Improvement technology of measurement of the flow of fluid hydrocarbons

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Abstract. Russian Federation is a world leader of oil production and has the world's longest system of oil pipelines. Therefore, there is a perfect fleet of technological equipment to meet the global trends in this industry. The oil and gas equipment market in Russia is widely represented by foreign and domestic manufacturers, the obvious challenge is to increase the share of Russian-made devices and, first of all, creation of their own technologies of measurement and monitoring.

This project is devoted to the creation of a device for measuring oil flow in the pipeline. The innovative design of the device is a set of straight-line oscillating tube, optical sensors based on the Michelson interferometer, analog-digital machine vision module and high-performance computer system. This technological solution allows to accurate mass oil flow measurement.

Development of the project is carried out in conjunction with the oil and gas equipment plant of JSC "HMS NEFTEMASH". Now, the concept of the measuring complex has been worked out, engineering and design documentation has been prepared and the test piece is being created. In addition, the patent RU 179 411 U1: "Device for measuring the flow of fluid and gas" was obtained by the team of authors.

1. Introduction

The oil and gas producing industry plays an important role in maintaining the economic independence of the country, so the tasks aimed at developing its own material and technical base of devices and technologies for the petroleum industry do not lose their relevance. Among other technological equipment in the industry, petroleum product metering systems play a key role, because the accurate measurement of the amount of oil product flowing through the pipeline at the place of its production, recycling points or oil transshipment for export carries the most important function of commercial accounting. Deviations and inconsistency of meter readings by interest share on the scale of products’ millions of tons accumulate significant financial costs. Requirements for metering devices include high accuracy, compliance with current trends in technology, easy integration into existing measuring systems and components, the availability of convenient and understandable visual and software interface produced in the Russian Federation mainly by domestic components.

The research is devoted to the development of a modular measuring complex for measuring the mass fluid hydrocarbons flow, which has the necessary qualities and characteristics. The complex operating principle is based on the Coriolis Effect, which arising in the fluid flow under the external forces influence; it allows to directly measure the mass flow, bypassing the preliminary calculation of the volume flow and the mathematical transformation of the volume flow into mass.

For the first time in the design of the device, a set of components is proposed: a linear measuring oscillating tube, optical recording devices operating on the Michelson interferometer principle, an
2. Methods and materials

Original technology that allows direct measurement of the hydrocarbons mass flow from the analysis of the measuring tube vibrations starting from the value of \( \approx 10^{-6} \) meters was described in the research.

Figure 1 shows a functional diagram of an interference Coriolis flowmeter. The modular measuring complex includes a housing (2) with attachment flanges (3), a straight-line measuring tube (1) built between the flanges, which makes forced sinusoidal oscillations under the action of an electromagnetic drive (4) consisting of a coil and a magnet, optical sensors which were made in the form of a Michelson interferometer (5) placed in the case at two different points relative to the measuring tube, and a signal converter (6).

![Figure 1. Model of the measuring system.](image)

The device works as follows: when the fluid moves through the measuring tube, which is under the influence of forced force, there is a Coriolis Effect. The Coriolis force, at every moment of time, acts in the opposite direction from the tube section movement. As a result, the force acting on the side of the fluid in the inlet half of the tube impede the tube division displacement, and contributes to the entrance part, so there is a difference in the positions of the pipe divisions at one time, therefore, there is an asynchronous oscillations of these divisions [1].

The developed sensors, due to their design, allow to fix the phase difference of sinusoidal oscillations of the two points of the measuring tube on the input and output sides [2]. The time difference between sensor signals is directly proportional to the flow rate of fluid hydrocarbons. Hence, the more the phase shift between signals, the more the mass flow. Thus, the flow rate is determined by measuring the time delay between the signals of optical sensors.

The operation of the sensors is based on the optical interference method. Light interference is a redistribution of light intensity because of superposition of several coherent light waves. This phenomenon is accompanied by the maxima and minima of intensity in space. Its distribution is called interference pattern. The location of the interference fringes depends on the wavelength and the path difference of the rays. For a given wavelength of the radiation source by the type of interference pattern or the displacement of the bands in the picture, accurate distance measurements are made. The interference method allows measuring the distance change from \( 10^{-6} \) meters with very high accuracy.

The basis of the optical sensor (figure 2) is the Michelson Interferometer, which registers the micro-oscillations of the measuring tube.
Figure 2. Operation scheme of the optical sensor.

The sensor consists of a laser beam source (1), a beam splitter (2), and a fixed mirror (3), a movable mirror (4) fixed to the pipeline division (5), a lens (6).

The light beam emanating from the laser radiation source (1) is divided into two equal beams by means of a beam splitter (2), with one of these beams passing the way to a fixed mirror (3), and the second to a movable mirror (4) fixed on the measuring tube (5). Under the influence of electromagnetic drive and fluid flow in the measuring tube, its division changes its position in space, thus changing the position of the moving mirror; therefore, the second beam passes a path different from the path of the first beam. Further, the beams are collected into one with the help of a beam splitter, these beams are already able to interfere with each other and, when applied, represent an interference pattern. When passing through the lens element (6), the interference pattern increases and enters the camera lens (7).

When the measuring tube oscillates, its division, as well as the movable mirror fixed on it, has a different position in space at each time, this leads to changes in the interference, namely, a shift of the bands. By the number of displaced bands it is possible to determine the distance by which the tube division moves from the equilibrium position (the tube equilibrium position is the tube position in space, when it is not affected by an electromagnetic drive and in which there is no moving fluid flow) and to plot the sinusoidal oscillations of this division. These data are paramount in the calculations when determining the mass flow rate of the substance.

The flow meter SOFTWARE, shown in figure 3, is developed in LabVIEW 2014 (National Instruments), using Vision and Vision Acquisition modules.
With the help of machine vision modules, the signal of optical sensors is analyzed with subsequent mathematical processing and calculation of the number of passed bands, as well as the speed of their passage and, accordingly, the flow rate of the fluid.

An important task in the development of the SOFTWARE was to accurately determine the boundary of the interference pattern band and its further tracking. To do this, the image obtained from the camera goes through several stages of processing and then converted into a binary data array in which the illuminated areas of the picture are a logical zero, and unlit - unit. Then, using the ROI tool, the most significant part of the picture is selected, which is divided line by line and the number of zeros and ones (light and dark pixels) is calculated in each line.

This information is displayed on the graph in the upper part of the screen on the front panel of the program, shown in the figure 4.
After that, the graph is analyzed, in which each point is compared with the preset value. The sequence of two points, one of which is greater than the preset value, and the next is smaller and is the lower boundary of the desired line of the interference pattern. The preset value is necessary to avoid false alarms caused by image noise. Thus, knowing the change in the position of the band between two frames and the time between them, you can easily determine the speed of the band, as well as the number of lanes for a certain time.

Since the mass flow rate is determined from the resonance frequency of the tube (depends on the constant geometric characteristics, material, etc.), the challenge is to determine the displacement of the tube, which also depends on the resonance frequency of the tube.

The mathematical description is based on the model of forced flexural vibrations of a pipeline with a fluid flow. The traditional model of bending vibrations takes into account the centrifugal and Coriolis forces caused by fluid motion and pipe bending and is described by a linear problem. The basic equation used in this model as follows:

\[ EJ \frac{\partial^4 w}{\partial x^4} + (m_1 + m_2) \frac{\partial^2 w}{\partial t^2} + m_2 U^2 \frac{\partial^2 w}{\partial x^2} + m_2 2U \frac{\partial^2 w}{\partial x \partial t} = f(x,t), \]

The flow gives two additional terms: the fourth term (which is proportional to the first degree of velocity) and the third term (which is proportional to the square of velocity).

The solution of the original equation is a dimensionless displacement value expressed from the equation [3]:

\[ \xi(\Omega, \omega) = A(X_0, X) + \frac{B(X_0, X) + C(X_0, X i \hat{U})}{-\Omega^2 + \Omega_2^2 (1 + i \varepsilon)}, \]

\[ A(X_0, X) = \frac{1}{-\Omega^2 + 1 K_1}, \]

\[ B(X_0, X) = \frac{1}{K_2} \Phi_1(X_0) \Phi_2(X), \]

\[ C(X_0, X) = \frac{D_1}{K_1 K_2 (-\Omega^2 + 1)} \times [\Phi_2(X_0) \Phi_1(X) - \Phi_1(X_0) \Phi_2(X)]/\Omega^m M \]

\[ \hat{U} = \frac{2U}{\omega_1^2} = \frac{6 U L}{C_1^2 C_2^2} \sqrt{1 + \frac{1}{2} \rho \frac{d}{\varepsilon}} \] – normalized flow rate, \( \Omega, \Omega_2 \) – frequency, \( \Phi_1, \Phi_2 \) – displacement field.

It can be said that the most effective method of measuring the displacement of tube vibrations near the second resonant frequency, since it gives the greatest contribution. When working near the second resonance frequency, we are able to increase the ratio of the useful primary signal to the signal in the absence of flow and, consequently, more accurately measure the mass flow rate of the fluid. Thus, after digitizing the data of optical sensors, and making the necessary constants, the described [3] equation allows to carry out an accurate calculation of the mass flow rate of the fluid pumped through the flow meter.

3. Results
To date, the following tasks have been completed: the concept of a modular measuring complex; preliminary design; engineering and design documentation; formulation of technical requirements. The design phase is in the final stages.

The patent RU 179 411 U1: “A device for measuring the flow rate of fluid and gas” was obtained by the authors.

4. Discussion
According to the results of the research, it can be concluded that the technology described in the research allows the proposed modular measurement complex to meet the required technological characteristics of the devices of the oil and gas industry. Thus, the development of an interference Coriolis flowmeter is an urgent task aimed at the development of the material and technical base of devices and technologies for the oil and gas industry in Russia.
5. Conclusion
The completed stage of the research work provides a theoretical justification for the performance of the final project in the sections of the design and physical and mathematical model. The proof of practical applicability of the development will be possible at the stage of design and testing of the finished prototype with the specification of the implicit features of the proposed design and method of converting the primary signals into the final flow rate.

References
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