The Development of Radio and 3G Based Telemetry System for the Remote Gas Accounting and Control Nodes

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Abstract**:** ***In this article we have described the use of vortex and recently developed ultrasonic flowmeters with high dynamic range of 1 to 1500 for industrial applications. 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. 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. Shown is the new telemetry system that was developed to unite flowmeters in the severe conditions of the desert with power supply problems and low GPRS signal quality. 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.***

Index Terms**:** ***telemetry, ultrasonic flowmeter, signal transmission, calibration stand, Wi-Fi, HTTP.***

I. INTRODUCTION

Telemetry is an automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring [1]. Systems that need external instructions and data to operate require the counterpart of telemetry, telecommand[2].

Although the term commonly refers to wireless data transfer mechanisms (e.g., using radio, ultrasonic, or infrared systems), it also encompasses data transferred over other media such as a telephone or computer network, optical link or other wired communications like power line carriers. Many modern telemetry systems take advantage of the low cost and ubiquity of GSM networks by using SMS to receive and transmit telemetry data.

A telemeter is a device used to remotely measure any quantity. It consists of a sensor, a transmission path, and a display, recording, or control device. Telemeters are the physical devices used in telemetry. Electronic devices are widely used in telemetry and can be wireless or hard-wired, analog or digital. Other technologies are also possible, such as mechanical, hydraulic and optical.

Telemetry may be commutated to allow the transmission of multiple data streams in a fixed frame.

II. MATERIALS AND METHODS

The aim of our work was to develop an automated system of control and accounting of associated petroleum gas in remote and inaccessible oil fields in the Kara Kum desert.

Gas was used in the gas-lift method of well operation, which is a logical continuation of the fountain method of oil production. The missing amount of associated petroleum gas for oil recovery was pumped into the well from the surface. It was necessary to constantly monitor the temperature, pressure and volume flow of gas, as well as remotely control solenoid valves and gates for effective management of oil production in wells.

Metrological data had to be transferred to a remote control center, analyzed and archived. The information needed for familiarization or decision-making had to be visualized on the screen of any mobile or stationary device equipped with a modern Web browser. Stakeholders had to have different access rights to this information[7].

For each well, a metering unit for associated petroleum gas was designed and installed. Electronic components such as computing devices (electronic correctors), multiplexers, modems, logic controllers, drivers, power supplies were located inside the instrumentation cabinets (cabinets for instrumentation and automation). Flow meters, valves and plugs were installed directly on the gas pipeline laid in the sands of Kara Kum.

To measure the volume flow rate of associated petroleum gas, full-pass vortex flow meters with nominal flow diameters from 50 to 200 mm were selected. The vortex motion in such flow meters is provided by a flow body located in the path of the moving flow, which in the cross section has a shape close to the trapezoid. The system of

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vortices arising behind this obstacle is called the Karman vortex path, and the frequency of the collapsing vortices in the first approximation is proportional to the flow velocity [8]. The flow rate, in turn, allows to calculate the gas flow rate under operating conditions with an accuracy of 1%. The conversion of the flow rate into operating conditions into a unified flow rate under standard conditions was carried out in the computing device, which received the necessary metrological data from the pressure and temperature sensors. These sensors were located in the pipeline together with the flow meters.

Given the instability of electricity metering units, as well as the abundance of solar energy in the desert, instrumentation cabinets were equipped with autonomous power supply from solar panels (panel controllers and batteries were also installed in instrumentation cabinets).

For effective management of the gas lift process, monitoring of metering stations and control of associated gas flows had to be carried out continuously and without interruptions. Also, for the full automation of the process in the future, a thorough analysis of the accumulated statistical data was required, for which a detailed archiving of the transmitted metrological information was necessary[9].

III. Results and Discussion

The data was transmitted to the server via the Internet. The HTTP protocol was used as the application layer protocol. Users with the appropriate access rights, using modern Web-browsers sent GET-requests to the server. The server stored various temporary archives that contained all the information necessary for monitoring and decision-making (environment temperature, air, gas temperature, atmospheric pressure in the area of the well, pressure drop at different points of the pipeline, the presence or absence of electricity, battery charge, occurrence and description of emergency situations, etc.). These archives were sent to the server by POST requests from the computing devices located in the accounting nodes. POST requests were formed automatically in accordance with the established time schedule [10]. Thus, the server had two types of clients: web-browsers of telemetry system users and special software of the client device developed by our group.

The module developed by our group was used as a transmitting POST-requests device, which was installed in the control point at a distance of no more than 10 km from each of the wells. This IRGA-LT device served as an intermediate between the accounting nodes and the server. It included a 3G module controlled by a special microcontroller with the help of automated AT-commands. It was decided not to install similar 3G modules in each metering station due to 3G communication failures in the vicinity of the fields and the need to pay for and maintain SIM cards, as well as to simplify the transmission system.

Each metering point contained another self-developed device IRGA-NT connected to the computing device using UART protocol. Transfer of data from IRGA-NT to IRGA-LT was carried out via 433 MHz radio frequency [11]. Code and time modulation was used. Each radio module placed in the unit IRGA-NT, was assigned its own unique number, and the data was passed in turn from each node after the receipt of the request from the IRGA-LT radio module. In case of transmission errors signals of emergency situations were generated.

When creating models of IRGA-NT and IRGA-LT devices, AVR microcontrollers installed in Arduino boards (UNO for IRGA-LT and NANO for IRGA-NT) were used to control the operation of radio modules, 3G modules and other electronic components. Arduino board software was developed in the Arduino IDE in the C++ programming language [12].

The server contained a PHP file to handle requests from the client IRGA-LT, as well as the HTML page passed as the response to the Web browsers. These HTML pages used JavaScript language, especially for a periodic AJAX poll to the server to inquire if the new data from IRGA-LT had arrived.

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 [13].

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. 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 [14].

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

Structurally, the flow meter consists of three blocks:

- primary flow converter, which is a housing with built-in ultrasonic transceivers;
- 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;
- 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 [15].

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[16]. 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% [17]. In future it will also lead to calibration interval decrease.

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.

Our colleagues from Turkmenistan gave us a possibility to test our device 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 [17].

Information from IRGA-RU was transferred to the computing device and then transmitted via above described telemetry system. The same system was also used to unite our flowmeters into the network.

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 [18]. This is a standard procedure for all metrological devices despite of their prices, conditions used, dynamic ranges, types, sizes and other properties.

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 [19]. Such stands cost about several million rubles.

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. 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 [20].

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.

ESP8266 board [21] was chosen as the main module of the stand control. It has accumulated data from

- ultrasonic sensor control module,
- power management module,
- digital thermometer, digital pressure sensor, and
- 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[22]. (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.)

For domestic gas meters equipped with a slot for connecting an electromagnetic sensor (reed switch) [23], 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 [24] 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 [25]. 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.

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[26]. 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.

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 [27], 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.

KRAB-UM does not need any additional calculating devices to be connected to the above described telemetry system. So it can remotely perform verification and the data can be also remotely archived.

IV. CONCLUSION

We have developed and effectively tested the telemetry system in a set of applications and conditions. This system united gas flow monitoring and control nodes at oil fields, giving us the opportunity to manage oil production process from another city. It also combined several high dynamic range ultrasonic flowmeters in the network, providing gas consumption map of the region. At the same time, we managed to test our new flowmeters in real operating conditions. This telemetry system also helped us to remotely verify domestic gas flowmeters by our new ultrasonic mobile stand.

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