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Research paper

Assessment of Technical Condition of Polyurethane Foam Thermal Insulation Pipelines of Heating Networks Using Neural Network Technologies

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Abstract

Pipelines of heat networks are an important element of heat supply to cities and industrial facilities. To increase the reliability of the operation of pipelines of heating networks, reducing the number of their accidents and increasing the economic parameters of transportation of heat energy, it is required to constantly increase the volumes and quality of complex diagnostics. The instruments currently used for the diagnosis of pipelines have many shortcomings. Among them, low reliability of detection of defects and subjectivity of decision-making, as well as lack of funds for diagnostics of pre-insulated pipelines (in polyurethane foam insulation). To simplify, accelerate and improve the reliability of monitoring the technical condition of pipelines, the authors set the goal of diagnosing the object of research using acoustic methods, using neural network technologies to process acoustic signals. The article describes experimental studies of pipelines of heating networks in polyurethane foam insulation with various sizes of defects and an analysis of the acoustic signals obtained at the same time is made. The frequency of natural oscillations of the pipeline is chosen as the determining parameter of the acoustic signal. To process and analyze the frequencies obtained as a result of the experiments, a neural network of back propagation of the error was constructed.
The results of the classification of the neural network of back propagation of the error trained by the neural network showed its good ability to analyze unknown samples and a high degree of reliability of their recognition.

Keywords: *diagnostics, corrosion, defect, pipelines, acoustic signal, heat networks, finite element model, neural network*

1. Introduction

Detection of defects and, in particular, corrosion is one of the most important problems, the solution of which will ensure trouble-free operation and increase the service life of pipelines, reduce the cost of transferring heat energy. The solution to this problem is related to the improvement of methods for calculating and diagnosing heat networks based on the search for optimal solutions and the system approach. At present, there is a great variety of methods and means of leak testing, but from the ecological and economic point of view, it is more expedient to anticipate the occurrence of accidents in pipelines in advance, and not to state the fact of their occurrence [8, 10, 15]. Modern diagnostics of pipelines is based on various methods of nondestructive testing, among which acoustic ones are distinguished due to a number of positive features [16]. However, they also have a number of drawbacks: for example, only local locations are diagnosed, not the entire length of the site; impossibility to diagnose pipes with polyurethane insulation; the difficulty in determining the location of defects, their size and type; the complexity of highlighting useful information from noisy signals; the need for work with the withdrawal of the site from operation with the discharge of the transported product; a long process of obtaining the final information; the high price of equipment and the need for special personnel training [1-5, 16].

In this connection, it is proposed to develop research in the field of acoustic monitoring of pipelines. To do this, it is proposed to analyze the effect of the presence of a defect, their type and size on the acoustic characteristics of the pipes, in particular, on their natural oscillation frequencies. To simplify, accelerate and increase the reliability of control, the authors set the goal to diagnose the object of research using neural network technologies.

2. Methods

To achieve this goal, it is necessary to solve the following tasks:
1) to develop an experimental installation and conduct experimental studies to obtain the frequencies of natural oscillations of the real part of the pipeline;
2) to build a neural network;
3) to process the data obtained on the basis of experiments with the help of the created neural network.
To obtain the frequencies of natural oscillations of the pipeline with subsequent processing of the obtained data, an experimental setup was constructed.
The experimental setup includes (Fig. 1):
• Studying the pipeline;
• Control and measuring devices;
• Software and hardware complex.

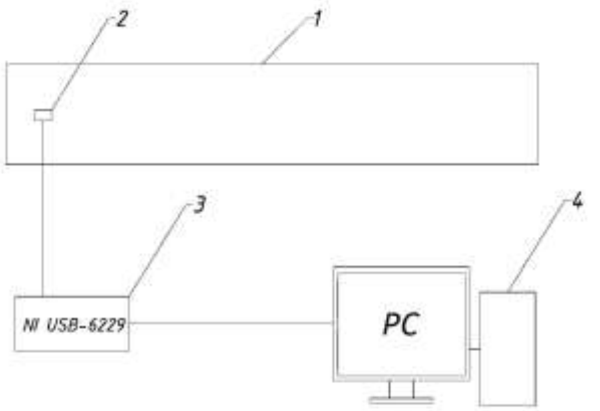


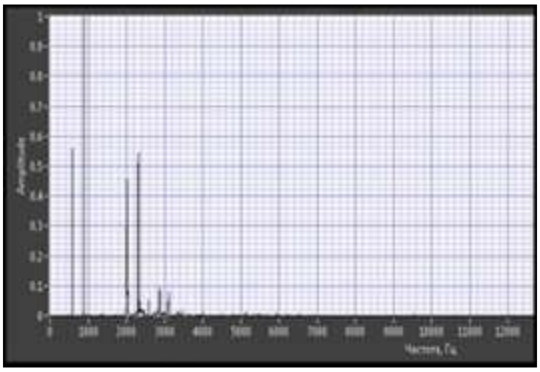
Figure 1:. The composition of the experimental setup: 1- studied pipeline; 2 - piezoelectric sensor; 3 - DAQ device NI USB-6229; 4 - Personal computer.

During the experiment, strokes of the tube with the same period and impact force excited the frequencies of natural oscillations, which were recorded on a personal computer.

The pipeline was chosen as the object in the polyurethane foam insulation with the following geometric characteristics: pipeline length L = 995 mm, pipe outer diameter D1 = 220 mm with wall thickness δ1 = 6 mm. The thickness of the layer of polyurethane insulation was 45 mm, and the thickness of the polyethylene sheath δ2 = 5 mm.

As a control and measuring complex, piezo sensors were used with the possibility of measuring the frequencies in three axes: X, Y, Z.

Reception, primary conversion and transmission of the signal are carried out using the NI USB-6229 data collector. The analog signal from the sensors is converted by the controller and transmitted to a personal computer. Recording and processing of acoustic signals is carried out using a specially developed package of applied programs Inspector (A.S. No. 2009612056) [6, 7, 9]. The measurements were carried out for both a defect-free pipeline and a pipeline with artificially applied defects in the form of holes with diameters of 7 mm, 11 mm and 15 mm (Fig. 2).



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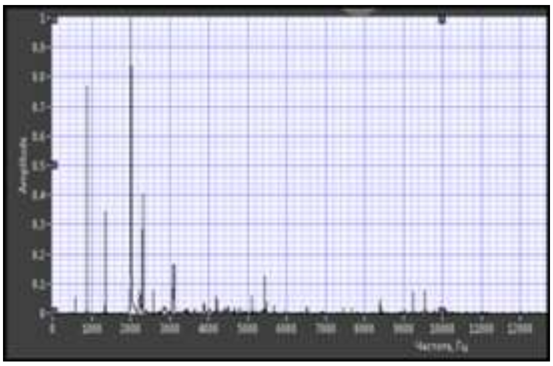

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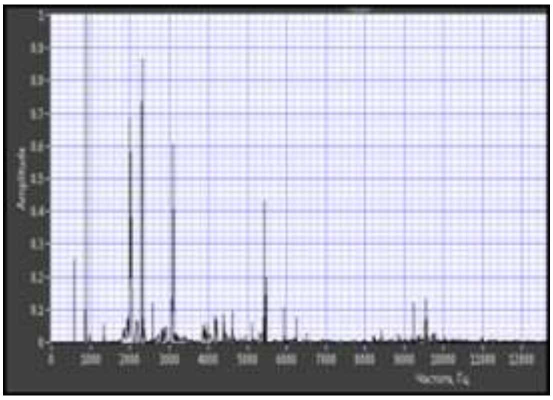

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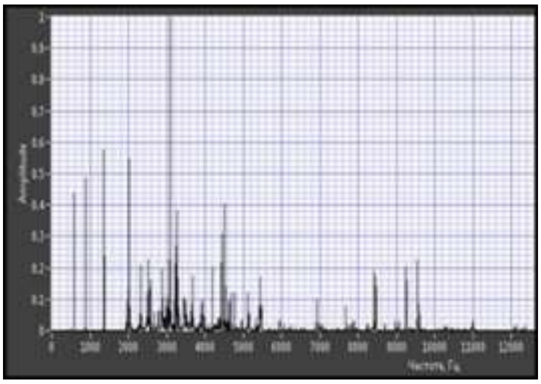

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Fig. 2: Spectra of natural frequencies of the tube, recorded in the program Inspector:
a) a defect-free pipe, b) pipes with a defect of 7 mm, c) pipes with a defect of 11 mm, d) pipes with a defect of 15 mm

Features of the Inspector program also allow you to write a spectrum into a file in tabular form, where the first column contains the number of the waveform, and in the second column - the frequency corresponding to this form (Table 1).

Table 1:. Comparison of frequencies ω, (Hz) recorded with the Inspector program for pipes with defects of different diameters on the surface.

Shape of oscillation	Defectless	7 mm	11 mm	15 mm
1	584	582	582	580
5	892	892	886	886
7	1436	1436	1434	1434
10	1558	1560	1560	1558
12	1738	1736	1736	1738
14	1970	1968	1964	1966
18	2002	2000	1998	1984
25	2062	2062	2058	2058
28	2160	2156	2154	2150
35	2198	2198	2198	2198
45	2270	2270	2270	2270
55	2330	2332	2332	2336
….	….	….	….	….
125	4022	5442	5118	3926
126	4028	5448	5322	3932
127	4158	5460	5420	3994
128	4178	5472	5426	4000
129	4184	5478	5432	4006
130	4190	5678	5438	4016
131	4200	5942	5444	4176
132	4206	6218	5470	4182
133	4212	6224	5476	4192
134	4448	6258	5942	4198
135	4454	6526	6064	4204
136	4514	8228	6222	4380
137	4684	8586	8398	4396
138	4964	8708	9248	4426
139	4970	8914	9254	5104

140	5122	9148	9532	5110
141	5128	9252	9538	5116
142	5134	9448	9544	5438
143	5324	9546	9550	5444
144	5390	9552	9604	5478
145	5684	9608	9610	5678
146	5944	9722	9720	8402
147	6066	10034	9780	9256
148	6516	10044	10044	9544
149	6532	10050	10306	9602
150	7342	10838	10996	10040

An analysis of the experimental results obtained showed [11-14] that these spectra differ significantly, but in this form it is problematic to assess the condition of pipelines and the classification of defects.

The use of neural networks will allow you to quickly and efficiently analyze data and reduce errors in decision making. A neural network is a system capable of changing its structure under the influence of external factors. It is said that an artificial network is trained on input data. During the training, the internal parameters of the artificial neural network are adjusted to the input data, which makes it possible to isolate patterns in the data or to solve problems of prediction, classification, and clustering [18-20].

Further processing is performed using the neural network of back propagation of the error. The neural network for processing and analyzing the frequencies obtained as a result of the experiments was built on the basis of the back propagation network of the error (Fig. 3).

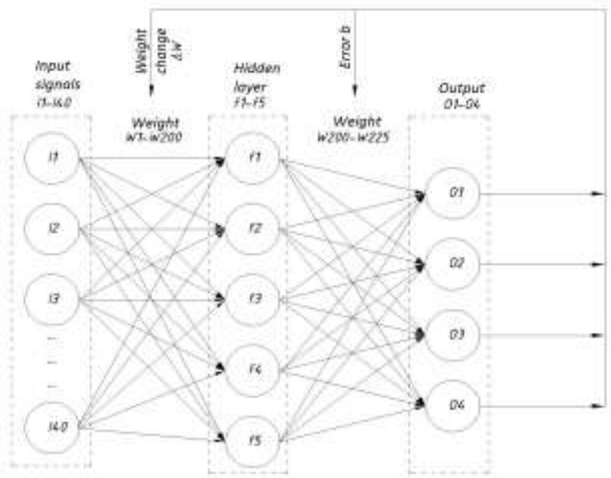

Figure 3:. Structural diagram of the neural network of back propagation of the error

The neural network is inputted by signals, which are the natural frequencies of the pipelines. From the first to the tenth input signal corresponds to a defect-free pipeline, from the eleventh to the twentieth - pipeline with a defect of 7 mm, from the twenty first to the thirtieth - 11 mm, from the thirty first to the fortieth - 15 mm.

Each synapse (connection between neurons) has a parameter - weight. Weight is responsible for changing the input parameter when transferring from one neuron to another, also weight is responsible for the priority of the neuron. That neuron, whose weight will be greater, that information will be dominant in the next neuron. On the structural scheme of the neural network of back propagation of the error (Figure 3), all input information multiplied by their weights is hidden:

$$f_{i,input} = (I_1 \cdot W_1) + (I_2 \cdot W_2) + \cdots + (I_i \cdot W_i),$$

where I_1 — is the input neuron, a W_1- is the weight.

Since the range of operating the numbers on the neural network is [0; 1] or [-1; 1], the input values ($f_{i,\,input}$) are transformed through the activation function [17]. In our case, the sigmoid activation function is used, since the range of its values is [0; 1].

Training for this neural network is based on the determination of pipeline defects, the frequencies of which were obtained as a result of experiments. When processing the data, the weights of the synapses were randomized, in subsequent calculations the weights were recalculated taking into account their gradient, and each subsequent iteration passed with updated synapse weights. To find the output neuron parameters more accurately, the minimum error percentage at which the calculation ended was 0.001. The number of processing iterations was 1085.

3. Results

Based on the obtained data, the following data were obtained from the experiment and their processing in the neural network of back propagation of the error (Table 2).

Table 2:. Results of calculations of frequency samples of free oscillations

Sample No.	Output values of a neuron №1 (defect-less)	Output values of a neuron №2 (defect 7 mm)	Output values of a neuron №3 (defect 11 mm)	Output values of a neuron №4 (defect 15 mm)
1	0,97092871	0,9618962	0,945176	0,925762
2	0,99873259	0,98693	0,9693198	0,948772
3	0,98730021	0,9800126	0,963156	0,9451093
4	0,97681356	0,971562	0,9521223	0,934956

As can be seen from the data obtained, the values of the output neurons of the pipelines tend to unity. The unit is an idealized calculation result, the output values for the defect-free pipeline are closest to this value.

It is also possible to identify the size of the defects, for neurons No. 2, 3 and 4, the output values lies further from unity. These values indicate that as the defect increases, the values of the output neurons have large deviations from unity in the direction of decrease.

4. Summary

With the help of this neural network, experimental data were processed, which were obtained in the experimental setup. The task of computing a neural network is to find an error that does not exceed the set values. After training the neural network and processing the experimental data it was possible to determine the technical condition of the pipelines.

5. Conclusions

The results of the classification of the neural network of back propagation of the error trained by the neural network showed its good ability to analyze unknown samples and a high degree of reliability of their recognition..

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