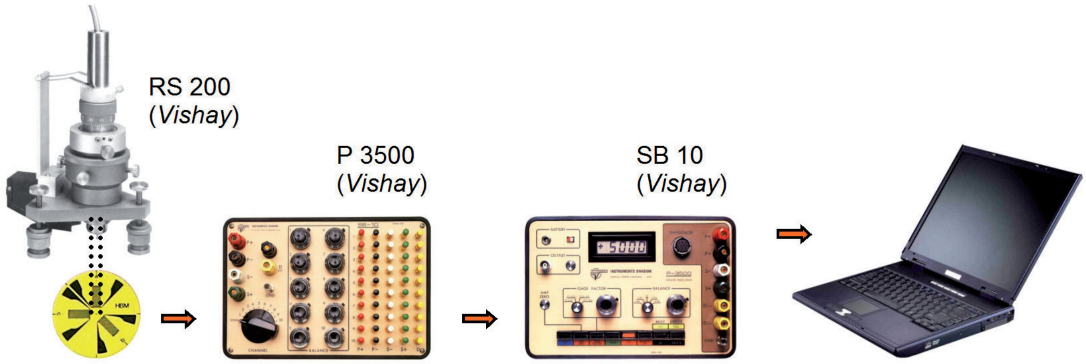

Fig. 12: *Measurement chain of the hole-drilling method for the measurement of residual strains.*

4. Assesement of residual lifespan of pipeline

For the assessment of residual lifetime of pipe yards KS 1 and KS 2 was applied procedure according to Standard STN EN 1993-1-9 – (Eurocode 3. Design of steel structures. Part 1-9: Fatigue). The welds used for pipe yards KS 1 and KS 2 were for the analysis considered as structural detail, more specific, as welded joint detail, with crosswise butt weld, welded from both sides, elaborated under flux, with coarse surface without outer defects.

With respect to the plane stress state, it was necessary to use the theory of strength for a material in ductile state. Precondition for its application was that individual components of gained stresses were not phase-shifted. Corresponding values of equivalent stresses were determined by von Mises theory. Such values were finally used for assessment of fatigue for loading of structural detail with constant stress amplitude. All computational relations and corresponding algorithms were incorporated directly into programs for processing of measured data. The results are given in Tab. 1 [6], [7].

Whole process of assessment of pipe yards KS1 and KS2 from the point of view of fatigue and used methods of random loading processing respected to the whole extent orientation, technical equipment, practical opinions and scientific potential of Department of Applied Mechanics and Mechatronics, Faculty of Mechanical Engineering, TU Košice.

Table 1: *Overall results.*

Structures of pipeline systems of compressor stations			
Equipment or structure (investigated element or structural member)	Reason for determination of cumulation of fatigue failure and prediction of fatigue lifespan	Specific operational conditions and other conditions of measurement	Results and recommendations of expert examination
Pipe system (yard) of compressor station KS 1 (pipes of suction, medium pressure and discharge)	Assessment of residual lifespan of system after more than 25 year operation in case of using vibroinsulation elements	Considerable influences of pressure pulsation, surging and whistle effects	Resulting from analysis according to current standards rejection of influences of cumulation of fatigue failure (lifespan without limits) due to decrease of maximum stresses by cca 40 %
Pipe system (yard) of compressor station KS 2 (pipes of suction, medium pressure and discharge)	Assessment of residual lifespan of system after more than 25 year operation in case without using vibroinsulation elements	Considerable influences of pressure pulsation, surging and whistle effects	Guaranty of residual lifespan during period of 38,2 to 63,6 years of operation

5. Conclusion

By the comparison of maximal normal stresses measured during start of compressor KS 2 ($\Delta\sigma_{max}$ = 82 MPa – pipe without vibroinsulation elements) and KS 1 ($\Delta\sigma_{max}$ = 52 MPa - pipe with vibroinsulation elements) was found out that the maximal normal stresses decrease by approximatelly 40 %, which indubitably affirm decreasing of dynamic loading and increasing of residual lifespan of pipeline due to application of elastic bases. In case of compressor station KS 1 in accordance with the corresponding Standard was not necessary to take into account fatigue because of low stress amplitudes. Accordingly, under some circumstances it is a structure with unlimited lifespan, i.e. the structure is without limit state of fatigue.

6. Acknowledge

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