

Improving the principle of liquid level measurement in “Trap” type automated group metering units

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ABSTRACT

The article deals with the improvement and technical implementation of the principle of measuring the flow rate of oil wells with the U6M-VZG liquid level sensor to improve their operational characteristics. In the article, we conduct a systems analysis of the principle of operation and component elements of the U6M-VZG liquid level sensor, showing the main causes shown of the reduction of operational characteristics and disadvantages due to the complex mechanical units housed inside the explosion-proof housing in the hazardous area to receive signals to reach the measured levels: the bottom of the metering tank, the “water - oil” and “liquid” section. We consider the possibility of controlling the levels: bottom of the metering tank, “water - oil” and “liquid” section by the values of the currents consumption by synchronous electric motor when lifting the load in order to increase the operational characteristics and disadvantages of the AGM automated group metering unit series on the basis of Trap. The proposed method of improving the principle of measuring the oil well flow rate separately for water and oil is based on the measurement of synchronous motor current in the supply circuit from an intelligent device. The graph of change of current consumption by synchronous motor in time is given, where the values of currents are indicated depending on the change of load on its shaft. A flow chart of the algorithm is constructed for calculating time intervals between the signals: bottom of the metering tank, “water - oil” and “liquid” section, which correspond to the levels of water and total liquid in the metering tank.

1. Introduction

One of the most important indicators of the oil reservoir operation is the average daily flow rate, which is used to set the technological regulations, extraction mode by wells. Only accurate knowledge of this value for each particular well will make it possible to make a conclusion about the correct operation of the “reservoir-well – production equipment” system, make forecasts and plan the

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necessary preventive works, which will allow to avoid emergencies and, consequently, costly repairs and shutdown of oil production in the future. Determining the productivity (oil and gas flow rate) of oil and gas wells during the operation of oil and oil and gas fields is one of the most difficult and urgent challenges in field development [1].

To control the operation of the field it is necessary to accurately measure the oil, water and gas flow rates of each well. This data makes it possible to control the operation mode of wells and fields as a whole, which allows taking necessary measures to eliminate possible deviations [2, p.259].

Analysis of the principles of operation and functions of automated group metering units for measuring the flow rate of oil wells shows that for the oil fields of the Republic of Azerbaijan it is economically advantageous and expedient to improve “Trap” type group metering units. Improvement should be carried out as part of the technological scheme, as well as the means of automation, telemetering equipment, taking into account the achievements of information and communication technology [3].

Works [4-8] proposed new principles for radical improvement of group measuring installations of the “Trap” type. However, many years of experience in oil fields shows that carrying out radical improvements for old fields is not economically justified, since at this stage of operation the volume of oil produced in the total fluid is sharply reduced.

However, it is not economically justifiable to carry out drastic improvements for old fields, because at this stage of operation the volume of oil produced in total fluid is sharply reduced. Therefore, often old fields are in a difficult situation and their profitability decreases sharply every day. In such cases it is necessary to offer ways to upgrade the existing equipment at low costs.

This article addresses one such problem in “Trap” type group metering units.

2. Problem statement

It is known that the main meter in “Trap” type group metering units is the U6M-VZG liquid level sensor [9-13].

U6M-VZG liquid level sensor is a primary device of the pulse telemetering system; together with a secondary indicating or regulating device it is intended for measuring the levels of one or two immiscible and different in density liquids (for example, when measuring the flow rate of oil wells separately for water and oil).

The principle of operation of the level sensor is based on the conversion of interaction forces, lifted by synchronous motor from the bottom of the metering tank at a constant speed, of the magnetic indicator with float bushings into electrical pulses, the time intervals of which correspond to the distance between the interface levels, i.e. the thickness of the measured layer of “water” and “total liquid”. However, the pulses are generated in a complex and unreliable mechanical system housed inside an explosion-proof housing, which further complicates the operation of the entire metering system. This often results in incorrect measurement results.

Kinematic (a) and circuit (b) diagrams of the U6M-VZG level measurement sensor control are shown in Fig.1.

Before the start of measurement, magnetic indicator 14 is in the lowest position inside separating tube 15, resting on bar 16. In this case, flexible branch 12 is relaxed, and cable 10 is kept taut by load 11.

When the sensor is working as part of a set of time-pulse telemetering system, measurement starts by switching on relay R_{n_i} of this system (and in manual by pressing button B), and its normally open contact (in circuit 4-10) switches on measuring relay R_1 , which remains switched on for the whole measurement time under the influence of the normally open contact (circuit 4-10). Relay R_1 in its turn switches on the synchronous electric motor by normally open contact in circuit 3-14. The latter through shaft 20 with leash 4 drives in a uniform rotation of measuring drum 5, sitting on slide

6. By means of a threaded coil sliding on the thread of slide 6, drum 5, rotating, simultaneously makes a translational movement relative to slide 6, equal to the pitch of the thread for each turn. Cable 10 is wound on drum 5 in a single layer, which ensures uniformity of linear velocity and indicator 14 suspended thereon.

The vertical scheme of interaction of the magnetic field of the indicator with the float bushing increases the tension of cable 10 at the moment of passing float indicator 13 (“Water - oil” section). Crosshead 3 and its connected double-arm lever 20 rotate around its axis clockwise, turning on limit switch LS_3 (in circuit 4-5), which in turn turns on relay R_3 , whose normally open contact forms a synchronous signal (SS1). The time interval between the start of measurement and actuation of LS_3 corresponds to the distance traveled by the indicator, corresponding to the water level in the meter.

At further upward movement of the indicator the interaction of its magnetic field with the float bushing stops and the crosshead with the double arm turns counterclockwise. At this, limit switch LS_3 in circuit 4-5 is switched off and relay R_3 is de-energized, terminating signal SS1. Continuing the uniform upward movement, the indicator interacts with float bushing 9 (“Oil - gas” section), which repeats the above-described actuation of limit switch LS_3 and similarly obtains signal SS2. The time interval between the two actuations of LS_3 corresponds to the distance traveled by the indicator between the floats, corresponding to the level of oil in the meter. Thus, the time interval between the beginning of measurement and the emergence of signal SS2 corresponds to the level of total liquid accumulated in the meter.

After interaction with upper float 9, the indicator continues to move upward until drum shoulder 5 pushes back the lever of reverse switch 7. This triggers limit switch LS_2 , whose contact, closed (in circuits 4-6), turns on reverse relay R_2 . This relay, remaining switched on during reversing by means of the normally open contact in circuit 4-6, breaks the supply circuit of measuring relay R_1 (circuit 9-10) at the moment it is switched on.

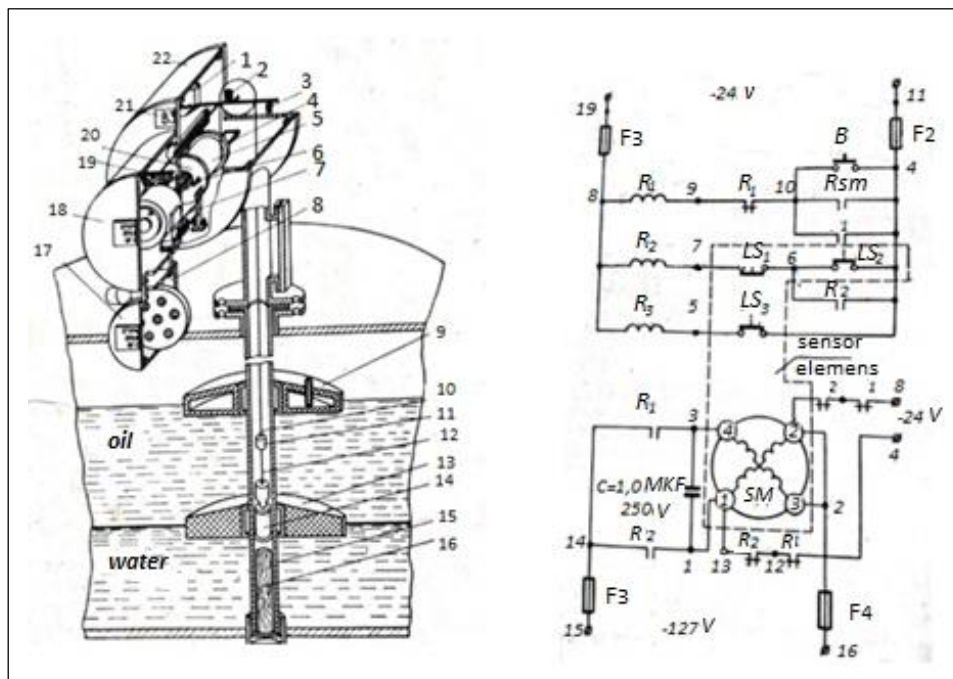


Fig.1. a) Kinematic, b) Circuit diagrams of the of the U6M-VZG level measurement sensor control

Switching on of relay R_2 and subsequent switching off of relay R_1 cause switching in the supply

circuit of the SM-54 synchronous motor (break in circuit 3-14 and short circuit in circuit 1-14).

The direction of rotation of the SM-54 motor changes and the indicator is lowered to contact with bar 16. At the moment of the indicator landing on the bar, the tension of cable 10 decreases, and the crosshead under the influence of the counterweight together with double-shoulder arm 20 rotate around its axis counterclockwise and, overcoming the resistance of compensator 2, cause the operation of limit switch LS_1 .

Contacts LS_1 open, breaking the power supply circuit of reverse relay R_2 , thereby switching off the SM-54 motor (contact R_2 in circuit 1-14 opens). At the same time the electric brake is switched on, preventing the motor rotor from rotating by inertia. Braking is performed by supplying 24 V DC current to the motor winding of SM-54 through normally closed contacts of R_1 and R_2 (circuit 4-12-13-8). The complete cycle of the sensor operation ends here. The motor SM-54 and limit switches LS_1 , LS_2 and LS_3 are inside explosion-proof housing 21 equipped with a plate indicating the explosion-proof rating of the product, and covers 18, 17 and 8 have plates with warning inscriptions.

An analysis of the principle of operation of the U6M-VZG liquid level sensor shows that the conversion of the forces of interaction of the magnetic indicator with the float bushings into electrical impulses is carried out by mechanical units. Long-term experience of operation of these sensors shows that the most frequent failures are caused by mechanical units, and their repair is difficult due to the fact that they are housed inside an explosion-proof sensor installed on the measuring tank in an explosion hazardous area. As a result, the performance of the entire “Trap” type metering unit is reduced.

To eliminate this disadvantage of the U6M-VZG liquid level sensor, this article considers the possibility of controlling the current consumed by the synchronous electric motor during the lifting and lowering of the load and their values during the lifting of the load to determine the moments: “the beginning of magnetic indicator lifting” and passing of the indicator through the float bushings “Water - oil” and “liquid”, which correspond to the levels: the bottom of the meter, the “Water - oil” and “liquid” sections.

3. Solution

From Fig.1 it is easy to see that in the whole range of operation of SM the following two modes of operation are possible: “Measurement”, when the motor vertically raises the cable with the magnetic indicator and load upwards, measuring the levels, and “Reverse” (return to the initial state), when the cable drops to the bottom of the metering tank.

In the “Measurement” mode the following options (Fig.2) and their corresponding values of SM currents are possible (see Fig.2):

- Lifting the cable only with load – I_{U_1} ;
- Lifting the cable with load and magnetic indicator – I_{U_2} ;
- Overcoming the force of interaction between the magnetic indicator and the float bushings of the “Water-Oil” and “Liquid” interface – I_{U_3} .

In “Reverse” mode, in which the motor vertically lowers the cable down to the bottom of the meter:

- Lowering the cable with load and magnetic indicator downwards – I_{D_1} ;
- Lowering the cable only with a load in the bottom of the meter – I_{D_2} .

The values of currents in the variants differ dramatically:

$$I_{D_1} < I_{D_2} < I_{U_1} < I_{U_2} < I_{U_3}, \quad (1)$$

Then, taking advantage of this feature to determine the level of water and total liquid in the vessel by passing limit switches LS_1 , LS_2 , LS_3 and their connected mechanical parts, it is possible to

use the levels of currents drawn from the SM in different states when the load is moving in both “Measurement” and “Reverse” mode.

Moments and states during the up-mode “Measurement” and down-mode “Reverse” load movements are shown in Fig. 3. Here, t_1 is the moment of the beginning of the lifting of the cable (switching on of SM), corresponding to the current consumption value I_{U1} ; Δt_1 is the time interval between the beginning of the lifting of the cable and the magnetic indicator; t_2 is the moment of the beginning of the lifting of the magnetic indicator corresponding to the current consumption value I_{U2} ; Δt_2 is the time interval between the beginning of the lifting of the magnetic indicator from the bottom of the metering tank and the “Water-oil” float reaching the level of water accumulated in the metering tank; t_3 is the the moment when the magnetic indicator reaches the “Water - oil” float, corresponding to the current consumption value I_{U3} ; $\Delta \tau_1$ is the промежуток времени за которое магнитный индикатор проходит через the “Water oil” float; t_4 is the the moment the magnetic indicator leaves the “Water oil” float; $\Delta \tau_3$ is the time interval between the two floats corresponding to the level of oil accumulated in the metering tank; t_5 is the the moment when the magnetic indicator reaches the “liquid level” float; $\Delta \tau_2$ is the time interval during which the magnetic indicator passes through the “liquid level” float; t_6 is the the moment the magnetic indicator leaves the “liquid level” float; Δt_4 is* time interval between when the magnetic indicator reaches the “liquid level” float and the start of reversal; t_7 is the the moment of motor reversal start, lowering the cable with a load and magnetic indicator; $\Delta \tau_5$ is the total reverse time; t_8 is the the moment the bottom is reached (i.e. consumption increases); $\Delta \tau_6$ is the time interval of reaching the bottom and motor braking; t_9 is the moment of motor switch-off and braking (SM off).

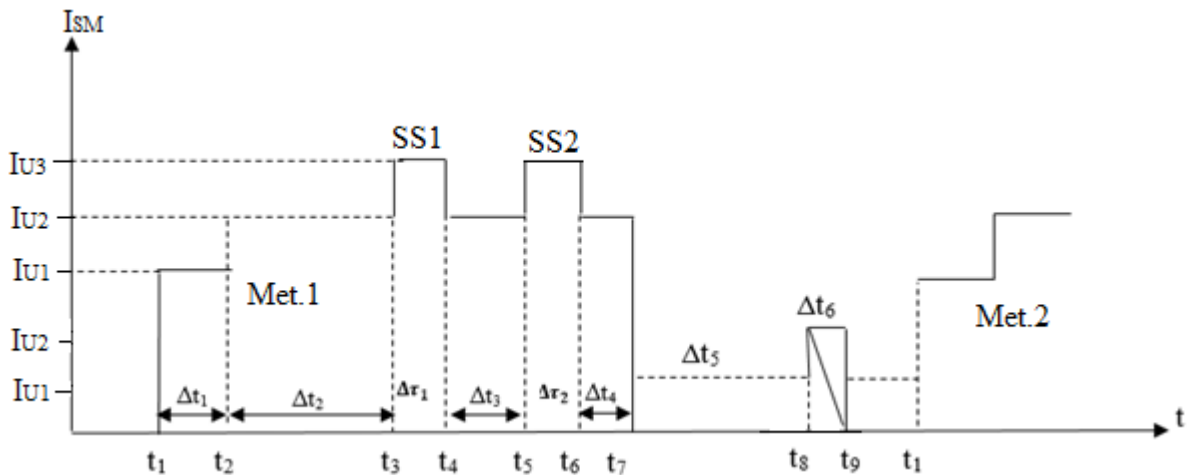


Fig. 2. Graph of change of current consumption by synchronous motor in time with the indication of current values depending on the change of load on its shaft.

The principle of operation of the upgraded U6M-VZG liquid level sensor is based on the direct measurement of current consumption by the synchronous electric motor, the value of the load on the shaft of which in the “Measurement” and “Reverse” modes, created as a result of: lifting only the load; lifting the load with magnetic indicator; overcoming the forces of interaction of the magnetic indicator with the float bushings; lowering the cable with the load and the magnetic indicator to the bottom; lowering the cable with the load only to the bottom of the metering tank are significantly different. Thus, the value of the measured current consumed by the synchronous electric motor is a sign for determining the levels of one or two immiscible and different in density liquids in the tank.

An algorithm was developed (Fig.3.) for measuring and analyzing the current consumption of the synchronous electric motor to determine the time intervals, based on which the water and oil levels are calculated using the following formulas:

$$V_{wat} = \pi \cdot r_{met.tank}^2 \cdot h_{wat} ; \tag{2}$$

$$V_{oil} = \pi \cdot r_{met.tank}^2 \cdot h_{oil}; \tag{3}$$

where $r_{met.tank}$ is inner radius of the metering tank, M ; h_{wat} , h_{Doil} are the height of the water and oil layers, respectively, accumulated in the metering tank.

The values of h_{Uwat} and h_{oil} are determined according to Fig. (2) and (3) as follows:

$$h_{wat} = s \cdot \left(\Delta t_2 + \frac{\Delta \tau_1}{2} \right); \tag{4}$$

$$h_{oil} = s \cdot \left(\frac{\Delta \tau_1}{2} + \Delta t_3 + \frac{\Delta \tau_2}{2} \right); \tag{5}$$

where s is the speed of lifting the load by synchronous electric motor, m/min;

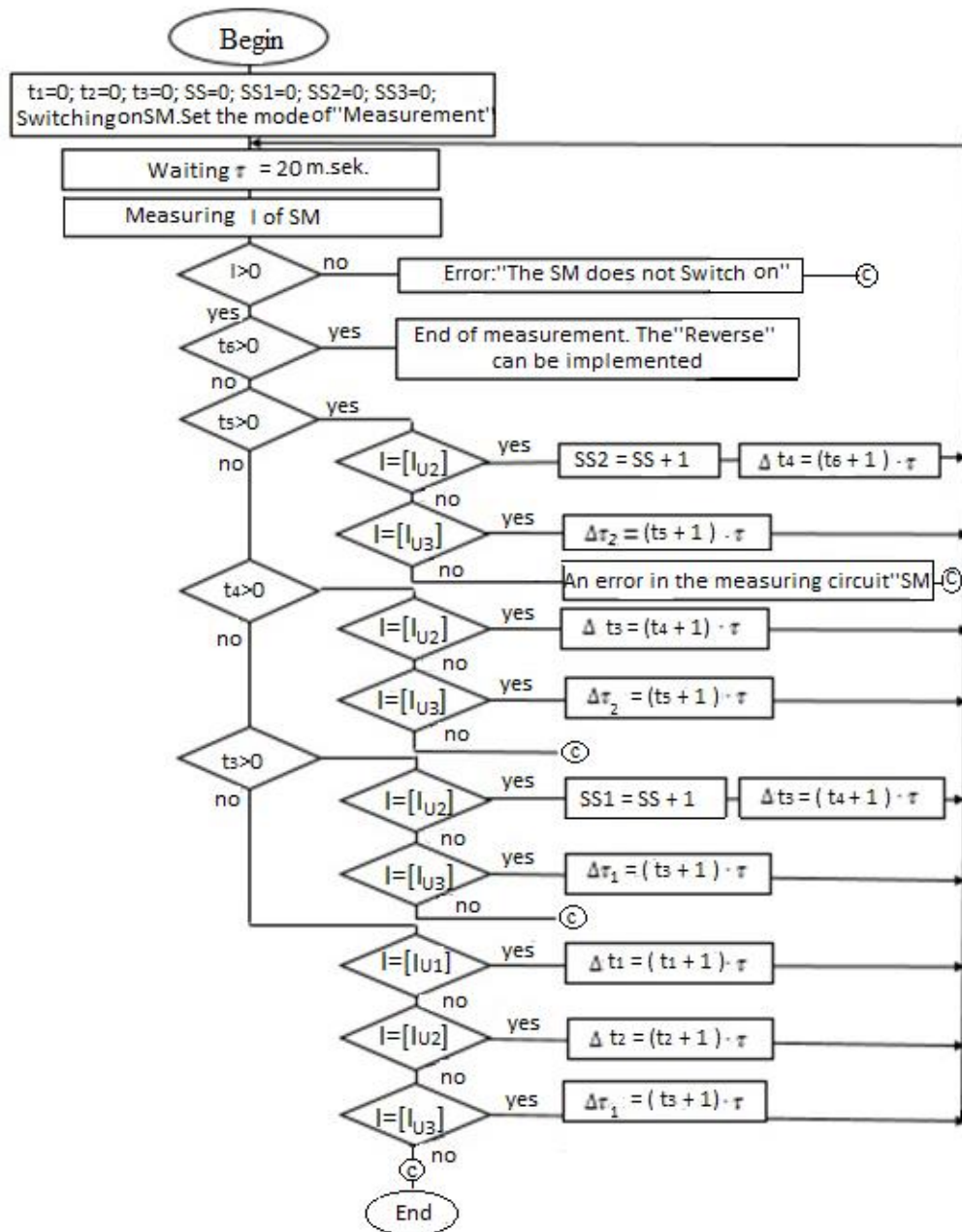


Fig.3. Algorithm for measuring and analyzing current consumption of synchronous motor to determine time intervals

Considering (4) and (5) in expressions (2) and (3), respectively, we get:

$$V_{wat} = \pi \cdot r_{met.tank}^2 \cdot s \cdot \left(\Delta t_2 + \frac{\Delta \tau_1}{2} \right); \quad (6)$$

$$V_{oil} = \pi \cdot r_{met.tank}^2 \cdot s \cdot \left(\frac{\Delta \tau_1}{2} + \Delta t_3 + \frac{\Delta \tau_2}{2} \right); \quad (7)$$

For the period of installation of the given i -th well for metering (time of metering $\Delta T_{i.w.}$, hour); Then the water and oil flow rates of this well can be calculated as follows:

$$Q_{i.w}^{wat} = V_{wat} / \Delta T_{i.w.}, m^3/h. \quad (8)$$

$$Q_{i.w}^{oil} = V_{oil} / \Delta T_{i.w.}, m^3/h. \quad (9)$$

Thus, the essence of the upgrade is to eliminate unreliable limit switches LS_1 , LS_2 , LS_3 and related mechanical parts of the U6M-VZG liquid level sensor installed in the explosion hazardous area and replace their functions with measurement and algorithmic analysis of the current consumption of the synchronous motor of the sensor, in an intelligent device, which is installed outside the explosion hazardous area.

4. Conclusion.

Thus, the proposed method of the improved principle of measuring oil well flow rate separately for water and oil in the AGM series automated group metering units on the basis of Trap has the following advantages in comparison with the ones currently in operation in the fields of the Republic of Azerbaijan, Turkmenistan, etc.:

- a meter of current consumption of synchronous electric motor is installed in the intelligent control device of the “Trap” unit, installed outside the explosion hazardous area, and the production parameters of oil and water are determined based on the results of the current values obtained there. This greatly increases the operational characteristics of the whole process of measuring the flow rate of oil wells due to the elimination of mechanical relays inside the flameproof housing of the sensor;

- the accuracy of measuring the time between pulses of different loads, which directly affect the measurement result, is increased due to the elimination of inertial mechanical transformations in electromechanical relays to obtain electrical pulses.

References

- [1] С.И. Райкевич, Нетрадиционные способы определения производительности скважин на нефтегазовых месторождениях, Международный технологический симпозиум «Интенсификация добычи нефти и газа», Москва, (2003). [In Russian: S.I. Raykevich, Non-traditional methods of determining well productivity at oil and gas fields, International Technological Symposium “Intensification of oil and gas production”, Moscow].
- [2] В.В. Андреев, К.Р. Уразаков, В.У. Далимов и др., Справочник по добыче нефти, Под редакцией К.Р. Уразакова, МООО «Недра Бизнес центр», (2000) 374 p. [In Russian: V.V. Andreyev, K.R. Urazakov, V.U. Dalimov et al, Handbook on Oil Production, Edited by K.R. Urazakov, Nedra Business Center LLC].
- [3] Ас.Г. Рзаев, Способы и средства автоматизированного измерения дебита нефтяных скважин, Известия НАНА, Серия физико-технических и математических наук. 33 No.3 (2013) pp.110-117. [In Russian: As.H. Rzayev, Methods and means of automated measurement of oil well flow rate, Transactions of the ANAS, Series of Physical-Technical and Mathematical Sciences].
- [4] Т.А. Алиев, Г.А. Гулуев, Аб.Г. Рзаев, Ас. Г. Рзаев, И.Б. Юсифов, Способ измерения дебита нефтяных

- скважин и устройство для его осуществления, Евразийский патент №019596, Дата выдачи патента 30 апреля 2014 г. [In Russian: T.A. Aliev, G.A. Guluyev, Ab.H. Rzayev, As.H. Rzayev, I.B. Yusifov, Method of measuring the flow rate of oil wells and the device for its implementation, Eurasian patent No 019596, Date of issue April 30, 2014].
- [5] Т.А. Алиев, Г.А. Гулуев, Аб.Г. Рзаев, Ас.Г. Рзаев, И.Б. Юсифов, Способ измерения дебита нефтяных скважин и устройство для его осуществления, Евразийский патент №019274, Дата выдачи патента 28 февраля 2014 г. [In Russian: T.A. Aliev, G.A. Guluyev, Ab.H. Rzayev, As.H. Rzayev, I.B. Yusifov, Method of measuring the flow rate of oil wells and the device for its implementation, Eurasian patent No 019274, Date of issue February 28, 2014].
- [6] Т.А. Алиев, Г.А. Гулуев, Аб.Г. Рзаев, Ас.Г. Рзаев, И.Б. Юсифов, Способ измерения дебита нефтяных скважин, Евразийский патент №020663, Дата выдачи патента 30 декабря 2014 г. [In Russian: T.A. Aliev, G.A. Guluyev, Ab.H. Rzayev, As.H. Rzayev, I.B. Yusifov, Method of measuring the flow rate of oil wells, Eurasian patent No 020663, Date of issue December 30, 2014].
- [7] Аб.Г. Рзаев, Г.А. Гулуев, Ас.Г. Рзаев, С.Р. Расулов, Модифицированный автоматизированный групповой мерник, Автоматизация, телемеханизация и связь в нефтяной промышленности, Москва, ОАО «ВНИИОЭНГ». No.3 (2015) pp.43-46. [In Russian: Ab.H. Rzayev, G.A. Guluyev, As.H. Rzayev, S.R. Rasulov, Modified automated group meter, Avtomatizatsiya, Telemekhanizatsiya i Svyaz v Neftyanoy Promyshlennosti, Moscow, VNIIOENG OJSC].
- [8] Аб.Г. Рзаев, Ас.Г. Рзаев, Г.А. Гулуев, С.Р. Расулов, А.М. Абдурахманова, Косвенный метод измерения дебита продукции нефтяных скважин, Автоматизация, телемеханизация и связь в нефтяной промышленности, Москва, ОАО «ВНИИОЭНГ». No.7 (2015) pp.16-18. [In Russian: Ab.H. Rzayev, G.A. Guluyev, As.H. Rzayev, S.R. Rasulov, A.M. Abdurakhmanova, Indirect method of measuring oil well production rate, Avtomatizatsiya, Telemekhanizatsiya i Svyaz v Neftyanoy Promyshlennosti, Moscow, VNIIOENG OJSC].
- [9] А.А. Абдуллаев, И.А. Набиев, Система автоматического контроля телеизмерения дебита нефтяных скважин, Баку, Азернешр, (1963). [In Russian: A.A. Abdullayev, I.A. Nabyev, A system of automatic control of telemetering of oil well flow rate, Baku, Azerneshr].
- [10] Т.М. Алиев и др., Информационные системы в нефтяной промышленности, Издательство «Недра», (1972) p.240. [In Russian: T.M. Aliev et al., Information Systems in the Oil Industry, Nedra].
- [11] Паспорт датчика уровня жидкости У6М-ВЗГ, Москва-ООП ОНТИПРИБОР, (1967). [In Russian: Passport of U6M-VZG liquid level sensor, Moscow, OOP ONTIPRIBOR].
- [12] Ас.Г. Рзаев, Я.Г. Алиев, М.Г. Резван, Микропроцессорное устройство контроля, измерения и управления АГЗУ «трап», Проблемы получения, обработки и передачи измерительной информации: Сборник научных трудов I международной научно технической конференции, Уфа: РИК УГАТУ. (2017) стр.181-184. конференции Уфа: РИК УГАТУ, 2017, pp.181-184. [In Russian: As.H. Rzayev, Y.G. Aliyev, M.G. Rezvan, Microprocessor control, measuring and management device for "Trap" AGMU, Problems of obtaining, processing and transmission of measurement information: Proceedings of the I International Scientific and Technical Conference, Ufa: RIK UGATU].
- [13] As.H. Rzayev, G.A. Guluyev, Y.G. Aliyev, M.H. Rezvan. Operating algorithms of the "TRAP" automated group measuring device controller, Informatics and Control Problems. 43 No.1 (2023) pp.66-76. <https://doi.org/10.54381/icp.2023.1.09>