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The use of modern highly precise ultrasonic gas flowmeters and etalon stands to enlarge industrial resource efficiency

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Abstract. In this article we have described our new development that is the ultrasonic flowmeter with high dynamic range of 1 to 2000 for industrial applications. Its high accuracy of measurement can help gas consuming enterprises to save resources. Its software and the software of corresponding computing device is able to avoid gas leakage, to minimize energy consumption and to save human resources while maintaining metrological data. Shown are the new anti-adhesion technologies that can help to increase measurement accuracy and enlarge interval between counters verifications. Described is the low power consumption that makes it possible to use this ultrasonic flowmeter in hard remote environment without direct management for a period of several months. Experiments held in Turkmenistan have shown that device indications didn't drift and remained stable during the year that is a great advantage in comparison to rotary and turbine flowmeters. Also described is the mobile ultrasonic calibration stand that uses the same physical principles and similar software. Outlined is the usage of modern wireless technologies to collect and transmit metrological data.

Key words: ultrasonic flowmeter, verification stand, etalon, WiFi, gas consumption, energy saving.

1. Introduction

Gas is the main fuel in Russia and it shares more than 50% of primary energy consumption, that is quite a lot according to the world standards. No country with advanced economy has such a high share of gas in the fuel balance. As a comparison, the UK's gas ratio in energy consumption is 40%, for Netherlands this figure is 38%, for Canada – 27%, for the US – 26%. Hydropower predominates in Norway and its share of gas is only 9%. However, at the background of such countries as Iran, where gas also gives 55% of all primary energy, or Algeria, where its share is 60%, Russia looks quite organically.

Nevertheless, gas consumption in Russia is huge. It is reasonable to mention that it is equal to the combined consumption of Germany, France, Italy, Japan, China and India. Annually Russia burns and processes more than 420 billion cubic meters of gas, yielding only the USA on this indicator. In Russia the share of exported blue fuel reaches only 30%, while the rest of it is consumed domestically. In order to maintain its position in foreign gas markets or even win new ones, Russia needs to reduce its domestic consumption.

2. Materials and Methods

Measurement and comparison of gas flow rates at all stages from gas companies to gas consumers is a rather complicated job. In particular, it includes efficient gas metering and accounting, gas flow monitoring and telemetry [1].

Gas flow rates have to be measured under various temperature, pressure and humidity conditions. Different gas composition, changing dynamic range is also a great challenge. There is no uniform solution for all circumstances, multiple physical principles are used to measure gas flow.

The gas flowmeter usually consists of three main parts, such as sealed case, measuring converter and counting device. The measuring mechanism is the main element, and the principle of converting the flow into mechanical, electrical or other impact on the counting device determines the type of flowmeter. Mechanical converters use different properties of gases to move the lever acting on the counting device. Electronic sensors convert the flow properties into an electrical pulse that increases the indication on the display.

3. Results

The measuring convertor uses the physical properties of the gaseous substance flow. According to the principle of its operation, there are several types of counters, particularly:

1) membrane or diaphragm meter, in which gas alternately fills the two measuring chambers separated by a membrane. Each camera has a fixed volume. The input and output valves are asymmetrically synchronized and alternately inlet and outlet gas. The movements of the membrane are converted by the lever into a turn of the counting device drive, which shows the volume of fuel passed through the device;

2) rotary gas meter, that uses the gas pressure in special tanks to drive two eight-shaped shafts (rotors), one of which is connected to the drive of the counting mechanism. Counter translates the number of revolutions in the amount of fuel;

3) turbine meter principle is based on flow rate measuring by counting the number of revolutions of turbines that rotate under the flow pressure. Such metering devices are used only in municipal and industrial enterprises to account for large volumes;

4) vortex flowmeter uses the dependence of the frequency of pressure fluctuations that occur after the jet of a gaseous substance is given a vortex shape. The mechanism of accounting for these oscillations is complicated, requires the use of complex microprocessor technology, therefore, such devices are expensive and are used only in large gas distribution enterprises;

5) ultrasonic flowmeter, that usually uses the difference of ultrasound waves propagation times along and against the flow to estimate the speed of flow and then convert it to gas consumption. Ultrasonic flowmeters also need high-accuracy electronics to convert nano- and pico-second pulses into digital signals [2, 3, 4].

Ultrasonic flowmeters are increasingly used in various industries. Combining the advantages of vortex and jet flowmeters, such as high measurement accuracy, wide dynamic range, low inertia, no additional pressure losses, simple design – ultrasonic flowmeters in most tasks successfully replace rotary and turbine flowmeters.

4. Discussion

Industrial ultrasonic flowmeter. We have recently developed the new industrial time-of-flight ultrasonic gas flow meter Irga RU that has already been entered into the State register of measuring instruments.

Its operation principle is based on the time-to-pulse method of gas flow measuring. It consists in measuring the time of ultrasonic pulses passage in the direction of the gas flow in the pipeline and against it. Excitation and reception of pulses is carried out by piezoelectric transducers, which are installed in an all-metal case of the flowmeter at an angle (from 30° to 45°, depending on the version) to the flow direction [5, 6]. The speed of ultrasound in the medium depends on the physical and chemical properties of this medium: temperature, pressure, etc. At the same time, it is much greater than the

speed of the medium, so that the actual speed of ultrasound in a moving medium is not much different from its speed in a stationary medium. The difference in transit times Δt even at flow rates of about 10 m/s is a fraction of a microsecond, while the measurement error should not exceed a few nanoseconds [7].

These circumstances necessitate the use of complex electronic circuits in combination with micro-processor technology, providing compensation for the influence of these factors.

Structurally, the flow meter consists of three blocks:

1) primary flow converter, which is a housing with built-in ultrasonic transceivers;

2) electronic unit, which carries out the reception and transmission of signals through ultrasonic transceivers, their conversion, processing and calculation of the volume flow of gas under operating conditions, followed by the formation of the output signal;

3) power supply unit with built-in spark protection barrier to provide explosion protection circuits if necessary.

The electronic unit controls ultrasonic transceivers, performs receiving, processing, converting and transmitting signals to the computing device. These signals contain, in particular, information about the propagation time of the ultrasonic pulses, that is required to calculate the volumetric gas flow rate in operating conditions:

$$v = \frac{L \cdot (t_2 - t_1)}{2 \cdot t_1 \cdot t_2 \cdot \cos \alpha},$$

where: v is velocity of flow in the pipeline, L is the distance between the transceivers, α is the angle between the axis of the sensors installation and the axis of the conduit, $t1$ and $t2$ are times of ultrasonic pulses propagation along the flow and against it.

The design of flow meter eliminates the possibility of unauthorized influence on the flow meter software and measurement information. We have developed and successfully tested our own control circuits for piezoelectric transceivers, and also created new original algorithms for processing received signals. It allowed us to:

– significantly expand the dynamic range of gas flow measurement to values of the order of 1:2000;

– increase the accuracy of measurements to 1% in most tasks;

– use our flowmeter on pipelines of almost any diameter;

– measure the flow rate of various physical and chemical properties of gas media;

– carry out measurements at high speed, in a wide range of temperatures and pressures;

– not to introduce additional pressure losses into the pipeline.

At the same time, our flow meter has a fairly simple design and does not require significant lengths of straight sections before and after its installation.

We have also mastered and successfully tested the technology of applying anti-adhesive coating on the inner walls of the flowmeter to avoid sticking of the solid fraction of the measured medium. This helped us to reduce the probability of non-reproducibility of measurement results by 0.2%. In future it will also lead to calibration interval decrease [8, 9, 10].

In our flowmeter design we have used modern time-to-digital microcontroller convertors, that apply energy saving technologies. We have also developed energy efficient algorithms of transmission, receiving and processing of ultrasonic pulses. Power consumption has decreased to several μW. It helped us to implement autonomous power supply from rechargeable batteries [11, 12, 13, 14].

Our colleagues from Turkmenistan gave us a possibility to test our devise powered by solar panels in desert conditions with almost cloudless weather and periodic changes in energy supply. Experiment has shown that our flowmeter is able to operate without direct maintenance for months.

In this case the only challenge is to receive information from the remote flowmeter, so we had to organize telemetry system and to develop additional software. We have tried several solutions, while transmitting metrological information from the flowmeter, such as radio modems, GSM/GPRS or 4G/3G modems. The most efficient solution for the desert was the radio modem with code modula-

tion, that transmitted data to more than 7 km to the central node. 3G signal was high enough only in the central node, where we created a solar powered microcontroller based HTTP client that periodically posted data to the web server located in Ashgabat [15, 16,17].

Mobile ultrasonic calibration stand.

Though ultrasonic flowmeters are very effective in a high dynamic range, they also have to be calibrated, that means that their indications have to be synchronized with the etalons. This is a standard procedure for all metrological devices despite of their prices, conditions used, dynamic ranges, types, sizes and other properties.

In accordance with the Federal law of Russian Federation that deals with "Ensuring the unity of measurements" it is necessary to verify the gas meters. Only in the course of such verification it becomes clear whether the equipment meets the metrological requirements. Verification is carried out before putting the devices into operation and periodically during their exploitation [18, 19, 20]. This is associated with certain difficulties both for industrial enterprises, that have to either stop the section of gas consumption, or install a similar flowmeter for the time of verification of the main one, and also for private consumers, who have to remain without gas for the period of verification. In any case, verification takes time and money.

Verification can produce only specialized organizations with high-precision stands, that have to be included into the State register of measuring instruments. Usually these stands are bulky systems that require a lot of free space and a highly skilled operator. In addition, such stands or their parts (e.g. nozzles, in the case of stands on critical nozzles) themselves require periodic recalibration in standardization organizations. Such stands cost about several million rubles [21].

We have applied similar to Irga-RU principles of flow measurement, electronic circuits and signal processing algorithms while developing and creating ultrasonic testing facility, which we have called KRAB-UM (Its appearance in shown in figure 1.). The principle of its operation lies in automatic selection of verification points and a set of conditions for measurements, monitoring the readings of temperature and pressure sensors, automatic flow control, comparison of the volumes of gas passed through the household meter and through a high-precision ultrasonic reference system, analysis of the measurements and decision-making on the success of verification.

It is the first ultrasonic mobile calibration stand, which among other things uses wireless technology for transmission, storage and display of metrological and other data, and is able to work on batteries for 8 hours. The picosecond accuracy of electronic calculation of the time difference between the ultrasonic pulses passing between the receiver and the transmitter, which was impossible until recently, as well as the improved design of the reference device hydraulic part, made it possible to develop a compact high-precision reliable stand [22, 23].

ESP8266 board was chosen as the main module of the stand control (figure 1). It has accumulated data from:

– ultrasonic sensor control module;
– power management module;
– digital thermometer, digital pressure sensor;
– reed switch connected to the verifiable domestic meter.

Based on the results of data processing obtained from various modules, the ESP8266 controller generated information about the reference gas flow rate in operating conditions. The reference flow rate was calculated from the calibration table recorded in the ESP8266 EEPROM memory (EEPROM-Electrically Erasable Programmable Read — Only Memory is electrically erasable reprogrammable memory, a type of nonvolatile memory used in computers and other electronic devices to store relatively small amounts of data but with the ability to read, delete, or write bytes individually) [24].

For domestic gas meters equipped with a slot for connecting an electromagnetic sensor (reed switch), an output for reading signals from such a sensor was provided in the ultrasonic calibration unit. Interfacing with household meters with the help of reed switch made it possible to significantly simplify the process of verification and improve its accuracy, reducing to zero the operator's error. For meters that do not provide for the connection of the reed switch, the operator had to visually monitor

the passage of a certain volume of gas and then manually record it in the inspection program. The mobile unit allowed to check up to 4 domestic meters at the same time, but it made sense only when using reed switches, otherwise 4 operators would be needed for accurate visual control of household meters.

The flow rate generated in ESP8266 took into account the difference in gas temperature during verification and during the initial calibration of the installation itself. The instantaneous temperature value was also displayed as reference information in the verification program. A platinum resistance thermometer mounted near the location of one of the ultrasonic sensors was used to measure the temperature. To digitize the thermometer signal, a 24-bit analog-to-digital converter was used, which made it possible to measure the temperature value up to a fraction of a degree. The inertia of the thermometer is high enough, but the temperature of the gas in the pipeline does not undergo sudden changes, so this fact does not significantly affect the accuracy of measurements [25, 26, 27].
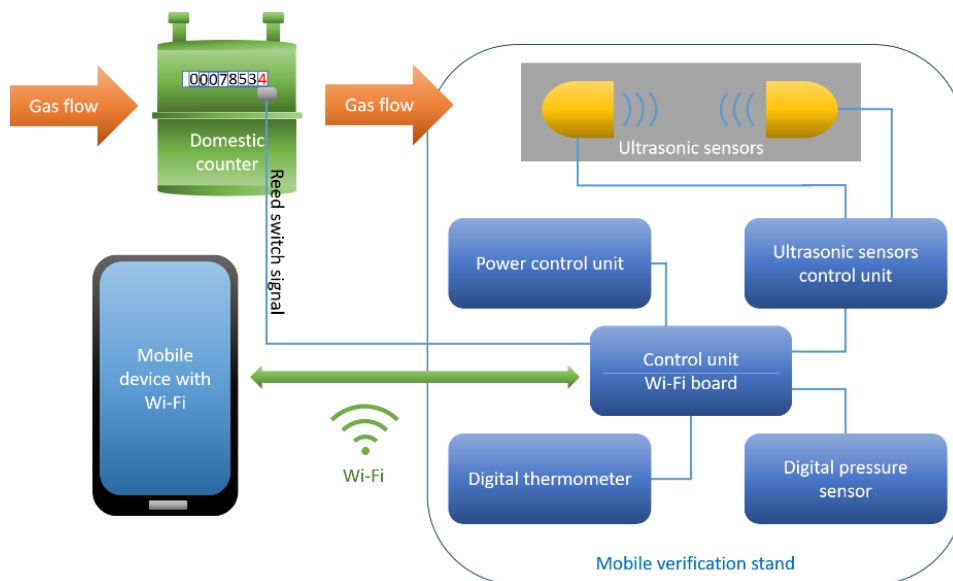

Figure 1. Mobile verification stand general scheme

When carrying out verification without removing the domestic counter seal on it should remain intact, so to account for the pressure drop, we were forced to measure the pressure at least twice at each point of verification: with the inlet valve closed and open. The digital pressure sensor used data transmitted once a minute to the ESP8266 controller via the UART protocol. It did not need additional analog-to-digital converters. But it was necessary to use a software UART, as the built-in UART in ESP8266 was already reserved. Opening / closing of the valve was carried out by the operator manually, the information about the measured pressure was stored already in the verification program, so the pressure drop was taken into account in the flow value outside the ESP8266 controller.

Power supply of the mobile unit in the absence of a 220V network was provided by a 5V battery operated by the battery shield controller. It has been technically and programmatically modified for optimal operation as part of the mobile calibration facility. In particular, the indicator diodes were transferred to the unit housing, and information about the battery charge and other power parameters was transmitted to the ESP8266 controller via the I2C Protocol (its software implementation). Information about the battery charge was also displayed in the verification program.

The most important information for verification – the time difference between the propagation of ultrasonic pulses – was generated in ultrasonic transceivers control board. This information was transmitted via the UART Protocol and converted to a flow rate according to the calibration table. Then the temperature difference was corrected and in this form the information was received in the verification program and in the "Current flow" field was displayed on the screen of a mobile or sta-

tionary device. The program for the AVR controller that controled this board was written in Assembler.

Programming ESP8266 was carried out in C++ in the Arduino IDE. The program blocks for each of the components described above were contained in separate files. The program also included a file of the real-time operating system functions, procedures to work with Wi-Fi, functions for the HTTP, DNS server, etc. The interface was written in JavaScript in NetBeans environment. HTML-pages, CSS and JavaScript files were entered into the memory of the ESP8266 controller using a special script.

All the information described above (service and necessary for verification) was transmitted via Wi-Fi network to a computing device (smartphone, tablet, desktop computer or laptop) for further processing and storage. To do this, the ESP8266 module was set to the access point mode. The name of the Wi-Fi network (ESPWiFi) and the password to access it, as well as the IP address of the server (which was also the ESP8266 module) were recorded in the program of the ESP8266 controller. Network ESPWiFi automatically became viewable for all mobile devices. After connecting to the network in the command line of the mobile device browser, it was enough to dial the IP address of the ESP8266 module to load the page with the verification program. In this case, the computing device could be under control of any operating system. The main condition of the program was installed on a computer device modern browser with support for HTML5. (The application was designed to work in Chrome and Yandex Browser, so its optimal performance was guaranteed only in these browsers.)

Information on the Wi-Fi network was transmitted in the form of JSON-files. ESP8266 acted as an HTTP server responding to continuous requests from an HTTP client (modern browser). On HTML pages, the information was updated without reloading all the content, using AJAX technology.

Thus, we have developed and assembled a working model of mobile ultrasonic reference unit for automatic verification of household meters. In the case of verification of counters with the support of electromagnetic sensors, the process can be almost completely automated and simultaneously carried out for 4 counters. The only concern of the operator, in addition to switching the verification points, will be the measurement of pressure with the inlet valve closed and open. This can be corrected if necessary by installing electronically controlled valves. The unit has been successfully tested in the laboratory and is ready for field testing.

The KRAB-UM can be used both on the gas pipeline that allows to carry out verification of domestic and communal gas counters without removal, and as stationary reference installation (in this case it needs a flow compressor).

Thus, the mobile calibration using our ultrasonic stand can greatly facilitate life for private gas consumers, saving them from necessity to remove the counters and take them for testing, as well as for industrial enterprises. It is quite easy to work with our stand, because the whole process is automated and requires only to move between pages in a Web browser, and pressing one button. The information on the performed verification is stored and encrypted, which ensures the reliability of the results and the ability to trace the process of all measurements.

Figure 2. Mobile ultrasonic calibration stand

5. Conclusion

So we have developed and created the modern industrial ultrasonic flowmeter with great dynamic range. Its high accuracy of measurement can help gas consuming enterprises to save resources. Its software and the software of corresponding computing device is able to avoid gas leakage, to minimize energy consumption and to save human resources while maintaining metrological data. Our flowmeters can be organized in the network operated from single remote central unit. New anti-adhesion technologies can help to increase accuracy of measurement and enlarge interval between verifications. Low power consumption and high reliability makes it possible to use our ultrasonic flowmeter in hard remote environment without direct management for a period of several months. Experiments held in Turkmenistan have shown that device indications didn't drift and remained stable during the year, that is a great advantage in comparison to rotary and turbine flowmeters.

Using the same physical principles and similar to our ultrasonic flowmeter software we have also created the mobile ultrasonic calibration stand. It uses modern wireless technologies to collect and transmit metrological data. It is compact, energy effective and easy-to-use. Almost any mobile device can operate as an interface for verification computer, receiving metrological data from both etalon and counter under calibration over local WiFi network. It is the first mobile ultrasonic etalon device.

Both ultrasonic flowmeter and mobile ultrasonic etalon stand use modern high accuracy time-to-digital technologies, that are at the same time very energy effective. Low power consumption makes it possible to operate from batteries of from solar panels. It can become a very interesting option for industrial measuring devices. Besides our devices can be operated by non-specialists, as they are almost fully automated. It can save time and financial resources. Their most significant features is high precision and high dynamic range, as the greater accuracy leads to better effectiveness of gas resources saving.

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