Method of assessing the thermal state of the heat transfer surfaces

E R Saifullin¹, Yu V Vankov², E V Izmaya³, E R Bazukova³

¹Kazan Federal University, 18 Kremlyovskaya str., Kazan 420008, Russian Federation
²Kazan state power engineering university, 51 Krasnoselskaya St., Kazan , 420066, Russia

yvankov@mail.ru, evgeniya-izmailova@yandex.ru

Abstract. One of methods of increase in efficiency of the heat exchange equipment is timely detection of a sludge formation and scum on heat exchange surfaces. Deposits of salts and products of corrosion from technical water on the surface of heating of heat exchange devices reduce coefficient of a heat transfer and efficiency of heat exchange that leads to a considerable overexpenditure of energy carriers, overheating of surfaces of heating of coppers, decrease in service life, increase in costs of service and repair of the heat exchange equipment. Reliable methods and control devices of intensity of formation of deposits in the heat exchange equipment don't exist now. In work the method the express of control of thickness of deposits on heat exchange surfaces allowing to make control of a thermal condition of heat exchange surfaces is offered and in due time to carry out washing of devices.

1. Introduction
Deposits of salts and products of corrosion from technical water on the surface of heating of heat exchange devices reduce heat transfer coefficient, efficiency of heat exchange and as a result there are essential losses of energy [1, 2].

At power stations at the growth rate of deposits on the heat exchange surfaces of turbines condensers from technical water from 0,5 to 3 mm/year there is a decrease in power production from 120 to 250 million kWh or from 1,7 to 3,47% respectively for 1000 MW of rated capacity [3].

The cost of replacement of heat exchangers and coppers tubes insignificantly is less than the cost of the new equipment. Existence of deposits on the surface of heat exchange in coppers considerably reduces their efficiency (see Table 1). So, existence of 1 mm of deposits increases fuel consumption approximately by 12% [4].

| Thickness of a scum layer (mm) | 0.4 | 0.8 | 1.6 | 3.2 | 4.8 | 6.4 | 9.6 | 12.7 | 15.9 | 19.1 |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Excessive consumption of liquid fuel on 1000 l | 40  | 70  | 110 | 180 | 270 | 380 | 480 | 600 | 740 | 900 |
| Excessive consumption of coal on 1 t | 80  | 140 | 220 | 360 | 540 | 760 | 960 | 1,200 | 1,400 | 1,800 |
In housing and communal services and the industry cases of operation of heat exchange devices and package boilers without special preparation of water aren't rare. It leads to formation on the internal surface of devices and units (drums, tubes) of the scum worsening a heat transfer and in whole reducing the efficiency of installations. Heat conductivity of a scum of metals more than 40 times lower than heat conductivity. Therefore even the thin layer of scale leads to sharp decrease in heat conductivity and temperature increase of metal surfaces of heating which reaches dangerous sizes and reduces the mechanical durability of metal. Metal damages are a consequence of it, namely - emergence it is made bulge out, fistulas, and it is frequent also ruptures of pipes of boilers.

At high content in water the scum-forming salts and products of corrosion the settlement operating mode of heat exchangers is quickly broken. Most heat exchangers of tap water are subject to pollution. The polluted heat exchangers have an increase in an expense of the heat carrier and growth of temperature in the return pipeline that, in turn, leads to electricity consumption growth by pumps and thermal losses in pipelines. Restoration of a settlement operating mode requires an eduction of heat exchangers from operation and cleaning of the polluted surfaces.

The serious problem of fight against deposits arises in heat exchangers of hot water supply when the section of pipes through passage and the surfaces of heat exchange almost completely grows with deposits (Figure 1).
Overgrowing by deposits of pipelines of thermal systems including reverse water supply, leads to significant increase in their hydraulic resistance, maladjustment of heating systems and big power losses by pumping of system.

There is similar situation with power losses from deposits in air conditioning systems (Table 2).

**Table 2.** Losses from deposits in air conditioning systems depending on layer thickness

| Thickness of a scum layer (mm) | 0.5 | 1 | 2 | 4 | 6 | 8 | 10 | 12.7 |
|-------------------------------|-----|---|---|---|---|---|----|------|
| Decrease of the conditioner power | 5% | 9% | 17% | 23% | 29% | 34% | 50% | 56% |
| Increase of temperature at the exit from the evaporator (°C) | 0.4 | 0.8 | 1.6 | 3.2 | 4.8 | 6.4 | 8 | 10 |
| Electric power over expenditure | 5.8% | 10.6% | 20.2% | 29.4% | 35.6% | 46.8% | 66% | 76% |

It is possible to reduce power losses by timely cleaning of internal surfaces of a scum and deposits.

For this purpose it is necessary to have a reliable, available technique and the equipment for control of thickness of deposits.

Research objective: Decrease in power losses in the heat exchange equipment by control of thickness of deposits on the surfaces of heat exchange.

2. Methods

Reliable methods and control devices of intensity of deposits formation in the heat exchange equipment don't exist now.

Now acoustic methods of a research and tests of materials of products and constructions widely develop [5-7].

Low-frequency acoustic methods of nondestructive testing significantly differ from the ultrasonic methods which are also using elastic fluctuations and waves. These distinctions consist in other physical principles, scopes, range of working frequencies, designs of converters, etc.

The correlation dependence between elastic constants of material and physicomechanical properties of products is the basis of low-frequency control methods. There are following ways of excitation of oscillations in a product:

1) shock excitation;
2) continuous excitation. The block diagram of the devices realizing low-frequency control methods is provided on Figure 2 [8,9].

![Block Diagram](image)

**Figure 2.** The block diagram of the devices realizing low-frequency control methods

In the first case (Figure 2, a) at blow to a surface of a controlled product arise mechanical oscillations which will be transformed to an electric signal by the sensor, amplify, pass through the filter allocating from a range of the frequencies of own fluctuations (FOF) that, corresponding to the type of fluctuations chosen for registration and are registered a frequency counter. At a method of the compelled fluctuations (Figure 2, b), the electric fluctuations created by the generator with the changing frequency will be transformed by means of the converter to mechanical and transferred to a controlled product. Fluctuations of a product are accepted by the sensor, amplify and move on the indicator of a resonance which fixes the moment of coincidence of frequency of the generator with measured by the device of FOF frequency counter, a controlled product, and on previously received dependences, physicomechanical properties of a controlled product are defined [10].

Two absolutely identical bodies have identical own frequencies. Existence of deposits changes thickness, mass of surfaces of heat exchange, therefore, and own frequencies of fluctuations. Having "the acoustic passport" of a new product, knowing the current frequencies of fluctuations of controlled surfaces it is possible to determine thickness of deposits. For definition of a frequency range of fluctuations of products it is offered to use a finite element method.

3. **Accounting of interaction of a controlled design with the device equipment**

For increase in sensitivity of a technique of control it is desirable to force to fluctuate only the site of a design explored at present. It can achieve by means of the damping frame pressed to a design. After a frame clip to a design on area, the limited frame, strikes blow and in the same place the sensor fluctuations are registered.

Let’s write down the equation of the movement taking into account interaction of a design with a frame:

\[
\begin{bmatrix} M & \frac{\partial^2 q}{\partial t^2} \end{bmatrix} \begin{bmatrix} \frac{\partial q}{\partial t} \\ \frac{\partial^2 q}{\partial t^2} \end{bmatrix} + \begin{bmatrix} C \\ \frac{\partial^2 q}{\partial t^2} \end{bmatrix} + \begin{bmatrix} K \end{bmatrix} \begin{bmatrix} q \\ \frac{\partial q}{\partial t} \end{bmatrix} + \begin{bmatrix} M_r \\ \frac{\partial^2 q_r}{\partial t^2} \end{bmatrix} + \begin{bmatrix} C_r \\ \frac{\partial q_r}{\partial t} \end{bmatrix} + \begin{bmatrix} K_r \\ \frac{q_r}{t} \end{bmatrix} = P_0(t) \quad (2)
\]

where \( M, C, K \) - matrixes of masses, damping and rigidity of a frame of the device; \( \frac{\partial^2 q}{\partial t^2}, \frac{\partial q}{\partial t}, q \) - vectors of accelerations, speeds and amplitudes of a frame knots, \( M_r, C_r, K_r \) - matrixes of masses, damping and rigidity of a construction; \( \frac{\partial^2 q_r}{\partial t^2}, \frac{\partial q_r}{\partial t}, q_r \) - vectors of accelerations, speeds and amplitudes of constructions knots.

Let’s consider a subvector from \( \frac{\partial^2 q}{\partial t^2}, \frac{\partial q}{\partial t}, q \), corresponding to contact knots. Let’s designate
them $\frac{\partial^2 q'}{\partial t^2}, \frac{\partial q'}{\partial t}$ and $q'$. At small value of force of a clip $P_{cm}$ of a frame to a construction there is

$$\frac{\partial^2 q}{\partial t^2} \neq \frac{\partial^2 q_e}{\partial t^2}, \frac{\partial q}{\partial t} \neq \frac{\partial q_e}{\partial t}, q' \neq q_e,$$

then the equation (2) breaks up to two equations:

$$[M] \begin{bmatrix} \frac{\partial^2 q_e}{\partial t^2} \\ \frac{\partial q_e}{\partial t} \end{bmatrix} + [C] \begin{bmatrix} \frac{\partial q_e}{\partial t} \\ \frac{\partial q}{\partial t} \end{bmatrix} + [K_e] \begin{bmatrix} q_e \\ q \end{bmatrix} = P_{cm} + P_r(t)$$

and

$$[M] \begin{bmatrix} \frac{\partial^2 q}{\partial t^2} \\ \frac{\partial q}{\partial t} \end{bmatrix} + [C] \begin{bmatrix} \frac{\partial q}{\partial t} \\ \frac{\partial q}{\partial t} \end{bmatrix} + [K] \begin{bmatrix} q \end{bmatrix} = P_0(t) - P_{cm} - P_r(t),$$

the size $P_{cm}$ of influence doesn't render on dynamic amplitudes, and $P_r(t)$ - dynamic loading is caused by change in time of a contact zone of a frame and a construction. In other words, there is "beating" or "jingle". It is difficult to define concrete character of this loading, however it is possible to estimate her influence on design amplitudes. For this purpose let's notice that action of force $P_r(t)$ is directed to damping of knots fluctuations in a contact zone. And increase in $P_{cm}$ leads to increase in damping of these knots. In this regard, it is necessary to conduct a research of influence of increase in coefficients of damping of separate knots (local) of model on coefficients of damping of forms of own fluctuations. The ratio can be used for this purpose:

$$2 \times \xi_n \times \omega_n = q'_n \times C \times q_n,$$

where $\xi_n$ - coefficients of modal attenuation; numerical values of these coefficients directly depend on a force, pressing a frame.

With the certain force of a clip $P_{cm}$, we receive:

$$\frac{\partial^2 q'}{\partial t^2} = \frac{\partial^2 q_e}{\partial t^2}, \frac{\partial q'}{\partial t} = \frac{\partial q_e}{\partial t}, q' = q_e.$$

Then the equation (2) is given to standard record:

$$[M + M_e] \begin{bmatrix} \frac{\partial^2 q_e}{\partial t^2} \\ \frac{\partial q_e}{\partial t} \end{bmatrix} + [C + C_e] \begin{bmatrix} \frac{\partial q_e}{\partial t} \\ \frac{\partial q}{\partial t} \end{bmatrix} + [K + K_e] \begin{bmatrix} q_e \\ q \end{bmatrix} = P_0(t).$$

I.e., there is "gluing" of a frame to a design that involves change of the rigidity and weight making fluctuation, constructions and, as a result, change of frequencies and forms of fluctuations. At a certain ratio of a frame and a construction rigidity happens effect of hinged fixing of a construction in contact knots that allows reducing borders of the studied range of fluctuations significantly.

4. Conclusion
Preliminary calculations have shown that the offered method allows to find thickness of deposits in 0,5 mm. Carrying out further researches will allow to define such parameters as thickness, structure, porosity and heat conductivity of deposits.

Realization of the offered control method of thickness of deposits on heat exchange surfaces will give essential energy saving effect.

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