620. Analysis of fastening element impact on pipe modal vibrations

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Abstract. One of the approaches for noise reduction in pipeline transport systems lies in the selection of appropriate fasteners. Therefore, it is important to know how different pipe holders change vibrational behavior of the pipe. This paper investigates the influence of clamping elements on modal vibrations of the pipe. A measurement method is proposed for determination of the damping factor that appears due to the insertion of a pipe holder.

Keywords: pipe vibrations, fastening element, vibration modes, damping factor.

Introduction

Pipelines are one of the main fluid and gas transport means used for its simplicity and low cost. Therefore, pipelines are widely used both in industry and households, and not surprisingly are one of the main sources emitting noise to the environment.

Pipe holders are integral part of the pipeline and affect both the vibration propagation in pipes and transmission to the walls. Therefore, knowledge of pipe holder parameters and their influence on pipe vibrations could help dealing with noise reduction and sound control problems.

Problem

In order to describe the vibro-acoustic characteristics of the pipe fastening element it is necessary to highlight the parameters which could characterize this attribute, and to determine effective means to measure them. Method based on measurements of quasi-static characteristics of a pipe holder was described in paper [1]. According to this research work pipe holder quasi-static characteristics alone are not sufficient to completely describe vibroisolation parameters of the clamping element. This is due to the fact that inner part of clamping ring is made of rubber-like material which characteristics (damping, stiffness) heavily depends on frequency of excited vibrations.

Methodology for pipe holder stiffness and damping parameters evaluation using pipe imitator was presented in paper [2]. This method is based on low-frequency free vibrations. In order to assess weight of fastening element on higher frequency vibrations we proposed a different approach based on modal pipe vibrations.

Pipe fastening element

Pipe fastening element, the pipe and wall fixing components all together are depicted in Fig. 1. The vibro-acoustic property of the whole system is defined by all listed components. Scope of our work is to investigate parameters of clamping elements only. To achieve this goal clamping elements were screwed directly to the wall, without using studs. In this way we eliminated the element which changes vibration characteristics of the pipe holder the most.

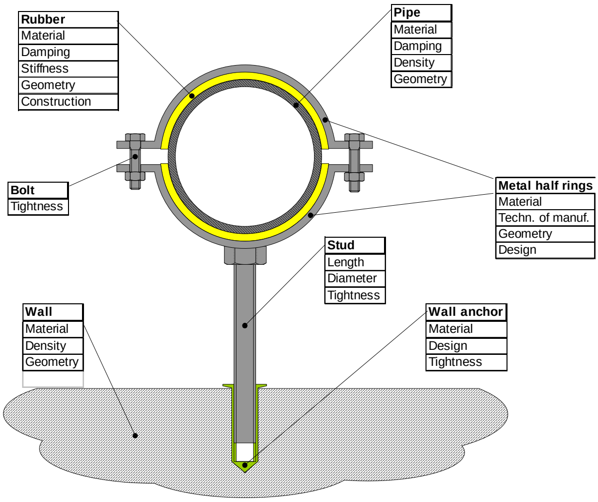

Fig. 1. Schematic of clamping element with listed factors on which vibro-acoustic characteristics of the element depends

Considering vibrating system of the pipe and the clamping element, we can separate two pipe holder modes, which are generated by the pipe vibrations:

- Transverse modes;
- Rotational modes.

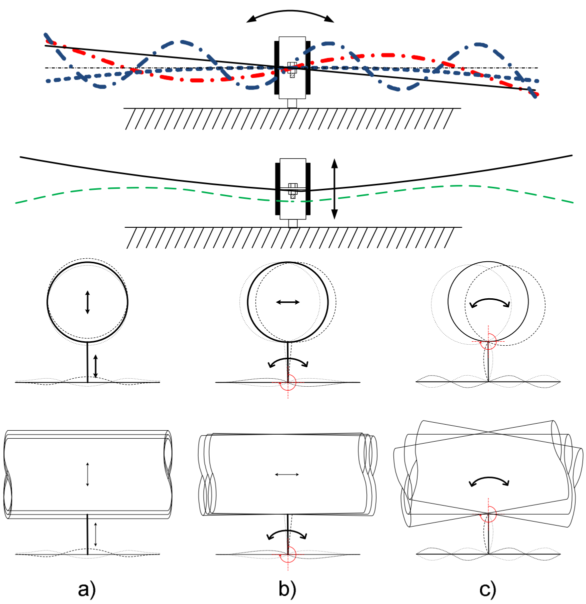

Fig. 2. Transverse and rotational modal shapes of the pipe and the pipe holder

In this work we assume that the main oscillation pipe plane is xz. The described method can also be applied to the xy plane vibrational testing.

Holder influence on pipe modal vibrations can be determined by comparing free tube vibrations to the vibrations of the pipe with the holder. In this manner, clamping element impact on the pipe modal vibrations can be evaluated.

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Vibration of the free-free thin pipe can be described by means of the Euler-Bernoulli theory:

$$EI\frac{d^4y}{dx^4}+\bar{m}\frac{d^2y}{dt^2}=0 \tag{1}$$

where E is Young's modulus, I is the second moment of area and m is the mass per unit length.

Equation (1) can be solved with the help of Krylov-Duncan theory [3]. Results are shown in Fig. 3.

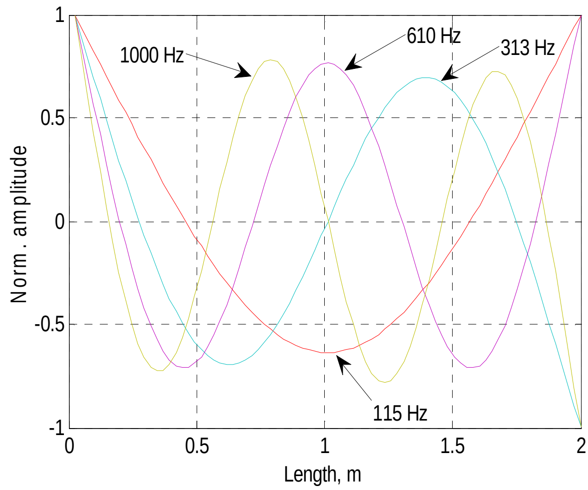

Fig. 3. Natural modal shapes and frequencies of the free-free pipe

Theoretical oscillation frequencies are compared to the measurement results. Thus we can easily estimate what modes are observed in a real pipe and what kind of movement clamping element is exposed to (Fig. 6).

Equipment and experiment

To evaluate the changes that the clamping element imposes onto the modal vibrations of the pipe, it is necessary to perform tests with the free pipe and the clamped one. Clamping element should be fixed exactly in the middle of the pipe, thus ensuring that the movement and influences of the pipe holder could be decomposed and analyzed separately. In opposite case it would be difficult to tell which transverse or rotational parameter of the pipe holder caused differences in pipe vibrations.

Metal pipe, 2 m in length, having 76 mm outer and 68 mm internal diameter was chosen for the experiments. For the free-free pipe test, the tube was hung on two bungee cords in a way that the suspension points better coincide with the mode nodes of the pipe.

Two types of transducers were considered for vibration measurement: contactless measurement with microphone or measurement using accelerometer. Microphone usage is attractive because it does not interact with the specimen and therefore has no influence on the measurements. On the other hand it is hard to measure low-frequency vibrations and in perfect scenario test should be performed in acoustically isolated room to eliminate external noise.

Accelerometers do not have these drawbacks but it interacts with specimen and therefore can and does influence the measurements. Since accelerometer weights less than the pipe and experiment methodology is based on comparative analysis, it is assumed that the accelerometer contributes the same amount of impact on free and clamped pipe and thus this impact could be eliminated.

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Because of bigger signal to noise ratio and opportunity to measure low frequencies accelerometer for vibration measurements was chosen:

Acceleration measurement range	±10 g
Frequency range	0… 6 kHz (-3dB)
Dimensions	25x25x22 mm

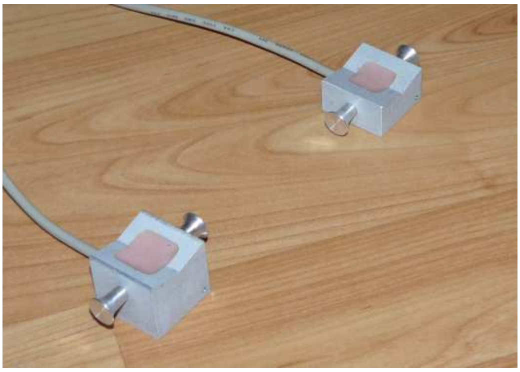


Fig. 4. Accelerometers used in experiment

Electromechanical hammer with changeable head was used for vibration excitation. By changing hammer head it is possible to choose duration of the impact that determines the bandwidth of exited vibrations (Fig. 5).

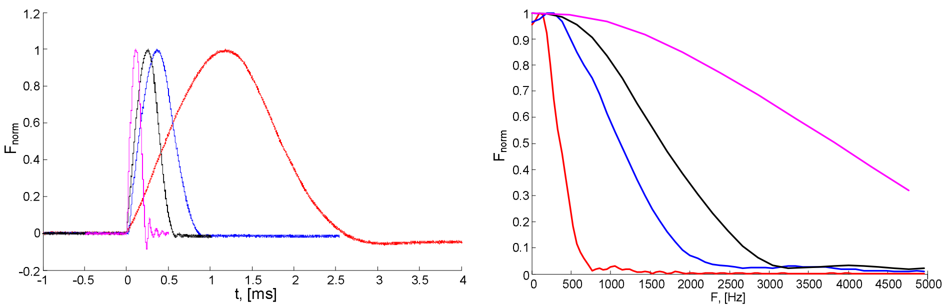


Fig. 5. Impact force duration and it's spectrum

For vibration signal digitization we have used USB data acquisition module Data Translation DT9816. Key features of this unit are:

Six, independent, successive-approximation A/D converters with track-and-hold circuitry. Each converter uses a common clock and trigger for simultaneous sampling of all six analog input signals at up to 50 kHz per channel.

A/D resolution of 16 bits and analog input ranges of +/-10 V and +/-5 V.

Results

Spectrum of the free-free pipe vibration is shown in (Fig. 6). Bandwidth of interest is limited to 1000 Hz because at higher frequencies (>1500 Hz) pipe walls start to vibrate and pipe cannot be treated as single rod. Experimental results demonstrated that frequencies of the first four modes does not differ more than 5 % from the theoretical ones.

Vibration of the free-free pipe is high-quality thus FFT does not produce enough points to accurately calculate the mode frequencies and quality from the vibration spectrum. Time domain method was chosen for this purpose, which consists of several stages:

- Mode of interest filtering in time domain;
- Vibration frequency calculation using a zero detector;
- Finding envelope of the filtered signal;
- Time constant calculation.

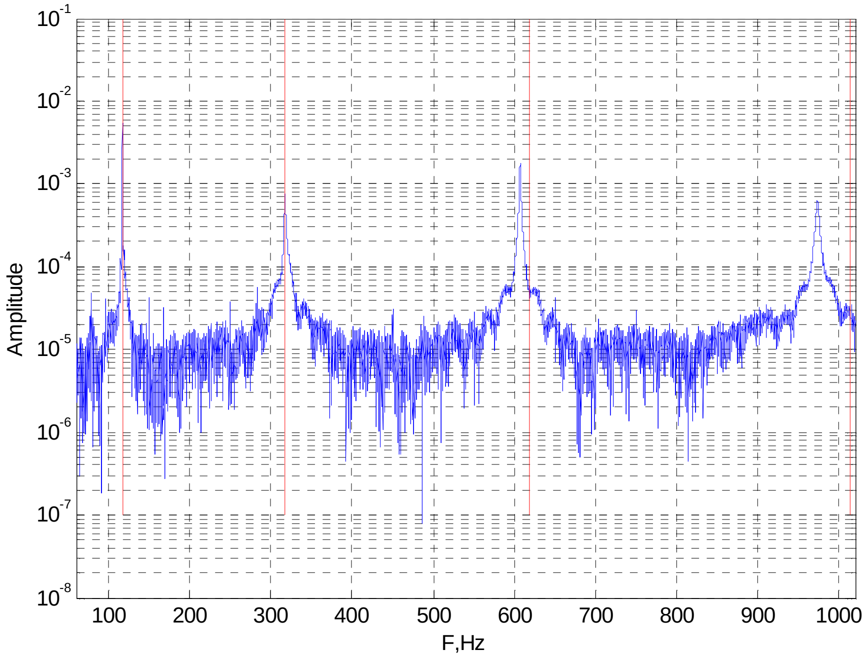


Fig. 6. Spectrum of the free-free pipe vibration (blue line) and theoretical frequencies of the first four modes (red line)

Time constant is calculated from the equation:

$$y(x) = a \cdot e^{-\frac{1}{\tau}x} \tag{2}$$

Least square method is used for parameter τ calculation. This parameter describes decay rate of the signal. Time constant relation to the damping ratio is expressed by equation [4]:

$$\tau = \frac{1}{\xi \cdot \omega_r} \tag{3}$$

were ω_r is the resonant frequency of a particular mode, and ξ – damping factor.

Further tests were carried out with two pipe holders manufactured by the same company but having different rubber inlays. Clamping elements have parameters listed in Table 1 [2].

Table 1. Parameters of holders under examination

Pipe holder	Stiffness along z axis	Around y axis
a	2.18 MN/m	312 Nm/rad
b	1.06 MN/m	195 Nm/rad

Pipe vibration spectrum is presented in Fig. 7. Vibration with clamping element *a* is shown as blue line and with clamping element *b* – green line.

After accomplishing finite element simulation of the pipe with the clamping element, the slight increase of the first mode frequency due to increased rigidity of the holder was identified. The trend is observed in experimental results as well. The first modal frequency of a pipe ring type *a* is 27 Hz and type *b* 11 Hz higher compared to the free vibration.

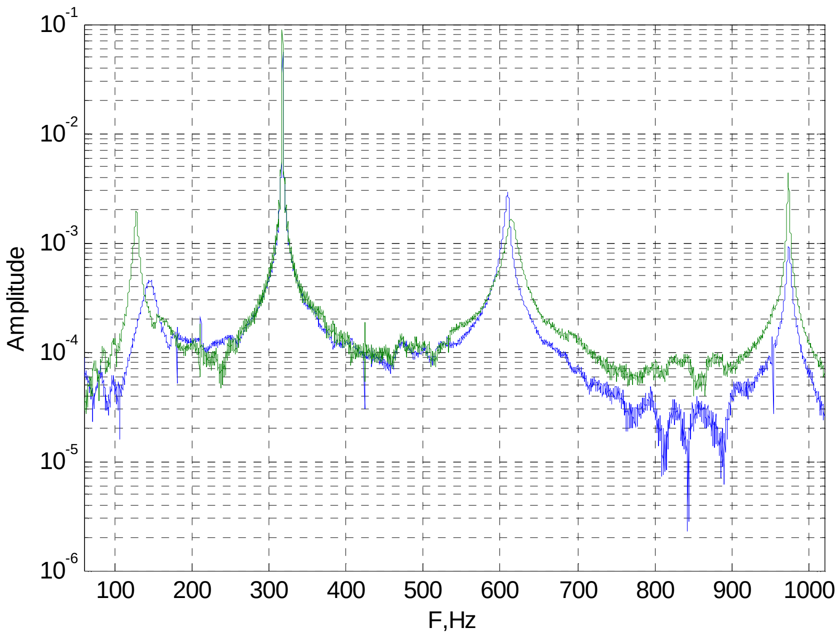
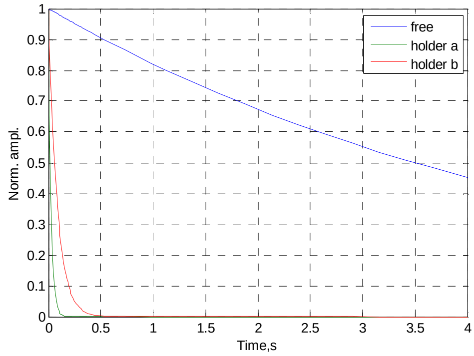


Fig. 7. Pipe vibration with different clamping elements mounted on. Element *a* – blue line, element *b* – green line

Time constant results indicate a greater suppression of transverse modes than rotational ones (Fig. 8). Such result is expected because the pipe holder is mounted on the bumps of pipe transverse mode and nodes of the rotating mode. Holder type *a* has higher damping ratio than the holder *b* in all modes except the second transverse. This mode is damped three times stronger by holder *b*. Also slight change of modal frequency is observed (615 Hz vs 609 Hz) and this suggests that fastener type *b* puts additional rigidity to this mode.

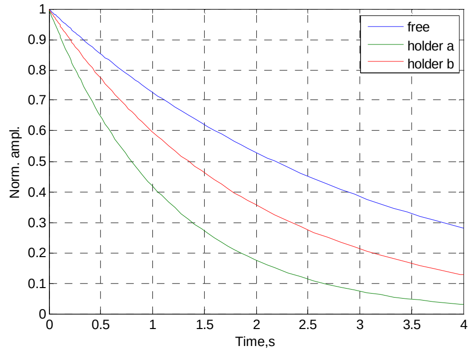
Conclusion

The proposed method for evaluation of holder effect on pipe modal vibrations enables fast and efficient comparison of different clamping elements. Measured time constants depend not only on holder itself but also on the pipe. This fact does not provide an easy means of calculation of damping coefficient of holder itself. Nevertheless, by knowing the difference in damping factor induced by particular holder we can predict its damping coefficient by the use of finite element modeling approach.



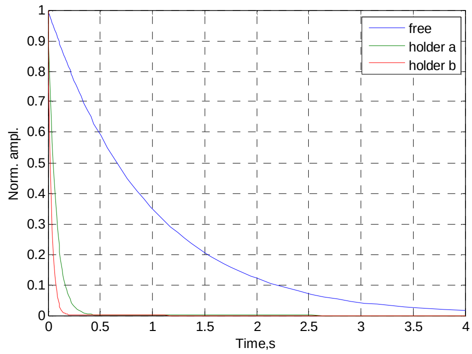
a

Holder	Frequency	Time constant
free	117 Hz	5.04 s
a	144 Hz	0.03 s
b	128 Hz	0.07 s



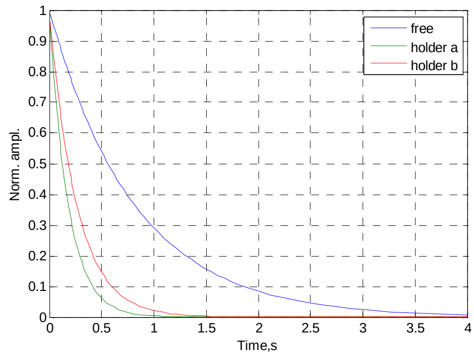
b

Holder	Frequency	Time constant
free	317 Hz	3.14 s
a	317 Hz	1.22 s
b	317 Hz	1.41 s



c

Holder	Frequency	Time constant
free	609 Hz	0.95 s
a	609 Hz	0.08 s
b	615 Hz	0.03 s



d

Holder	Frequency	Time constant
free	973 Hz	0.81 s
a	973 Hz	0.18 s
b	973 Hz	0.26 s

Fig. 8. Time constant results of the first four pipe modes

The overall damping impact on pipe modal vibrations is larger with the holder of type *a*. This result is consistent with the measurements provided in [2]. Discrepancy between overall damping tendency and damping obtained at 609 Hz demonstrates the usefulness of this method for the assessment of pipe holders.

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