Measurement of fluid pressure through the pipeline wall in heat and power processes

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Abstract. Pressure is one of the key parameters in the operation of technological systems of heat and power processes. The creation of a device that would allow measuring the pressure inside the pipeline without violating its integrity, stability, tightness and would not affect the coolant will significantly simplify the maintenance of heat and power systems and improve the efficiency of their operation. The team of authors has formed a hypothesis according to which it is possible to obtain the pressure value based on the rate of stabilization of temperature flows in the heat pipe. It is assumed that the pressure can have a sufficient effect, for registration by instruments, on the dynamic characteristics of thermal processes occurring inside thermal power systems.

1. Introduction
Pressure control in a heat and power system is an essential condition for their stable operation, and the quality with which pressure control is carried out depends on the efficiency and environmental friendliness of the enterprise. It is especially important for thermal power facilities that provide consumers with coolant for heating and hot water supply through heat supply systems [4-8].

For example, for the correct operation of these systems, it is necessary to periodically carry out maintenance and adjustment work, without causing inconvenience to the population. The peculiarity of carrying out regime and adjustment work in heat supply systems is to compare the calculated characteristics of the system with the actual ones and then use the refined calculation models to optimize the flow distribution, in particular, using specialized software. High-quality performance of regime and adjustment works allows to reduce the cost of energy resources in heat supply systems by an average of 10%.

For complex hydraulic systems, the process of comparing the calculated characteristics with the actual ones encounters the uncertainty of the hydraulic resistances of the elements of a real system. The hydraulics of a real system is influenced by many factors, such as the quality of the coolant, the quality of the pipe material, the service life, etc. The set of factors and the intensity of their influence are always random. The only way to obtain adequate data on the hydraulic resistance of an operating pipeline is to experimentally check the pressure drop across a section of the system with a known flow rate of the coolant. For this, just, it is necessary to know the exact value of pressure at various points of the pipeline system. In practice, it is practically impossible to obtain comprehensive data on pressure at all necessary points due to the lack of measuring instruments in them. There are two ways to solve the problem of the lack of measuring instruments:
• Stop the system, drain the coolant, mount the welding adapter and install a pressure gauge through the impulse tube and the three-way valve.
• Resort to an event called: "Push under pressure." The essence of tapping under pressure is to drill the pipe body through a pre-mounted weld-in adapter (or a specialized clamp) with a ball valve.

The first way is associated with a violation of the quality of heat supply and the economic costs of filling the system, and is most often implemented during the period of scheduled repair work. The second way is not safe, especially when implemented at thermal power facilities. As a result, heat power specialists sacrifice the number of measuring instruments in favor of reliability and uninterrupted heat supply.

The described difficulties in obtaining comprehensive data on pressure do not allow comparing the design characteristics of the system with the actual characteristics for all elements of the system, which leads to a decrease in the reliability of the calculation models and a deterioration in the quality of operational and commissioning work.

The creation of a device that would allow measuring the pressure inside the pipeline, without violating, at the same time, its integrity, would significantly simplify and improve the quality, not only of carrying out maintenance and adjustment work in heat supply systems, but would also improve the operating efficiency of many other enterprises.

2. Materials and methods

There are a number of devices for non-contact pressure measurement in pipelines that implement various physical and mechanical approaches aimed at recording changes in certain parameters of the pipeline material, which can potentially be interpreted into the pressure of the medium in the pipeline.

One of these devices is described in RF patent 2098782, IPC G01L9/04 [10]. The patent discloses a method for measuring pressure using a special measuring system. The described system consists of several windings, measuring and compensating, made of tensometric sensing elements. The patent gives an example of a measuring winding consisting of 20 turns of constantan wire with a diameter of 0.8 mm with a total resistance of 400 ohms, and an example of a compensation winding with equivalent resistance. Options for laying windings on the pipeline are shown in figure 1.

According to the description from the patent, the constantan wire is wound with an interference fit in the form of a loop lattice or in a spiral around the pipeline. A prerequisite for winding the measuring wire loop is the presence of a solid insulating layer between the surface of the pipeline and the wire.

![Figure 1. Options for laying the measuring winding of the strain gauge sensing element on the pipe, on the left is a looped lattice, on the right is a spiral, where: 1 - measuring winding.](image-url)
Correctly performed winding should provide sufficient tightness of the winding to the insulated pipe wall, which will ensure the joint deformation of the pipe wall and the measuring winding in the radial direction in the entire range of working and pressing pressures of the pipeline. The measuring winding and parts of the compensating winding are connected in a bridge circuit and covered with insulation from the outside to protect against moisture and mechanical damage.

Deformation of the pipe wall under the influence of pressure leads to deformation and a change in the electrical resistance of the measuring winding constantan wire relative to the resistance of the compensation winding. The difference in resistance with the help of a computer is converted into a specific pressure value. The transformation is carried out using the author's mathematical model.

The disadvantage of this device is that in the process of converting deformations into a signal, it is necessary to take into account the characteristics of the materials from which the pipes are made, as well as tolerances for their manufacture, which is not always possible. As a result, the measurement error can exceed 50%. Features of functioning also determine the sensitivity of the sensor, which is 100 kPa.

Another interesting example of a device for measuring pressure without violating the integrity of the pipeline is the device described in RF patent 2470274, IPC G01L11/00 [9]. The device also relates the pressure to the deformation of the pipeline material, however, unlike the previous invention, this connection is realized through a change in the natural resonant frequencies of the pipeline. To determine the natural resonant frequencies of the pipeline, the authors of the invention formed a software and hardware complex, which is based on a microprocessor-based spectrum analyzer with a resolution of 30–70 Hz, combined with a fast Fourier transform algorithm. For the operation of the software and hardware complex, vibration sensors with buffer amplifiers are installed on the pipeline. The sensors are installed sequentially at a fixed distance from each other. The authors estimate the necessary distance between the sensors at several kilometers. The spectrum of the signal from the vibration sensors is converted by the algorithm into natural resonant frequencies of the pipeline, from which the pressure in the pipeline is calculated.

The disadvantage of this device is its low mobility and significant capital costs for the organization of the control room and the laying of networks of cable lines. The time spent on installing vibration sensors and laying cable lines varies from 4 to 12 hours. The pressure measurement accuracy is about 1% of the measurement range of 25 MPa.

It is possible to eliminate the shortcomings by switching to other methods of pressure registration.

3. Results and Discussion

A team of authors has formed a hypothesis according to which it is possible to obtain the pressure value based on the rate of stabilization of temperature flows. It is assumed that the pressure can have a sufficient effect, for registration by instruments, on the dynamic characteristics of thermal processes occurring inside pipeline systems.

It means that the change in thermal inertia, in a particular section of the pipeline, expressed through the dynamics of changes in the temperature field, at a known flow rate, will allow us to describe the pressure as a function of thermal inertia. In the theory of heat and mass transfer, there is no such statement of the problem [1-3], it is new and does not have a ready basis for theoretical substantiation, however, this hypothesis can be confirmed experimentally.

To confirm the hypothesis, a prototype device for measuring pressure through thermal inertia is created, which is a heat-insulated vessel filled with liquid nitrogen, with a contact area cooled to a temperature close to -196°C (figure 2). The device takes current temperature readings by means of thermoelectric converters, which are connected to the contact area. The signal from thermoelectric converters is output to a computer through an analog-to-digital converter (ADC).

The operation of the device is implemented as follows. When the device and the pipeline wall come into contact, due to the cooled contact area, the thermal equilibrium is disturbed at the point of contact and the device initiates a transient process, which will be characterized by the transfer of heat from the pipeline wall and the liquid that flows in the pipeline to liquid nitrogen through the heat-
conducting element. Starting the transient process will allow registering the temperature change in the contact area and investigating the behavior of the temperature field during the stabilization of the transient process.

Based on the hypothesis, we can say that pressure, other things being equal, will be able to influence the process of stabilizing the temperature regime of the "device-pipe" system, and this will be reflected in the graph of the dynamics of temperature changes in the contact area (figure 3).

**Figure 2.** The design of a heat-insulated vessel with a contact area, where: 1 - vessel body, 2 - heat-insulating cavity, 3 - nitrogen tank, 4 - heat-conducting element, 5 - contact area with holes for thermoelectric converters.

**Figure 3.** The expected change in readings that can be obtained from thermoelectric converters in the contact area at different liquid pressures in the pipeline.
The device prototype consists of four elements:

- A vessel with a contact area cooled by liquid nitrogen.
- Thermoelectric converters fixed in the body of the contact area.
- Module for analog-to-digital signal conversion.
- Computer connected to the ADC module.

The signal converted by means of the ADC is transmitted to a computer that meets the recommended system requirements for the ADC software.

To test the developed experimental pressure measurement system, without violating the integrity of the pipeline, a test bench was developed that simulates a hydraulic system with the possibility of changing the flow rate inside the pipeline, while maintaining a constant pressure. Currently, work is underway to confirm or refute the hypothesis.

4. Conclusion
Further study of thermal processes in the prototype will make it possible to create a device that can significantly improve the operation of many industrial enterprises, and therefore increase their efficiency, environmental friendliness and economy, which will positively affect the quality of life of the population and working conditions at enterprises.

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