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Reducing labor input of monitoring condition of heat exchange equipment surfaces

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Reducing labor input of monitoring condition of heat exchange equipment surfaces

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Abstract. Deposits on surfaces of heat exchange equipment reduce the heat transfer coefficient, heat exchange efficiency, and lead to significant energy losses. The paper considers a hardware-software complex for monitoring the state of heat exchange surfaces. Studies were carried out using models of surfaces of heat exchange equipment – 400×160×2 mm steel plates, by the method of free vibrations. The studies have shown the possibility of using the method of free vibrations for the detection of deposits on the heat exchange equipment, which reduces energy losses and labor input of monitoring the condition of the surfaces of heat exchange equipment.

1. Introduction
The purpose of this work is to assess the possibility to control deposits on surfaces of heat exchange equipment by parameters of free damped vibrations. Thickness must be determined on the external side of the heat exchange surface while operating.

In the field of housing and communal services and industry the cases of operating heat exchangers and boilers without special water preparation are not rare. This causes scale on the internal side of apparatus and units (drums, pipes) which worsens heat exchange, and efficiency on the whole. Thermal conductivity of scale is more than 40 times lower than that of metals, so even a thin scale layer leads to dramatic decrease of thermal conductivity and increase of temperature of metallic surfaces being heated, which reaches dangerous values and reduces mechanical strength of the metal [1]. As a result, there occur damages of the metal. The problem of deposit control arises in case of operating heat exchangers of hot water supply system when the flow section of pipes and surfaces of heat exchange has been almost completely overgrown with deposits. So, when the thickness of a deposit layer is from 0,4 to 19,1 mm, the energy overrun is from 4 to 90% (figure 1).

2. Results and discussion
To reduce the energy losses is possible by means of well-timed diagnostics of surfaces of heat exchange equipment, in order to control the deposits thickness. For this you should have accessible techniques and equipment which allow monitoring in real time.

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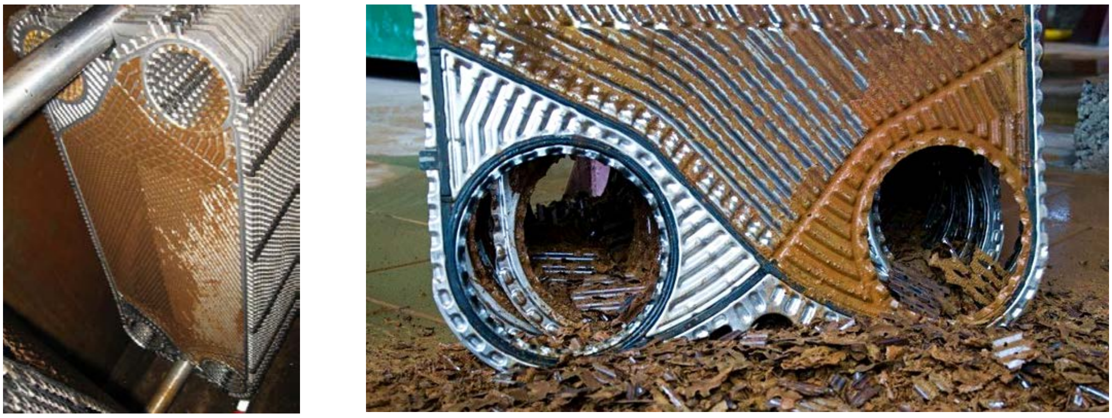

Figure 1. Flow section reduction due to deposits.

Acoustic control methods are based on measurement of physical parameters associated with the phenomenon of propagation of elastic waves in a solid [2, 3]. In the base of low frequency control methods there lies correlation dependence between elastic constants of material and physical mechanical properties of an item [4–6]. A free vibration method (FV) is based on the use of elastic properties of vibrating systems performing free vibrations. To control means to excite elastic vibrations in the object being controlled, as well as to analyze characteristics of proper vibrations of the object. The method is used to detect inner defects lying at the depth of several centimeters in massive details made of materials with a high coefficient of elastic wave attenuation. Spectrum frequency range of defective and high-quality zones of items which are usually controlled by the free vibration method lies within 0,5–20 kHz. Vibrations receiving is performed with the help of a piezoelectric receiver or a microphone [7, 8].

The authors developed a hardware and software complex which includes a device for controlling deposits thickness on heat exchange surfaces (figure 2) and two systems – registration of signals and their processing.

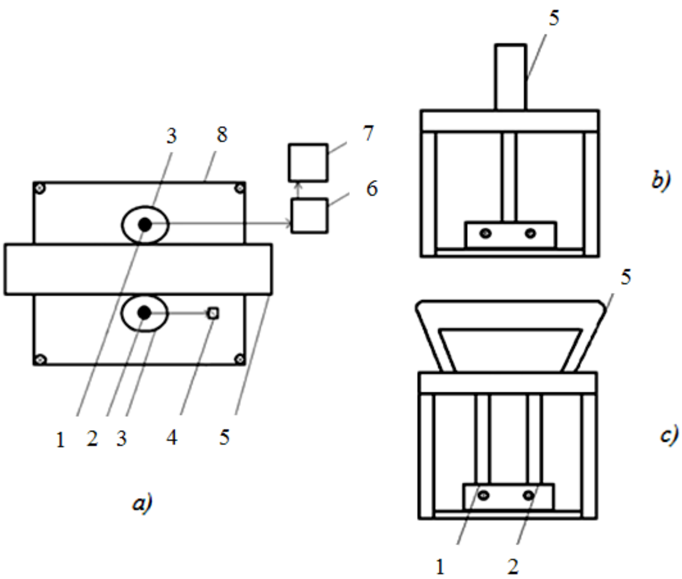

Figure 2. Device for controlling deposits thickness on heat exchange surfaces: *a*) view from above, *b*) side view, *c*) front view.

The numbers in figure 2 mark:

1 – piezoelectric sensor (microphone); 2 – hammer; 3 – openings; 4 – toggle switch; 5 – handle; 6 – analog to digital converter; 7 – computer; 8 – case.

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The registration system includes a control object (a plate being investigated) which is fixed around the perimeter, a sensor, and a hammer operated by a toggle switch. The processing system includes an analog to digital converter (ADC) and a computer with a specialized software installed on it.

The device works as follows: there are two openings, namely, a toggle switch and a handle, on the case. The handle allows the device to be replaced. In the first opening (figure 2) there is a hammer operated by the toggle switch. In the second opening there is a piezoelectric sensor connected with an ADC. The device case is placed on the first diagnosed site of the heat exchange surface. Then, at pressing the toggle switch, the hammer excites vibrations on the heat exchange surface, and the piezoelectric sensor receives an analog signal. Then the toggle switch is turned off. The constant strength of impact is provided by the abduction of the hammer at the same distance. After exciting the vibrations, the analog signal from the piezoelectric sensor goes to the ADC, at its coming out the digital signal enters the computer RAM, where, due to the special software (figure 3) written in a graphic programming environment LabVIEW of the Firm National Instruments, for which the authors obtained the certificate of state registration of a computer program [9], it is recorded, analyzed, and the sound signal is recorded.

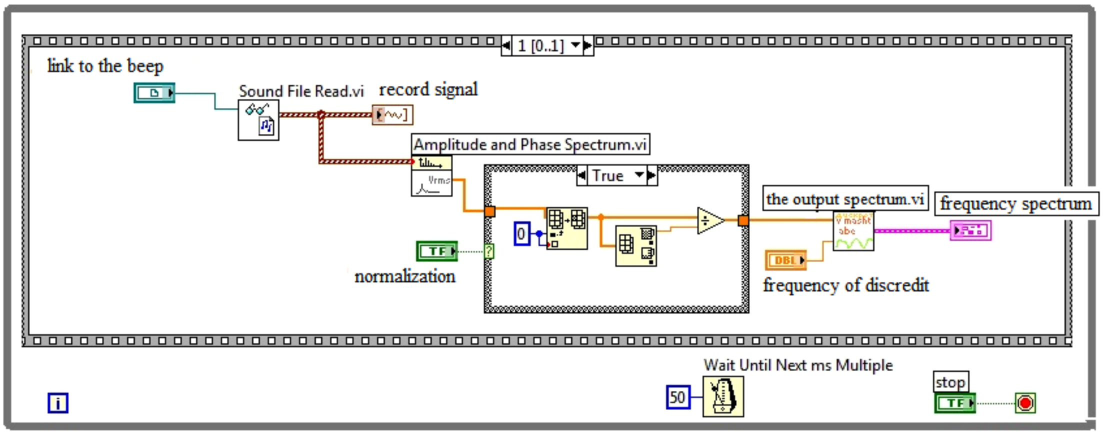

Figure 3. Part of program block-diagram.

Analysis program works as follows: signals are read, amplitude and frequency spectrum is formed for each signal, spectra are compared by correlation coefficients, the obtained coefficients related to one series of experiments are averaged, the averaged coefficients are compared with the confident interval boundary. Finally, the conclusion about the presence of deposits is made.

After diagnosing the first site, the device is replaced to the following site of the heat exchange surface.

As a heat exchange surface model, a steel plate which was 400 mm long, 160 mm wide and 2 mm thick was used. Investigations were made using a clean plate, as well as plates with various thicknesses of deposits.

While studying acoustic characteristics, the tenfold determination of frequencies of proper vibrations of the plate was being carried out for each plate type. The plate was struck, amplitude and frequencies characteristics of the response were measured by the microphone located in the control point.

After the experimental series a layer of deposits was placed on the plate, and investigations were repeated [10].

Figure 4 shows the example of the recorded signal and its amplitude spectrum, figure 5 gives the example of the current spectrum, the reference one, and the difference between them [11]. The plate with deposits is presented by the current spectrum, the clean one is presented by the reference spectrum.

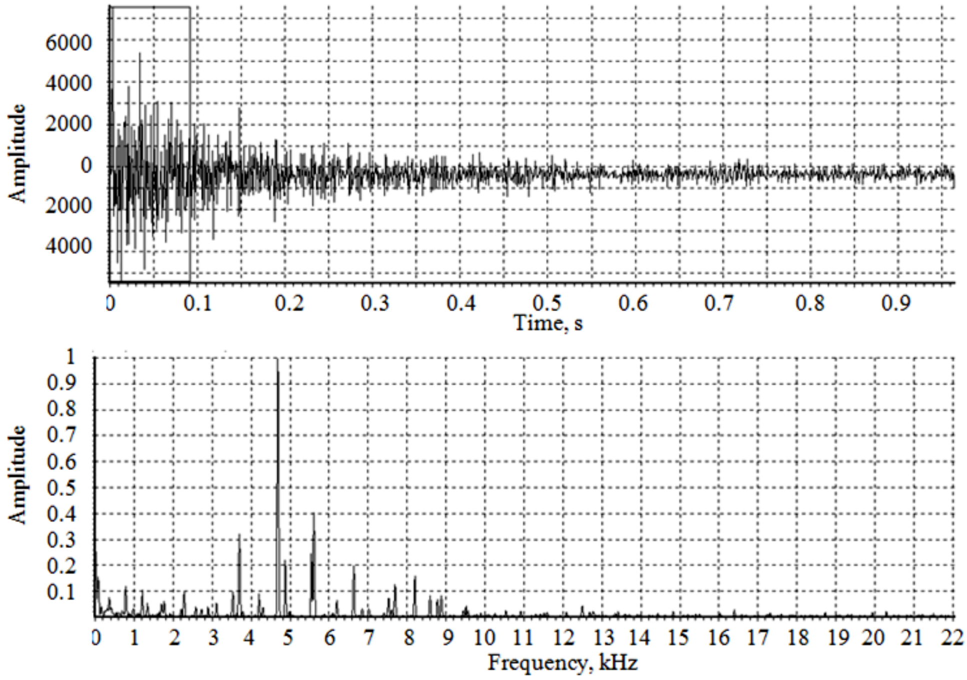

Figure 4. Signal and its amplitude spectrum.

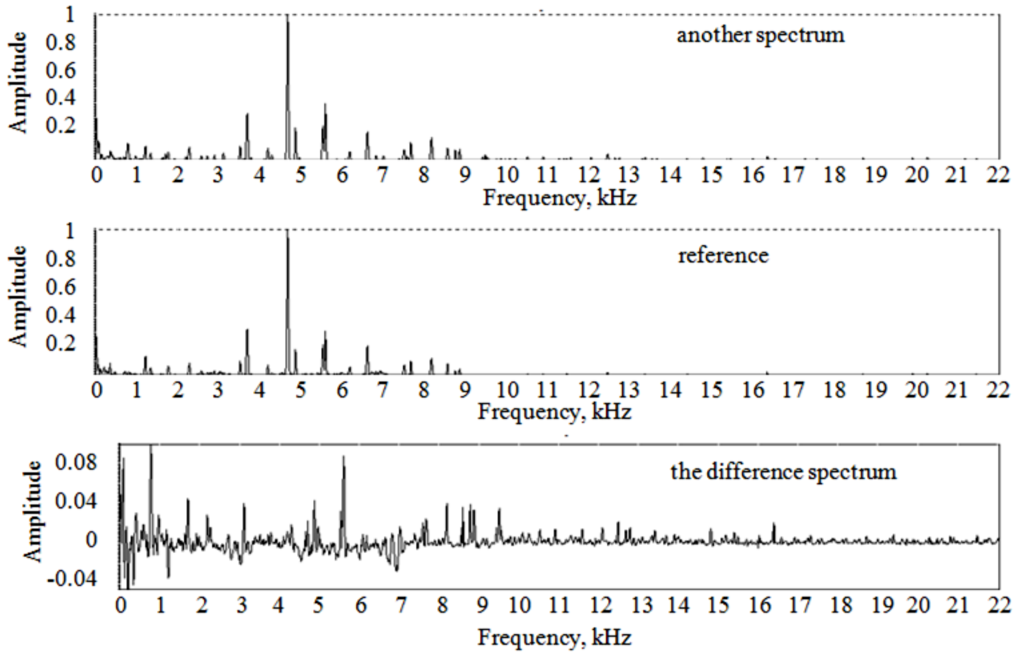

Figure 5. Example of current spectrum, reference spectrum and difference between them.

Criteria used for comparison, such as the Spearman Correlation Coefficient (figure 6) and the Fisher Sign Statistics (figure 7) showed that their values were in the confidence interval P = 0.95, which was constructed by each criterion.

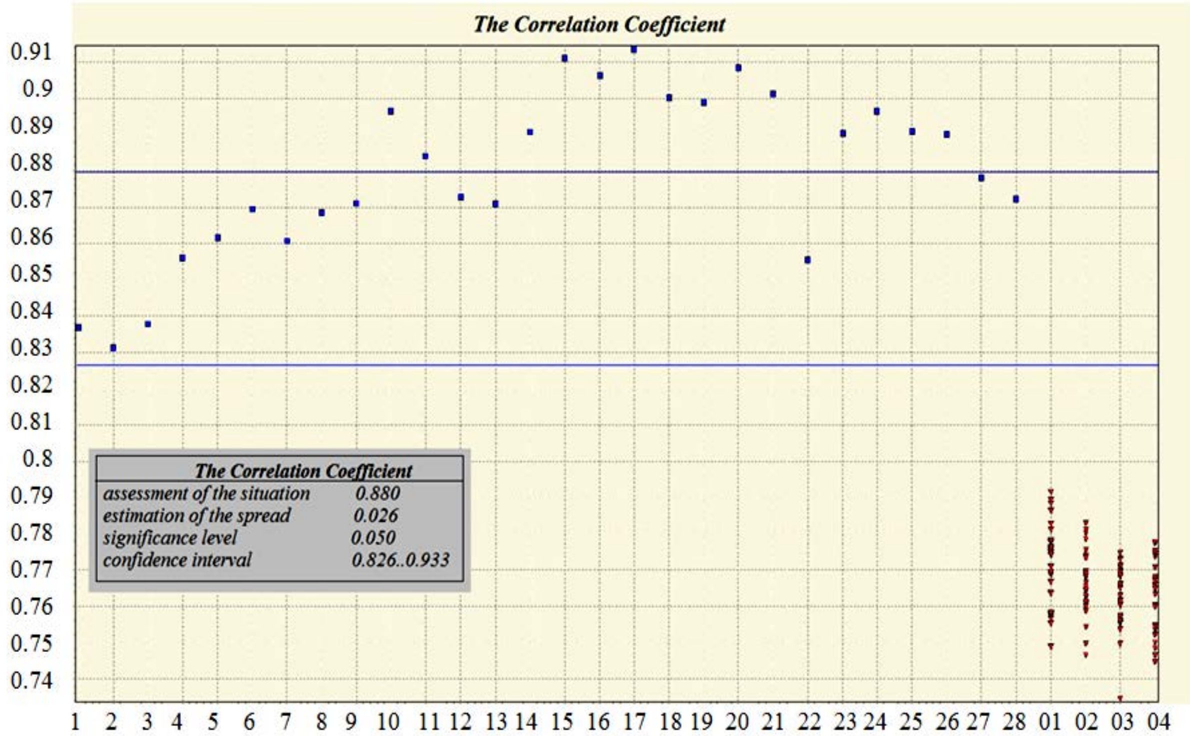

Figure 6. Spearman Correlation.

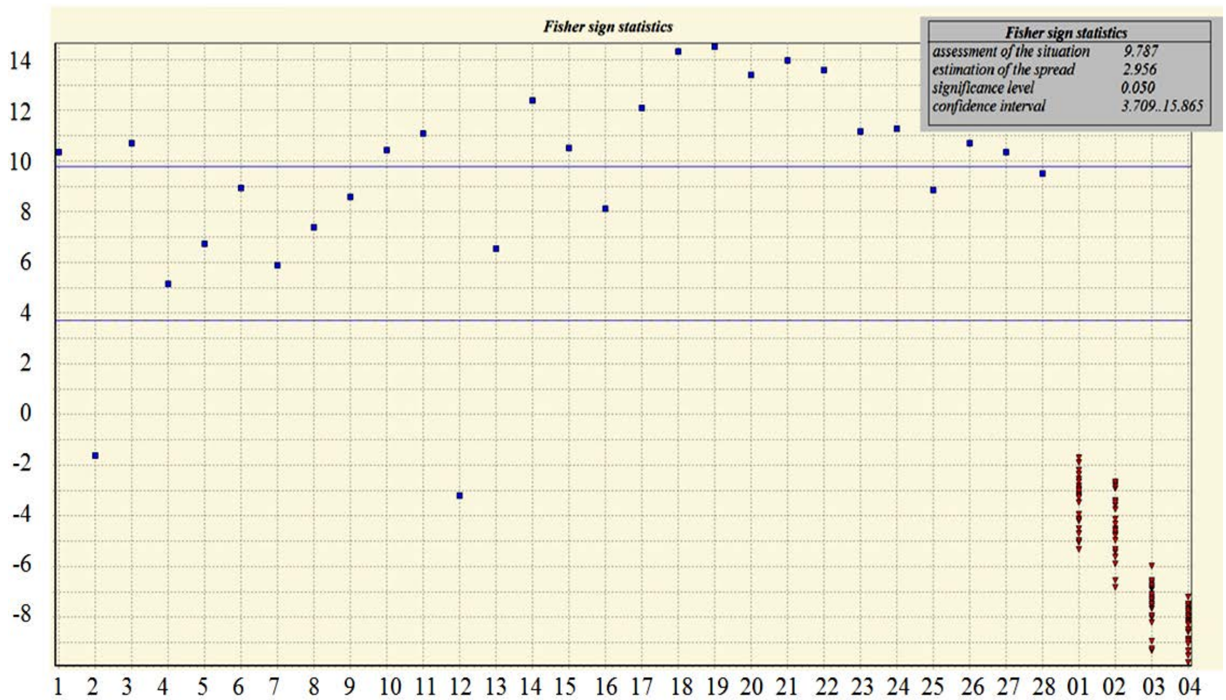

Figure 7. Fisher statistics.

Spearman nonparametric ranking is found:

$$r = 1 - \frac{6}{n\ (n^2 - 1)} \sum_{i=1}^{n} (ranka_i\ -\ ranka_{si})^2\ ,$$

where *rank* a_i – rank of amplitude a_i in the variation row of amplitudes of the checked spectrum (i.e. the number of the place which this amplitude takes among all amplitudes of the given spectrum sorted in ascending order); *rank* a_{si} – the same for the reference spectrum.

Fisher sign statistics S is calculated as the number of frequencies of positive amplitude of the difference spectrum (half of the number of frequencies of zero amplitude is added to this sum).

The analysis of spectra of plates vibrations shows that the presence of deposits on the plate surface significantly changes its spectrum of proper vibrations in the range from 20 Hz to 10 kHz. The obtained results showed that the method of free vibrations of the plate with deposits at the experimental complex provided the preset accuracy and reliability, this makes it possible for the method to determine the thickness of deposits of heat exchange equipment.

3. Conclusion

The studies showed the possibility to use the method of free vibrations to detect deposits on heat exchange equipment thanks to the developed hardware and software complex which allows to reduce the labor input of monitoring the condition of surfaces of heat exchange equipment.

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