23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

DETERMINATION OF THE STRESS - STRAIN STATE FOR INDUSTRIAL PIPELINE BASED ON ITS VIBRATION

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Abstract: *The pipelines are subject to various constraints variable in time. Those vibrations, if not monitored for amplitude and frequency, may result in both the fatigue damage in the pipeline profile at high stress concentration and the damage to the pipeline supports. The industrial system pipelines, unlike the transfer pipelines, are straight sections at some points only, which makes it more difficult to formulate the equation of motion. In those cases, numerical methods can be used to determine stresses using the kinematic inputs at a known vibration velocity amplitude and frequency. The study presents the method to determine the stresses.*

Keywords: Pipeline vibrations, Natural vibrations, Transverse vibrations, Resonance frequencies, Allowable pippes vibration levels.

1. Introduction

The literature includes the criteria for the analysis of the vibration levels for pipelines, which define the permissible displacement amplitudes or the vibration velocities as a function of the frequency (von Nimmitz 1974). Lin (1996) has observed that the criterion can mainly be used for the oil pipelines, where slim pipes are usually supported by very flexible supports. For rigid supports, the relationship must be modified. Long (1955) has presented an alternative solution of the equation of motion for the pipe supported on both ends and has compared the results of the analysis with the experimental results to validate the mathematical model used. The results were ambiguous, since the maximum medium velocity used in the experiment was too low to result in a significant change in the frequency of the transverse vibrations of the pipe. This issue has also been studied by Beniamin (1961) and Niordson (1953), who showed that the conditions for the stability of pipe vibrations depend on the support used. The vibrations of straight supported pipes, excited by the medium flow are characterized by high amplitude, if the flow velocity exceeds the critical velocity.

A simple fatigue analysis based on the displacement criterion was suggested for the oil system pipelines vibrations by Wachel and Bates (1976). A similar approach has been positively verified by an extensive study of the pipeline vibrations in the power industry (Mortiuk, 1994). The method can be used to determine the dynamic state of the pipelines in which the vibrations are excited at the lowest natural frequency, and the pipe is considered a vibrating beam. Its disadvantage is that it applies to the frequency range up to f = 300 Hz, which is significantly below the frequencies excited by the pump vanes. A wide excitation band may also include the frequencies higher than occurring in the oil pipelines (Graham, 1997), (Motriuk and Harvey, 1998).

2. Industrial pipeline testing

The subject of the test was a pipeline in the liquor circulation line of the digester used in a paper mill. The pipeline length is $l = 33\ m$. A medium transported in the pipeline is a soda lye (i.e. white liquor) at a concentration of several percent. It is a liquid with the density similar to water. The pipeline pressure is $p = 1.1\ MPa$. A volume flow rate of the medium is $Q = 0.07\ m^3 \cdot s^{-1}$.The medium flow rate is $4.5\ m\ s^{-1}$.

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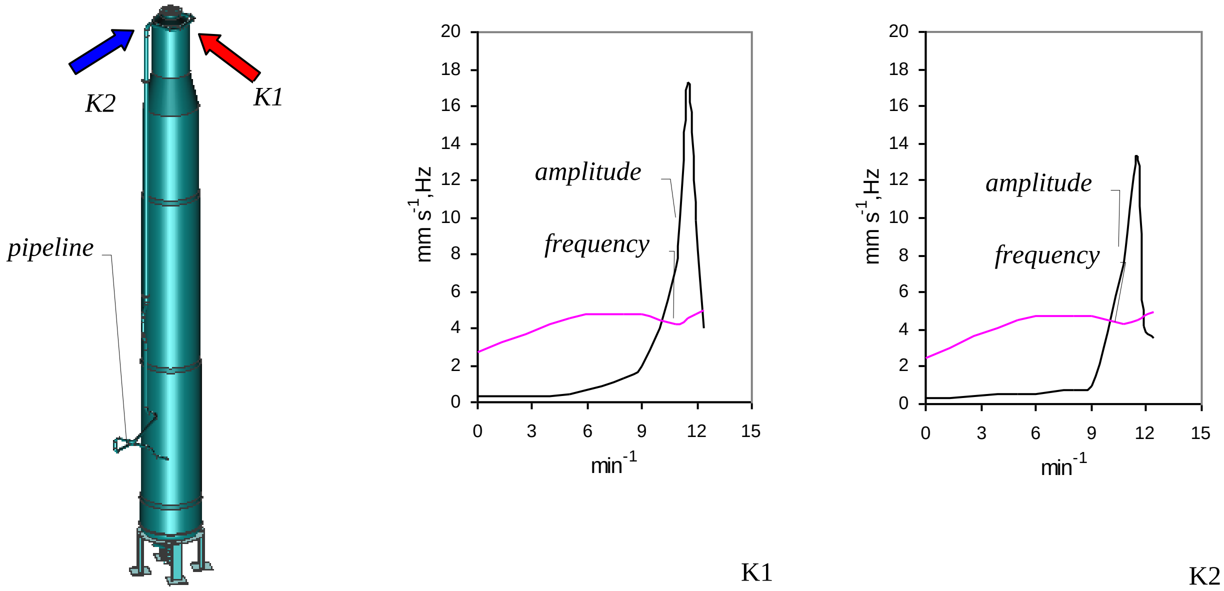


Fig. 1: Digester with a pipeline. Amplitude and frequency of the prevalent vibration velocity component in K1 and K2 direction as a function of the feeder speed.

The digester (Fig. 1) is a $1.2{\cdot}10^5$ *kg* vessel mounted on four supports. The digester filled with medium weights twice as much, approx.. $2.4{\cdot}10^5$ *kg*. The wood chips are fed to the loading chamber via a screw conveyor. The wood chips are fed to the digester from the low pressure zone to the high pressure zone via a high-pressure feeder.

The resonance curve of the digester vibrations is very steep and the frequency range within which a sudden change in the vibration amplitude is observed is narrow (Fig. 1). It is a preferred response, since the transition through the resonance zone is very rapid. The position of the resonance zone shows that the excitation of the digester vibrations is due to the pressure pulsation in the pipeline as a result of opening and closing the feeder chambers. The modal analysis of the digester vibrations confirms the previous hypothesis that the frequency is in fact the resonant frequency.

Fig. 2: The upper pipe section mounted to the digester.

The article includes an excerpt from the stress strain state analysis of the pipeline in its upper section with the diameter of $d = 273$ *mm*, i.e. by the digester and in its lower section including the section from level $h = 0$ *m* (pump level) to level $h = 9$ *m* . The pipeline section diameter is $d = 219$ *mm*. Fig. 2 shows the upper section as an approach to the digester. Fig. 3 shows a resonant response of the pipe section.

Fig. 4 shows the frequencies and corresponding natural vibration forms determined for the model.

A comparison between the calculation results and the measured values shows that the rigidity, damping and weight of the pipe section with medium are correct. The resonant frequency of the pipe section without medium is lower (Fig. 5).

The vibration velocity of the pipeline was measured at the fixing points at the support and at the straight pipe section. Fig. 6 shows the vibration amplitudes at prevalent frequencies.

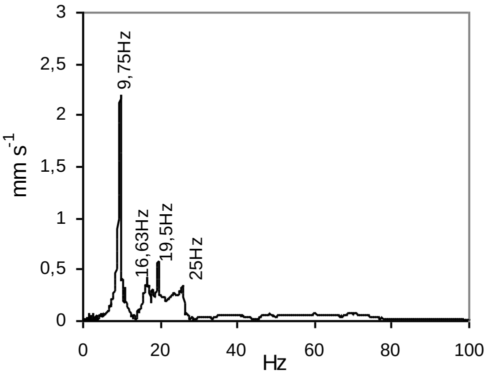


Fig. 3: The resonant response of the pipe section.

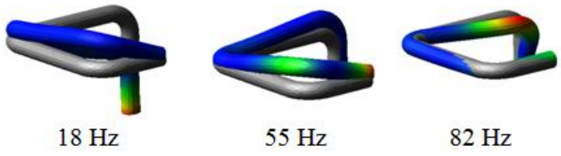
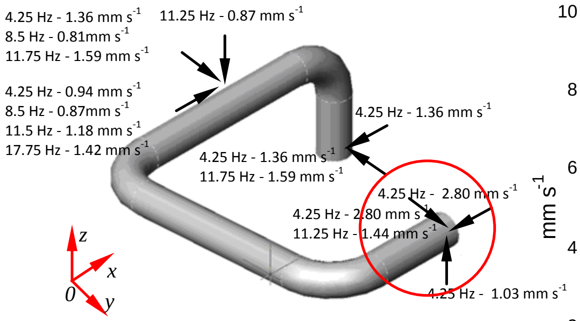


Fig. 4: The frequencies and corresponding natural vibration forms determined for the model.

Fig. 5: The method of excitation of the resonant vibrations in the pipeline.



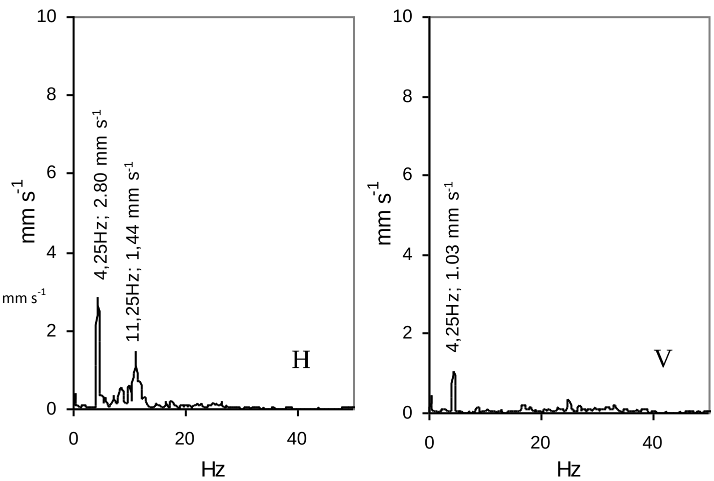


Fig. 6: The vibration amplitudes at prevalent frequencies.

Fig. 7: The vibration spectrums.

Fig. 7 shows the vibration spectra for the analysis of the characteristics of the pipe vibration in time in horizontal and vertical direction in point shown in Fig. 6.

The constraint used in the numerical analysis corresponds to the actual constraint due to the similarity between the measured and the calculated spectrum of the vibration velocity (Fig. 8).

Fig. 9 shows the stress pattern in the pipeline profile determined based on the measured vibration velocities. Maximum values of the stress reduced according to the Huber-von Mises-Hencky hypothesis in the analyses pipe section are between $\sigma_{zred} = 10 - 18\ MPa$. The values reach $\sigma_{zred} = 30\ MPa$ at the joint between the pipeline and the digester only. The values are considered safe.

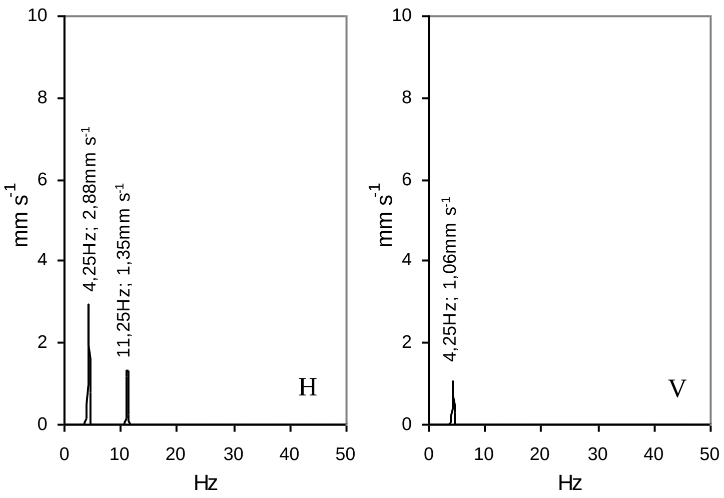


Fig. 8: The calculated spectrum of the vibration velocity.

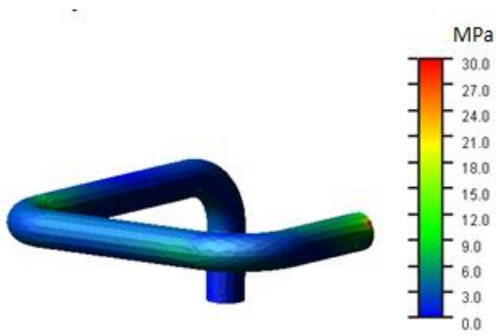


Fig. 9: The stress distribution in the pipe sections.

3. Summary

The presented method to determine the stresses in pipe structures based on their vibration velocities has a sound theoretical background. It is a tool, which is expected to be in common use due to the simplicity of both the measurement of the vibration parameters and the numerical analysis. It allows to determine the maximum strain and thus the stress strain state of the pipe. The main issue is, that the method requires to determine the parameters of the relative pipeline vibrations, when the pipeline is constrained by the structure characterized by vibrations at other frequencies. Use of the laser vibrometers to determine the time characteristics of the vibrations allows automatic measurements and stress strain state analysis of both short and very long as well as very complex pipelines.

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