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Method for vibration measurement in pipelines of residential buildings

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Abstract. The article is devoted to the problem of insufficiency and incompleteness of existing methods for measuring vibration in pipelines of residential buildings. Existing methods for measuring vibrations in pipelines are considered and their effectiveness is analyzed. The assessment of complexity, cost efficiency and accuracy of the existing vibration measurement methods is made. An improved method for measuring the vibration of a pipeline section with a tap based on the analysis of the trace of blurring a circular mark and the Doppler Effect is proposed.

1. Introduction

Technological processes need to be diagnosed. One of the main parameters of the diagnostics of engineering systems of buildings is vibration. Increased vibration has a negative effect on process equipment and people. Vibration is measured by vibrometers and vibration analyzers.

Vibration measurement is carried out by contact and contactless methods. The simplest contact method, based on the use of piezoelectric sensors, is highly inertial and not suitable for small mass objects. The open resonator method is also not applicable for objects of small mass, but it has a small inertia with respect to piezoelectric sensors.

Contactless vibration measurement methods are based on the use of sound waves and visible light. The method of ultrasonic phase measurement has the speed of measurement, relative cheapness and high accuracy, but it is sensitive to the measuring environment, it has a strong attenuation of the frequency in the air and reduced accuracy with increasing frequency of vibration of the object under study.

Optical methods have high speed and accuracy of measurement; they do not affect the object under study. The main disadvantages of optical methods are the high cost and complexity of the equipment, high energy consumption.

Technological processes require appropriate monitoring of the state of both the process itself and the state of the process equipment. One of the main controlled parameters of the process being studied is often the amplitude of vibration (vibration displacement) and the frequency of vibration (vibration velocity).

Vibrations are mechanical fluctuations of an object. The full body vibration can be described by a set of six simplest types of motion: translational motion in three mutually perpendicular directions of Cartesian coordinates and rotational with respect to mutually perpendicular axes X, Y, Z. Therefore, it is possible to speak about six degrees of freedom of the object under study.



Object vibration occurs due to various excitation forces acting on it. These forces may occur inside the object (the piping system vibrates due to water pulsations) or may act on the object from the outside (the piping system vibrates due to the distribution of vibration from the process equipment to the pipeline attached to it). To obtain the necessary information about the vibrations of the system under study, it is necessary to analyze the main parameters affecting the occurrence of vibration: the disturbance force, its frequency and direction [1].

Increased vibration of pipelines of residential buildings has a negative impact not only on the state of engineering systems, but also on people nearby. Low-frequency noise can contribute to increased fatigue, the emergence of unreasonable feelings of anxiety, irritation, which in general has a negative impact on human health.

To determine the vibroacoustic characteristics of the piping system, it is necessary to measure the vibration during operation and compare the maximum values of the vibration parameters with the standard values.

Often vibration measurement is performed with low accuracy or has significant costs, for example, for the purchase of expensive vibration measuring equipment, therefore the development of vibration measurement methods is relevant.

2. Vibration diagnostics of pipelines of building engineering systems

The purpose of the study is to find the causes of vibration pipelines. The causes of increased vibrations are [2]:

- the coincidence of the natural frequencies of vibration with the frequencies of the pumped water;
- the pulsation of pumped water arising due to various mechanical and technological reasons;
- suboptimal hydrodynamic characteristics due to deficiencies in the design or installation of pipelines.
- the inadequate condition or location of pipeline support structures.

For a full study of the vibration of the pipeline section, it is necessary:

- to measure the basic vibration parameters: vibration velocity, vibration acceleration, vibration displacement [3];
- to determine permissible vibration values of the piping system. For residential buildings, the permissible vibration values are given in Table 1 [4];
- to calculate the natural frequency of the piping system;
- to determine the effect of measuring equipment on vibration and correct values.

When detecting increased vibrations of the pipeline system that differ in frequency from the natural frequencies of the pipeline system, it is necessary to conduct a full diagnosis. Vibration diagnostics of building engineering systems is a complex and time-consuming task, requiring expensive instrumentation and software products, which is often beyond the capacity of service organizations.

Today, in the field of vibration diagnostics, methods using vibration meters and vibration analyzers are widely used [5-10].

In vibrometers, primarily piezoelectric sensors are used as primary transducers, which are fixed at the site of the pipeline system. Modern vibrometers measure the values of vibration velocity, vibration acceleration and vibration displacement. They are capable of storing and transmitting data for further research. They are also able to measure high frequency vibrations.

Recommended limits for measuring parameters for vibrometers are [2]:

- the RMS value of vibration velocity in the range of 0.5 ... 100.0 mm/s and higher in the working frequency range of 10 ... 1000 Hz;
- the range of vibration displacement in the range of 1.0 ... 1000.0 microns and higher in the working frequency range of 3 ... 300 Hz;
- the peak value of vibration acceleration in the range of 1 ... 200 m/s² and higher in the working frequency range of 10 ... 3000 Hz.

One of the drawbacks of a vibrometers is the ability to measure vibration parameters at a specific point in time without the ability to capture changes in parameters over time. This deficiency is absent in vibration analyzers.

A vibration analyzer in comparison with a vibrometer is a more complex measuring instrument. In addition to all the functions of a vibrometer, a vibration analyzer is able to record vibration parameters in the dynamics and output them in a form convenient for further analysis: graphs, tables, etc. Also, a vibration analyzer, unlike a vibrometer, has other functions, for example, the ability to determine the required additional weight for balancing the system [3].

Vibration analyzers provide [2]:

- the measuring of vibration parameters: vibration velocity, vibration acceleration and vibration displacement with a permissible error;
- the calculating of the main coefficients: coefficient of kurtosis, coefficient of peak, etc;
- the determining of natural frequencies of oscillations of the measured pipeline sections;
- the determining of the amplitude-phase-frequency characteristics of vibration when opening / closing valves, equipment start-up, etc.;
- the registering of the change in the shape of the vibration signal in time;
- the analyzing, transmission and storing of measured data in the memory.

Table 1. Maximum permissible vibration levels in residential buildings

Geometric average frequency bands, Hz	Valid values for the X, Y, Z axes			
	Vibration accelerations		Vibration velocities	
	$m/c^2 \cdot 10^{-3}$	dB	$m/c \cdot 10^{-4}$	dB
2	4.0	72	3.2	76
4	4.5	73	1.8	71
8	5.6	75	1.1	67
16	11.0	81	1.1	67
31.5	22.0	87	1.1	67
63	45.0	93	1.1	67
Equivalent corrected values of vibration velocities or vibration accelerations and their logarithmic levels	4.0	72	1.1	67

3. Methods for measuring vibration of technological pipelines

Methods for measuring vibration are divided into two groups:

- the contact methods have a direct mechanical connection of the primary converter with the measured object;
- the contactless methods have not a mechanical connection with the object being measured.

3.1. Contact measurement methods

The simplest contact vibration measuring method is the use of piezoelectric sensors. This method is quite accurate in the range of low frequencies and relatively large amplitudes of vibration. Measurement of high-frequency and low-amplitude vibrations by piezoelectric sensors is impossible due to the high inertia of the transducer, which leads to distortion of the waveform. Also, piezoelectric sensors have a significant impact on the vibration parameters of the studied objects of small mass.

Some disadvantages of using piezoelectric sensors are absent when using the open resonator method. This method is based on measuring the ultra-high frequencies of the resonator, which are changed by the vibration of the object under study. The resonator consists of two mirrors, one of

which has a mechanical connection with the object under study, the second is stationary. Measurement of small vibration amplitudes is performed by the amplitude method for changing the reflected or output power. The limit of measurement of this method is 3 microns. With respect to piezoelectric sensors, the open resonator method has low inertia. This method also has drawbacks: the mass of the mirror fixed on the object of study must be significantly less than the mass of the object itself, a constant power supplied to the resonator and a stable frequency of excitation is necessary [11].

3.2. *Contactless measurement methods*

The most contactless vibration measurement methods are based on the use of sound waves and visible light.

The method of ultrasonic phase measurement is based on measuring the current value of the phase difference between the reference and the reflected from the object of study signals. Signals are given at an ultrasonic frequency. Primary signal transducers are piezoelectric ceramics. The measurement limit of the vibration displacement of the object of study for this method at a frequency of 240 kHz ultrasound is 10 mcm at a distance from the object of 1.5 m. At increase in frequency of the original signal the sensitivity of this method increases. Among the advantages of this method, it is possible to specify a small measurement time, high measurement accuracy, compactness of equipment, relative cheapness, etc. The disadvantages include the dependence of ultrasound on the medium state through which it passes, the strong attenuation of the frequency in the air and the drop in the measurement accuracy with increasing frequency of vibration [12].

Optical methods are divided into holographic methods and methods based on the Doppler Effect.

The Doppler Effect is the basis of laser vibrometry. This is a modern method of measuring the vibration of the studied objects. The advantages of laser methods are:

- the high measurement accuracy;
- the ability to measure the vibration of objects of any mass;
- the remote measurement of research objects;
- the high measurement speed.

The main disadvantages of optical methods are the complexity and high cost of equipment. Also among the drawbacks, it is possible to specify the harmful effects on the staff, high energy consumption, special requirements for the surface of the object of study and the measurement environment.

4. **Measurement of vibration parameters by the trace of image blur**

Another optical method for measuring vibration is the method of measuring vibration parameters by the trace of a blurred image of a round mark [13, 14, 15]. This method consists of applying a round-shaped retroreflective mark to the object under study, forming a binary image of this mark without vibration and fixing the trace of vibrational blurring. A further comparative analysis of the geometrical parameters of the mark and the trace of the vibratory blur of the mark makes it possible to determine the modulus and direction of the amplitude vectors of the vibration displacement of the object under study.

The advantages of this method are the possibility of measuring the vibration parameters of objects of any mass, short measurement time, high accuracy, etc.

The main disadvantage of these methods [14, 15] is the impossibility of determining some important vibration parameters for analyzing the increased vibrations of pipelines, such as vibration velocity and vibration acceleration.

The improvement of this method for measuring the vibration parameters of a pipeline section with a tap consists of applying three reflective marks in mutually perpendicular planes, as shown in Figure 1. A light beam with a given frequency is fed to the reflectors. The device receiver registers not only the trace of the image blur, but also the frequency of the reflected flow. Registration must occur synchronously with the three tags.

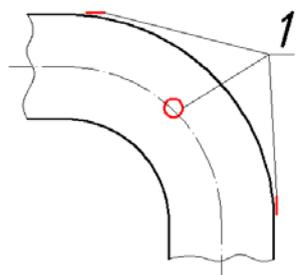


Figure 1. Reflective marks on the pipeline section
1 - reflective marks

The movement of the reflective marks relative to the device-receiver affects the frequency of the recorded signal of the reflected flow due to the Doppler Effect. Using this method, it is possible to calculate the vibration velocity of the object under study in three mutually perpendicular components and construct the amplitude-frequency characteristic of the vibration.

This method will provide all the necessary information about the vibration parameters of the pipeline section. Compared to the method of measuring vibration on the trace of blur of a round mark, it is more complex and expensive to perform.

5. Conclusion

Vibration control of high-rise building pipelines is an urgent task, since increased vibrations lead to accelerated wear of the piping system and process equipment, as well as the noise generated by vibration, have a negative impact on people.

Analyzed vibration measurement methods have several disadvantages. Contact methods affect the vibration parameters of the studied objects, especially low mass, which can lead to significant errors. Contactless methods are expensive and difficult to implement, but more accurate and fast.

The proposed method for measuring of the vibration of a pipeline section with a tap, based on the analysis of the trace of blurring of a round mark image and the Doppler Effect, makes it possible to determine all the pipeline vibration parameters necessary for the analysis. However, like other optical methods, it is quite complex in execution and expensive. This method requires experimental research and further improvement to reduce costs.

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