Vibroacoustic method of pressure control

I V Shvetsov\textsuperscript{1,3}, A R Zagretdinov\textsuperscript{2}, V E Izmestyeva\textsuperscript{2}, E V Izmaylova\textsuperscript{2} and Sh G Ziganshin\textsuperscript{2}

\textsuperscript{1,3}Yaroslav-the-Wise Novgorod State University, ul. B. St. Petersburgskaya, 41 173003 Veliky Novgorod, Russia
\textsuperscript{2}Kazan State Power Engineering University, Krasnoselskaya str., 51 420066 Kazan, Russia

\textsuperscript{3}E-mail: Igor.Shvetsov@novsu.ru

Abstract. The method was experimentally tested on a pipe with excessive internal pressure. It is established that the main frequency of its free-damp vibrations increases with increasing internal pressure of the pipe. The method of conducting experimental studies is described, and the main results are presented.

1. Introduction

The equipment of most technological systems operates under excessive steam water, oil, gas, air, fuel oil and other media pressure. Such equipment can include pipelines, vessels, reservoirs, tanks, etc. The reliability and efficiency of such systems undoubtedly depends on proper pressure control and regulation.

Pressure measurement methods are usually based on comparing the forces of the measured pressure with the forces of:

- the forces of fluid (mercury, water) column pressure of the corresponding height;
- the forces developed during the deformation of elastic elements (springs, membranes, barometric and aneroid capsule, metal bellows and manometric pipe);
- the forces of loading weight;
- the elastic forces that occur when certain materials are deformed and cause electrical effects.

In accordance with these methods, pressure measuring instruments can be divided into fluidal, deformational, piston-type and electric [1]. The most widespread in the industry are strain measuring devices.

The reliability of these pressure measuring devices depends largely on the operating conditions. An aggressive environment, extremely high or low temperatures, ripples and contaminations can cause device failure. In addition, their installation always requires an end-to-end embedding in the control object, which reduces the operational reliability of the equipment. The presence of these disadvantages contributes to the development of new methods of pressure control.

The internal pressure of the working medium influences the natural vibrations of pipelines and vessels [2–4]. The pressure of the process product can be determined by changing the natural frequency of vibrations of the equipment. Such pressure monitoring can be arranged by installing microphones or vibroacoustic sensors on the external surface of pipelines and vessels.
The vibroacoustic method does not require end-to-end insertion into the control object. It is acceptable for equipment working with aggressive and polluted environments.

The method can be organized basing on the analysis of the natural noise of the pumped product [5]. The flow noise always contains separate spectral components that are caused by resonant vibrations of the equipment [6].

The vibroacoustic method of pressure measurement has been tested in the course of experimental studies. An experimental installation has been developed, the block diagram and photo of which are shown in figure 1 and 2, respectively.

![Figure 1](image1.png)

**Figure 1.** An experimental installation block diagram: 1 – pipe (length 2 m, outer diameter 0.159 m, wall thickness 6 mm), 2 – check valve, 3 – gate valve, 4 – compressor, 5 – pressure gauge (accuracy class 2.5, measuring limit 10 bar), 6 – hammer, 7 – microphone, 8 – personal computer.

![Figure 2](image2.png)

**Figure 2.** The picture of the experimental installation.

The experimental installation functions as follows.

Compressor 4 creates excessive air pressure in pipe 1. The air pressure is controlled using a pressure gauge 5. Hammer 6 in the pipe 1 excites freely damping vibrations. The sound of the impact is recorded by a microphone 7 and then in a personal computer 8.
Audio signal analysis is performed using a software package written in the LabView programming environment [7–9].

The method of analyzing audio signals is as follows.

1) The signal duration is increased by adding zeros to the array of samples. The procedure for adding zeros allows you to increase the frequency resolution of the spectrum.

2) With the help of the fast Fourier transform procedure, the amplitude-frequency spectrum of the signal is calculated.

3) The frequency with the maximum value of the amplitude is being chosen in the spectrum.

2. Results and discussion

The sound of an impact on the pipe was recorded at a sampling rate of 44.1 kHz. The length of recorded audio signals (without adding zeros) is 44,100 samples.

To increase the spectrum frequency resolution, zeros were added to the signal. An example of a signal supplemented with zeros is shown in figure 3.

Figure 4 and 5 show the spectra of signals received from a pipe with a pressure of 0 and 5 bar, respectively.

The amplitude-frequency spectra were calculated for signals with a length of 44100, 88200, 176400 and 352800 samples. The results are summarized in table 1.

![Figure 3. The signal supplemented with zeros.](image1)

![Figure 4. The spectrum of the pipe with internal pressure 0 bar.](image2)
Figure 5. The spectrum of the pipe with internal pressure 5 bar.

Table 1. The results.

| Base harmonic frequency, Hz | Signal length, samples | Signal length, samples | Signal length, samples | Signal length, samples |
|-----------------------------|------------------------|------------------------|------------------------|------------------------|
| under a pressure of 0 bar   | 1296                   | 1296                   | 1296                   | 1296                   |
| under a pressure of 1 bar   | 1298                   | 1298                   | 1298                   | 1298                   |
| under a pressure of 2 bar   | 1300                   | 1300                   | 1299.75                | 1299.875               |
| under a pressure of 3 bar   | 1302                   | 1302                   | 1302                   | 1302                   |
| under a pressure of 4 bar   | 1304                   | 1304                   | 1303.75                | 1303.75                |
| under a pressure of 5 bar   | 1306                   | 1306                   | 1305.75                | 1305.875               |
| Frequency resolution, Hz   | 1                      | 0.5                    | 0.25                   | 0.125                  |
| Coefficient of determination for linear regression | 1 | 1 | 0.9992 | 0.9996 |
| Error in determining the pressure from the vibroacoustic signal, bar | 0.5 | 0.25 | 0.125 | 0.063 |

Table 1 demonstrates that with increasing internal pressure, the frequency of the main harmonic of pipe vibrations increases linearly (the coefficient of determination for linear regression $R^2 = 1$). The pressure changes by 1 bar leads to an increase in the frequency of pipe vibrations by 2 Hz.

The estimation of the error in determining the pressure from the vibroacoustic signal is made using the formula:

$$\delta = \frac{\Delta f}{2},$$

$\Delta f$ is the frequency resolution, Hz; 2 is the frequency difference of the pipe with a difference in internal pressure of 1 bar, Hz.

The dependency graph of the natural pipe frequency on its internal pressure is shown in figure 6.
3. Conclusion

Studies have confirmed the possibility of monitoring the pressure by changing the natural frequency of equipment vibrations.

It is established experimentally that the main frequency of free-damping vibrations increases linearly with increasing internal pressure of the pipe.

References

[1] Zamaletdinova E Yu and Egorychev A I 2014 Sravnitel'nyj analiz metodov izmereniya davleniya [Comparative Analysis of Pressure Measurement Methods] Bulletin of Kazan Technological University 8 124–7

[2] Bereznev A V 2011 Vliyanie vnutrennego gidrostaticheskogo davleniya na chastoty svobodnyh kolebanij krivolinejnogo uchastka truboprovoda [The Effect of Internal Hydrostatic Pressure on the Frequency of Free Vibrations of a Curved Pipeline Section] News of Higher Educational Institutions Oil and Gas 3 77–80

[3] Efimov A A 2008 Sobstvennye kolebaniya morskogo glubokovodnogo nefteprovoda bol'shogo diametr [Natural Vibrations of a Large Diameter Marine Deep-water Oil Pipeline] Bulletin of Civil Engineers 4(17) 26–9

[4] Sokolov V G, Ogorodnova Yu V, Dmitriev A V and Maslennikov A M 2019 Kolebaniya podzemnyh tonkostennyh magistral'nyh truboprovodov s uchetom vnutrennego davleniya i prodol'noj sily [The Vibrations of Underground Thin-walled Main Pipelines with Regard to Internal Pressure and Longitudinal Power] Bulletin of Civil Engineers 5(76) 105–112

[5] Balakin R A and Timets V M 2012 Pat. of the Russian Federation No 2470274 appl. 29.07.2011 publ. 20.12.2012

[6] Nazarychev S A, Vankov Yu V, Politova T O, Fominykh K S and Shlychkov V V 2019 J. of Phys.: Conf. Series 1328 012057

[7] Shvetsov I V, Vankov Yu V and Zagretdinov A R 2018 IOP Conf. Ser.: Mater. Sci. Eng. 441 012051

[8] Zagretdinov A R, Kondratyev A E and Gaponenko S O 2017 Reliability Increasing Solutions for Multilayer Composite Structures Shock-Acoustic Control Procedia Engineering 206 656–61

[9] Vankov Yu, Rumyantsev A, Ziganshin Sh, Politova T, Minyazev R and Zagretdinov A 2020 Assessment of the Condition of Pipelines Using Convolutional Neural Networks Energies 13(3) 618