Assessment of the technical condition of pipelines in polyurethane insulation

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Abstract. The paper considers issues of improving the reliability of operation of pipelines of heating networks. A description of the created diagnostic complex is given, with the help of which it is possible to determine the technical condition of pipelines in polyurethane foam insulation. Finite-element models were constructed and modal calculations of defective and defect-free pipelines in polyurethane foam insulation were carried out. The analysis of the received acoustic signals was carried out using neural network algorithms. The results of processing acoustic vibrations of pipelines by a neural network showed a high efficiency in identifying pipelines by their state (defective / defect-free).

1. Introduction
Ensuring the required reliability of heating systems is an important task, the solution of which will allow to maintain the accident-free operation of pipelines, reduce the heat losses and the cost of transfer of thermal energy. Creating a pipeline monitoring system can be one of the options for solving this problem. Modern heating systems mainly use pre-isolated pipes with polyurethane foam insulation. For this type of pipeline, there is a mandatory remote control of the watering of polyurethane foam with damage detectors. But this is not enough, as by this way it is impossible to determine exactly the location of the leak and the type of the defect. In this regard, there is a problem of lack of equipment for monitoring and diagnosing pipes in polyurethane foam insulation.

2. Results and discussion
This paper describes the diagnostic complex that has been created, through which it is possible to determine the technical condition of pipelines in polyurethane insulation. Diagnosis is based on an acoustic method of non-destructive control due to a number of features [1, 3, 4]. Information parameters are the frequencies of free vibrations or resonances of forced vibrations [10, 11]. These frequencies are related to the geometric parameters of the products and the speed at which the sound is distributed.

A pipeline in polyurethane insulation with the following geometric characteristics was selected as a the object of the study: the length \( L = 995 \) mm, the outer diameter \( D_1 = 220 \) mm, the thickness of
the wall $\delta_1 = 6$ mm, the thickness of the layer of polyurethane insulation $\delta = 45$ mm and the thickness of the polyethylene sheath $\delta_2 = 5$ mm. The dependence of the change in the acoustic characteristics of the pipeline on the presence of a “hole-type” defect on it was investigated. In order to obtain frequencies of their own fluctuations of defective and non-defective pipelines, it was necessary to carry out their modal analysis. Modal analysis suggests that the system is linear. All types of non-linearity – non-linear behavior of the material, contact boundary conditions, final movements – are ignored. It is assumed that free non-fading fluctuations are made:

$$[M] \cdot \{u''\} + [K] \cdot \{u\} = 0,$$

where $\{u\}$ is the vector of nodal displacements for the whole body, $\{u''\}$ is the vector of acceleration of body points, $[K]$, $[M]$ are “global” matrices of rigidity and mass for the whole body.

We note that the rigidity matrix of the design can include the effect of pre-loading For the linear system free vibrations will be harmonic:

$$(u) = (\varphi)_i \cdot cos \omega_i t$$

where the natural vector represents the $i$-form of oscillations; $i$ is natural circular frequency (radian per unit of time); $t$ is time.

The values of their own circular frequencies ($\omega_i$) and own frequencies ($f_i$) are related by the following ratio:

$$f_i = \frac{\omega_i}{2 \cdot \pi}$$

where $i$ is natural frequency (cycles per unit of time) [5].

Figure 1. Modeled in the ANSYS software complex, a defective pipeline in polyurethane insulation: (a) general view; (b) Pipeline model broken down into a grid of end elements.
A finite elemental simulation was used in the ANSYS software complex to solve the problems of modal analysis. The modeled pipeline (figure 1) consists of three layers with the following characteristics:
1. Steel St3 with the Poisson coefficient of $v = 0.3$, elasticity module and density;
2. Polyurethane with the Poisson coefficient of $v = 0.496$, elasticity module and density;
3. Polyethylene with the Poisson coefficient of $v = 0.42$, elasticity module and density.

The resulting dependence of the frequencies of own vibrations on modes for defect-free and defective pipelines are shown in figure 2.

As far as can be seen from the graph in figure 2, the noticeable difference in the frequencies of defect-less and defective vibrations is in intervals from the 10th to the 20th and from the 40th to the 80th modes. In the future, these areas should be preferred when analyzing acoustic signals.

![Figure 2](image-url)

**Figure 2.** Dependences on the frequency of natural oscillations from modes for defect-less and defective pipelines in polyurethane insulation.

To confirm the possibility of assessing the condition of pipelines in polyurethane insulation by acoustic method, an experimental installation was created, the structural scheme of which is shown in figure 3. The excitation frequency in the pipeline under study was carried out with the same period and force of impact. Reception, primary conversion and transmission of the signal is done using the ADC NI USB-6229. The analog signal from the sensors is converted by the controller and transmitted to a personal computer. Data is processed using a program written on the basis of the LabView software complex.

With the installation described above, it is possible to obtain the frequency of pipeline oscillations that can be judged on their condition, but the problem is the processing of a large amount of data and the unmistakable identification of pipeline defects. Therefore, further processing and analysis of the resulting frequencies were carried out using a neural network (figure 4). The use of neural networks allows you to quickly and efficiently analyze data and reduce error in decision-making [2, 6–9, 12].

Input signals are sent to the neural network, which are the frequencies of pipeline oscillations. During the initialization of the neural network, the weights of swaying frequencies take a randomized value. On the structural scheme of the neural reverse distribution network (figure 4), all the input information multiplied by their weight is the hidden layer:

$$f_{i,\text{input}} = (l_1 \cdot W_1) + (l_2 \cdot W_2) + \cdots + (l_i \cdot W_i)$$

where $l_1$ is an input neuron, and $W_1$ is weight.
Figure 3. Structural scheme of the experimental installation: 1 – the pipeline being studied; 2 – piezoelectric sensor; 3 – NI USB-6229 DAQ-device; 4 – personal computer.

Figure 4. Structural scheme of the neural network of reverse spread.
Since the range of number operations in a neural network is $[0; 1]$ or $[-1; 1]$, the input values $(f_{i, \text{input}})$ are converted through the activation function

$$f(x) = \frac{1}{1 + e^{-x}}$$

When the weight data was processed, randomized values were obtained, in subsequent calculations the weight coefficients were recalculated taking into account their gradient, and each subsequent iteration took place with the updated weights. To more accurately find the parameters of output neurons, the minimum error rate at which the calculation ended was 0.001. The number of iterations of data processing is 1085.

3. Conclusion
The results of the processing of acoustic oscillations of pipelines by the neural network showed high efficiency (98%) identification of pipelines by their condition: defective-less or defective. The efficiency of determining the size of the defect was at the level of 75%. To improve the effectiveness of diagnostics, the authors plan to accumulate a larger training base of acoustic signals of pipelines and use of deep convolutional neural networks.

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