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ABSTRACT

An ultrasonic amplitude-frequency meter of the velocity flowing environment was developed, where one channel for reception of the signal transmission for and against the flow was used, amplitude-frequency modulation scheme was performed, an experimental sample was developed and experimental research was conducted in the article.

Keywords: meter of the velocity flowing environment, ultrasonic method, amplitude-frequency modulation scheme, experimental investigations

1. ACTUALITY

Nowadays, one of the most progressive devices of measuring the flow of liquids and gases are flowmeters with ultrasonic primary converters. The share of ultrasonic flowmeters in the world market among all devices of controlling the flow of different energy sources is more than 10% [1-5.]

Ultrasonic flowmeters have a number of important advantages[6-7]: a wide dynamic range of measurements; absence of pressure losses due to lack of elements of the device in the measuring channel; absence of influence on the hydrodynamics of the flow; lack of moving elements and, consequently, increased reliability; possibility of measuring the consumption of petroleum products, aggressive, non-conductive, non-transparent non-uniform liquids, suspensions, pulps, including multicomponent environment ; low power consumption; the relative error of such devices, as a rule, is within the range of 1% -1.5% [7-8].

At the same time, the analysis of design features and technical characteristics of known ultrasonic flowmeters shows that the problems of creating sufficiently reliable working flow converters are not fully solved. Different types of flowmeters have their disadvantages, the main of which is, in particular, the need to provide a reliable definition of the flow of "contaminated" gas environments, as well as at moments of a sharp change in the velocity flow in the pipeline, which leads to a change in the type of flow, low accuracy of registration of the start position pulse signal, discreteness of measurements, complexity of signal processing. In addition, time-pulse or frequency flowmeters are used, as a rule, to measure the flow of the large diameter pipeline. And in pipelines of a small diameter or chordate channels, they have a sufficiently large area of insensitivity[9-11]. Therefore, there are no ultrasonic flowmeters with a pipeline diameter less than 25 mm, since the construction is complicated, and the cost does not satisfy the customer.

In order to eliminate the above mentioned disadvantages[12-13] an ultrasonic amplitude-frequency method for measuring the velocity flowing environment is proposed and described . The method is based on the dependence of the frequency of the acoustic signal on the velocity of ultrasonic wave propagation at the maximum amplitude of the output signal within the near area of the ultrasonic converter. This approach reduces the area of insensitivity and thus improves measurement accuracy.

The aim of the work is to study the amplitude-frequency velocity environment flowing meter using an experimental installation.

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2. THE MATERIALS AND THE RESULTS OF THE INVESTIGATION

On the basis of the proposed ultrasonic amplitude-frequency method for measuring the velocity flowing environment[12], the essence of which is to determine the resonance frequency of the ultrasonic wave propagation, which is uniquely related to the velocity of the flowing environment due to interference phenomena within the near-zone, a device for measuring the flow of natural and liquefied petroleum gas is developed.

Ultrasonic vibrations, which propagate through the flow and against the flow are produced and adopted by electroacoustic converters in this device. The block diagram of an ultrasonic device for measuring the velocity of flowing environment is shown in Figure. 1.

The device consists of a formation ultrasonic vibrations unit 1, a measuring section of a pipeline 4, and an indicator 6. The ultrasonic vibration formation unit contains electroacoustic converters 2, 3 which are cut into the measuring section of the pipeline, the frequency generator 7, the signal switch 8, the signal amplifiers 9, the ADC 10, comparator 11.

The ultrasonic flowmeter of the flow rate of liquid and/or gaseous environment works on the principle of radiation of the resonant frequency of ultrasonic vibrations by flow or against the flow of the investigated environment passing through it.

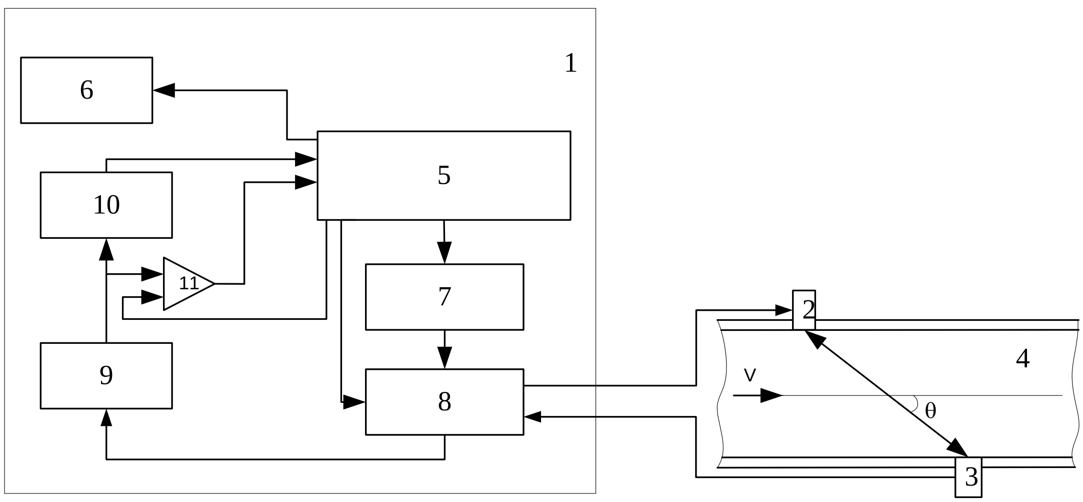

Figure.1. Scheme of ultrasonic flowmeter: 1 - block of formation of ultrasonic vibrations, 2 and 3 – electroacoustic converters, 4 - measuring section of pipeline, 5 - controller, 6 - indicator, 7 - variable frequency generator, 8 - switch, 9 - amplifier, 10 - ADC and 11 – comparator

The ultrasonic signal passes diagonally from one piezoelement to another and at a certain frequency, which will be resonant, the amplitude of the signal will be maximal. This frequency corresponds to the flow rate [14-16]. When changing the flow rate, the amplitude decreases. To restore the maximum value of the amplitude, it is necessary to change the signal frequency according to the near-band condition [17].

Volumetric flow rates of the flow environment are determined as

$$Q = \pi D^2 vt \,, \qquad (1)$$

where D - the diameter of the pipeline; ν - velocity of the flowing environment; t - the time at which flow control occurs.

On the basis of the dependence (1) and the formula of the difference of frequencies, we obtain a transformation function, which can be written as:

$$\begin{cases} Q = \dfrac{0,25\pi D \Delta f a^2}{tg\alpha} \\ N_{dig} = \dfrac{kU_{\max}}{U_{rv}}(2^{n_0 - 1}) \end{cases}, \qquad (1)$$

where a - the radius of ultrasonic converters; Δf - difference in the frequency of vibrations of ultrasonic waves; α - angle between the velocity of the ultrasonic wave propagation and the direction of motion of the fluid medium; N_{dig} - the binary value of the code of the n-bit ADC digitizing the maximum voltage $U_{\max}$ of the receiver over the flow, which corresponds to the resonance frequency of the ultrasonic wave; U_{rv} - reference voltage; n_0 - the number of vibrations of the ultrasonic wave at the main resonance.

The Experimental installation of the State Enterprise "Ukrmetrteststandard" was used for conducting experimental studies of the amplitude-frequency fluid flow rate meter and the method of conducting research was developed [18-19].

The Experimental installation contains reference gas meters Tempo-3 No. 001. The installation is intended to determine and control the volume flow of gases, the range of which is within the following limits: the minimum value is 0.016 m^3/h, the maximum value is 16.0 m^3/h.

In the installation, two methods of reproduction of volume consumption are realized: in the range of flow from 0.5 m^3/h to 16 m^3/h - the method of dilution of the working environment in the measuring path of the installation, in the range of flow from 0.016 m^3/h to 0.4 m^3/h is a method of injection of the working environment.

The structural scheme of the installation is shown in Figure. 2.

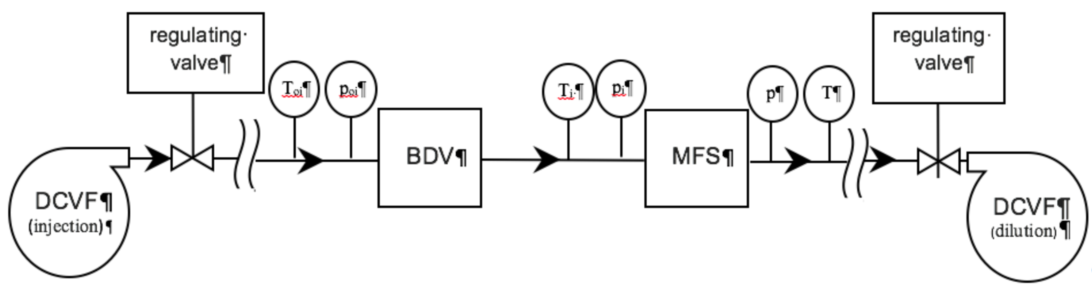

Figure.2. Structural scheme of the installation: DCVF - device to create a volume flow; BDV – benchmark device of volume measurement in the structure of the installation; MFS - meter of flow velocity; T_{oi}, P_{oi}- measurement of temperature and pressure before BDV; Ti, Pi - measurement of temperature and pressure before MFS; T, P - measurement of temperature and pressure after MFS

Figure 3 shows the appearance of the flow velocity environment meter, controlled by PC, and the device's connection system.

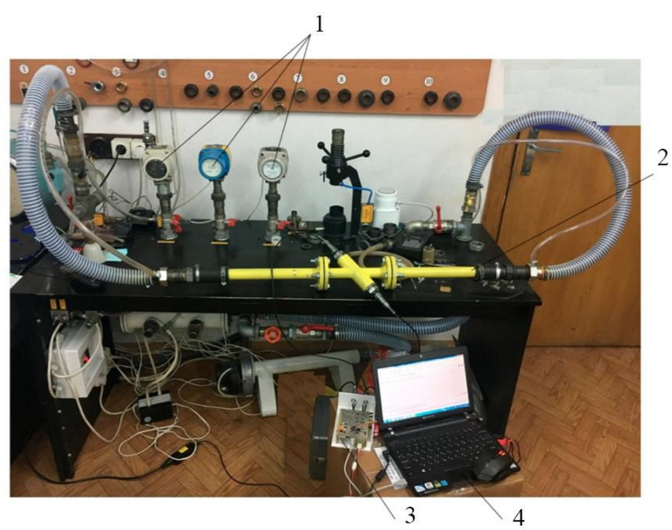

Figure.3. The appearance of the flow velocity environment meter controlled by PC and the system of connections: 1 - BDV; 2 - ultrasonic measuring converter of flow velocity; 3 - microprocessor information processing unit, 4 – PC

Operating environment of installation is air. The dilution and injection of the working environment in the measuring path of the installation are provided with the help of shut-off valves, namely the regulating valves, and device to create a volume flow (DCVF) as part of the installation.

The structure includes the following main benchmark meters and blocks: in the range of volumetric consumption from 8.0 m^3/h to 16 m^3/h - a gas meter of a rotary type, RL, No. 001; in the range from 2.0 m^3/h to 6.0 m^3/h - a gas meter of the rotary type RL, No. 400; in the range from 0,5 m^3/h to 1,6 m^3/h - a gas meter of the rotary type RL, No. 167; in the range from 0.016 m^3/h to 0.4 m^3/h - a gas meter of the drum type PL, No. 039; channels for measuring the temperature of the working environment T1 (in front of the MFS), T2 (after MFS), T3 (before the reference volume measurement and volume control in the installation); channels for measuring excess pressure of the working environment (dilution or injection), P1 and P4 (before MFS), P2 (after MFS), P3 (before the reference means for measuring volume and volume flow within the installation).

To determine the value of the temperature of the working environment in the measuring channels T1, T2 and T3 thermoconverters of the TO type with the following parameters are used:

- range of operating temperatures from 12 to 28 ºC;
- the class of the sensitive element of the thermal converter "A";
- the limits of the permissible absolute error ±(0.15 + 0.002 T) ºC.

In order to determine the value of the excess pressure of the working environment (dilution or injection), in the measurement channels P1, P2, P3 and P4, differential pressure sensors MPX 2010DP are used with the following parameters:

- range of operating pressures from minus 5.0 kPa to 1.2 kPa ºC;
- temperature compensation during measurement;
- indicator of inertia at pressure measurement 1 ms;
- limits of permissible error of ± 1%.

The installation software allows to define the values:

- excessive pressure (dilution or injection) at the input and output of the MFS;
- excess pressure at the input of the volume and control measuring devices which control the volume flow within the installation;
- the temperature at the input and output of the MFS and the control of the volume flow within the installation;
- control air volume, which was measured by the installation;
- the volume of air measured by the MFS , during the time of observation in the study;
- loss of pressure on each MFS, which is subject to investigation, as well as to control the threshold of sensitivity.

The settings and connections of the tools ,which provide the experiment, were carried out at the beginning of the research.

The microprocessor unit of the flowing environment meter velocity is in an aluminum housing, has a stand-alone indicator, as well as indicators of operating modes. In addition, this unit contains standard outputs as RS-232 interfaces for connecting to the gas sensor and USB to connect to one data acquisition system.

Indication of the relative error of the UPSS being investigated and other measured or monitored parameters is carried out on the PC monitor screen. Results of determination and control of metrological characteristics are archived. Protocols of research (or excerpt from it) can be printed on a printer.

Experimental investigations were carried out at a temperature of 20 °C at pressures of 1 atm, 1.1 atm, 1.2 atm, 1.25 atm. Ultrasonic measuring converters have been pre-tested. In the absence of a flow, the signal of ultrasonic vibrations was carried out with a change in frequency by using the alarm setup of the generator.

An ultrasonic signal passed through the measuring path came to an ultrasonic converter, from which an electrical signal came into a microprocessor processing unit, where it was amplified, digitized and transmitted to a microprocessor which processed and stored it in the memory. In this way, the AFC signals came through the measuring path were received. After that, the DCVF was switched on for injection with the known volume flow, which include the following ranges:

1. from 8.0 m^3/h to 16 m^3/h;
2. from 2.0 m^3/h to 6.0 m^3/h;
3. from 0.5 m^3/h to 1.6 m^3/h;
4. from 0.016 m^3/h to 0.4 m^3/h.

The amplitude displays were recorded at each steady-state mode of volume flow and excess pressure in the radiation of ultrasonic fluctuations along the flow and against the flow of the investigated environment in the pipeline in the frequency range of 180-195 kHz. This process of receiving the frequency response was repeated with each step of increasing the frequency of the signal with a resolution of 10 Hz.

3. RESULTS OF EXPERIMENTAL STUDIES

The main research was aimed at establishing the dependence of the resonance frequency on the velocity, and therefore on the flow of fluid. To do this, for each value of the flow rate, the frequency of the generator in a step of 1 Hz was changed in the range of 186000 Hz - 189000 Hz and an amplitude-frequency characteristic was constructed, on the basis of which was the maximum, that is, the value of the resonant frequency. Figure 4 shows resonance curves corresponding to expenses in the range of 0-16 m3/h. The shape of the resonance curves indicates a fairly low noise level, which makes it possible to perform measurements without further signal processing.

Figure 5 shows resonance curves corresponding to flow in the range of 16-65 m3/h. Data is obtained using the verification bench of PSC "Kyivoblhaz" in town Boyarka.

From the analysis of the obtained results it can be seen that with the increasing velocity flow, the frequency at which the maximum value of the amplitude of ultrasonic vibrations is observed decreases. The value of the maximum amplitude increases with increasing velocity. Also, a study of the effect of temperature on the frequency at which the maximum value of the amplitude is observed. The dependence of the frequency at which the maximum amplitude value is observed, from the temperature, is linear and with increasing temperature the frequency increases.

It can be seen from Fig. 5, as the velocity flow increases, so the noise component of the signal increases, which leads to an increase in measurement error, due to which additional signal processing is required.

Theoretical and experimental static characteristics are based on Figure 6.

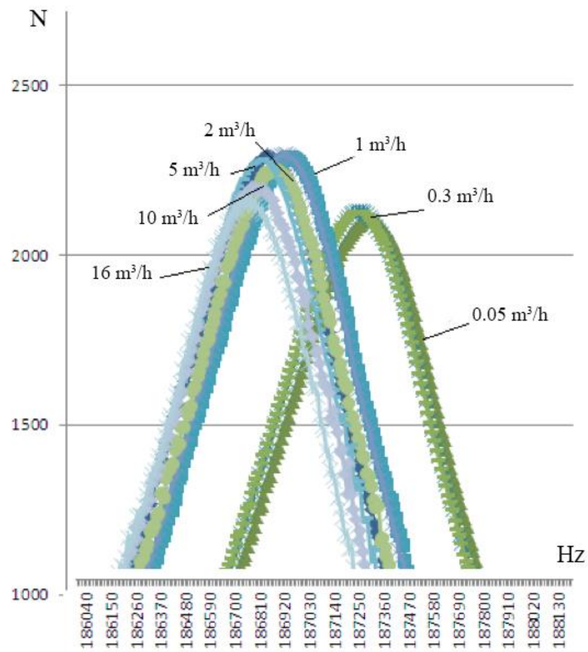

Figure 4. Resonance curves corresponding to flow in the range of 0-16 m3/h

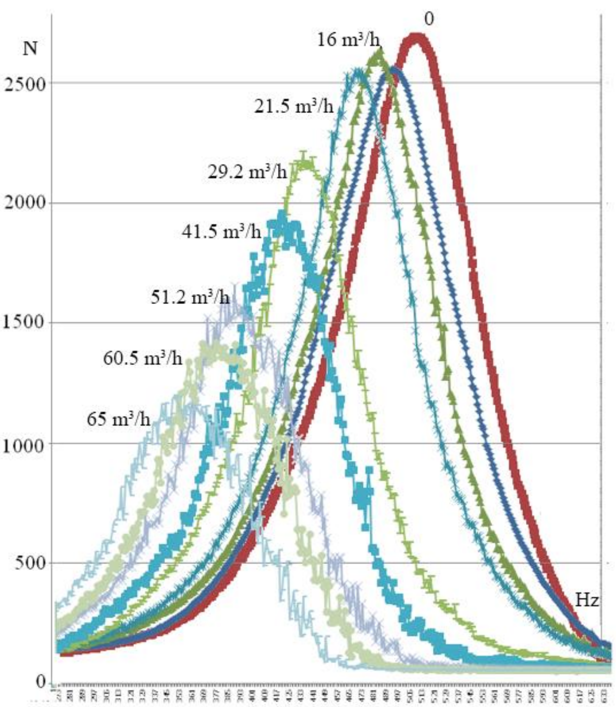

Figure 5. Resonance curves corresponding to flow in the range of 16-65 m3/h

As it can be seen from Fig. 6 convergence of modeling results with experimental data is satisfactory. The rejection of the experimental dependence on the theoretical does not exceed 10%.

According to the results of experimental studies, the change in the velocity of the flow environment and its relative error in time has been constructed. 200 values were obtained within 3.5 minutes in the range from 1.7038 m/s to 1.721 m/s. The dependences of the general law in the error distribution of measuring the velocity flow environment are shown and it is established that the distribution law is normal.

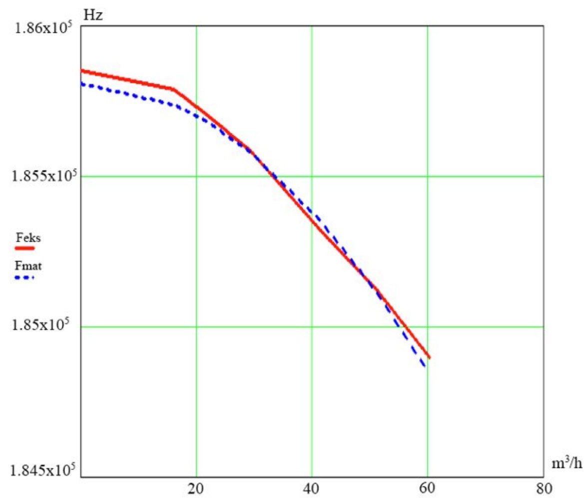

Figure 6. Theoretical and experimental static characteristics

4. CONCLUSIONS

An amplitude-frequency flow environment meter is proposed, which is characterized by the use of one channel for receiving the signal transmitted by and against the flow and the amplitude-frequency modulation scheme. An experimental sample of the flowmeter was manufactured and its experimental studies were carried out. As a result of the metrological research of the experimental flowmeter it was established that the instrument allows measuring the velocity of the gas flow environment in the range of 0.25 to 25 m/s, which corresponds to the world level. The analysis of the results of experimental studies of the device for measuring the flow environment has been carried out, which showed the convergence of theoretical and experimental characteristics. Model error does not exceed 10%.

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