UDC 681.5

Development of Scada-model for trunk gas pipeline's compressor station

Yury V. ILYUSHIN, Olga V. AFANASEVA✉
Saint-Petersburg Mining University, Saint-Petersburg, Russia

Nowadays, at all levels of created automated control systems for technological processes, programmable technical means are used that require specific software within framework of necessary functional tasks. This software should include a set of software tools that communicate with technical devices and organize «human-machine interface» (HMI) in the form of application software for AWPs with assigned communication tasks for persons, responsible for management decision-making: operators, dispatchers, managers. However, hardware architecture is unique for each particular case, so it is necessary to refine or create a new control system. This is a rather laborious process. To simplify creation of such systems SCADA-systems are used.

Article is devoted to development of SCADA-component for trunk gas pipeline's compressor workshop. Developed component allows tracking the characteristics of gas transportation process selected by operator. Development is based on «Windows» operating system and integrated environment TRACE MODE (SCADA/HMI).

Key words: analysis; monitoring; compressor workshop; management; gas

How to cite this article: Ilyushin Yu.V., Afanaseva O.V. Development of Scada-model for trunk gas pipeline's compressor station. Journal of Mining Institute. 2019. Vol. 240, p. 686-693. DOI: 10.31897/PMI.2019.6.686

Introduction. Automation of working process is not the only, but, perhaps, main direction of scientific and technological progress [4, 10]. Automation helps to increase production efficiency and eliminate various errors at working with huge amounts of information. Automation of industrial production is increasing each year, technological processes are becoming more complicated, unit capacity of various individual installations and plants is rising, requirements related to the safety of work, personnel and environment are growing, and service life of critical equipment is being extended. Safe, uninterrupted, reliable and economical operation of compressor stations can be ensured only with the help of advanced methods and technical means of control. One of the basic principles of creating automated control systems is creation of SCADA components designed to automate a specific unit and production cycle.

If considering compressor stations for transportation of gas, to eliminate human error, urgent question is creating control and monitoring systems for compressor units – SCADA components.

Statement of the problem. At considering specific trunk gas pipelines, unified, integrated SCADA systems are currently being created. Such systems are made as universal as possible. But, nevertheless, they require refinement for a specific element of the system [1, 5, 6]. One of the most vulnerable element of such a system is compressor workshop. This is mainly due to the dependence of units not only on the pumped raw material, but also on its chemical composition. Development of SCADA component of the compressor workshop provides access to output and input data of compressor workshop, such as presence of gas in trunk gas pipeline, gas flow rates at compressor workshop outlet, gas pressure at certain sections of gas pipeline and at outlets of gas compressing units, gas temperature at inlet (outlet) of a gas cooler. Let us consider a simplified diagram (Fig.1) of a gas compressor system (GCS).

Gas compressor system operates during season of gas injection into the storage facility. Gas (pressure 3.0-3.5 MPa) comes from trunk pipelines Novopskov – Aksai-Mozdok (D_N = 1200 mm), Izobilny – Nevinnomyssk (D_N = 1000 mm), then bypassing safety valves and inlets (7 and 7a) comes to mechanical cleaning, consisting of five dust collectors (DC) and three filter-separators, which are installed sequentially (capacity depending on pressure is up to 45 million m^3/day), where mechanical and liquid impurities are cleaned.

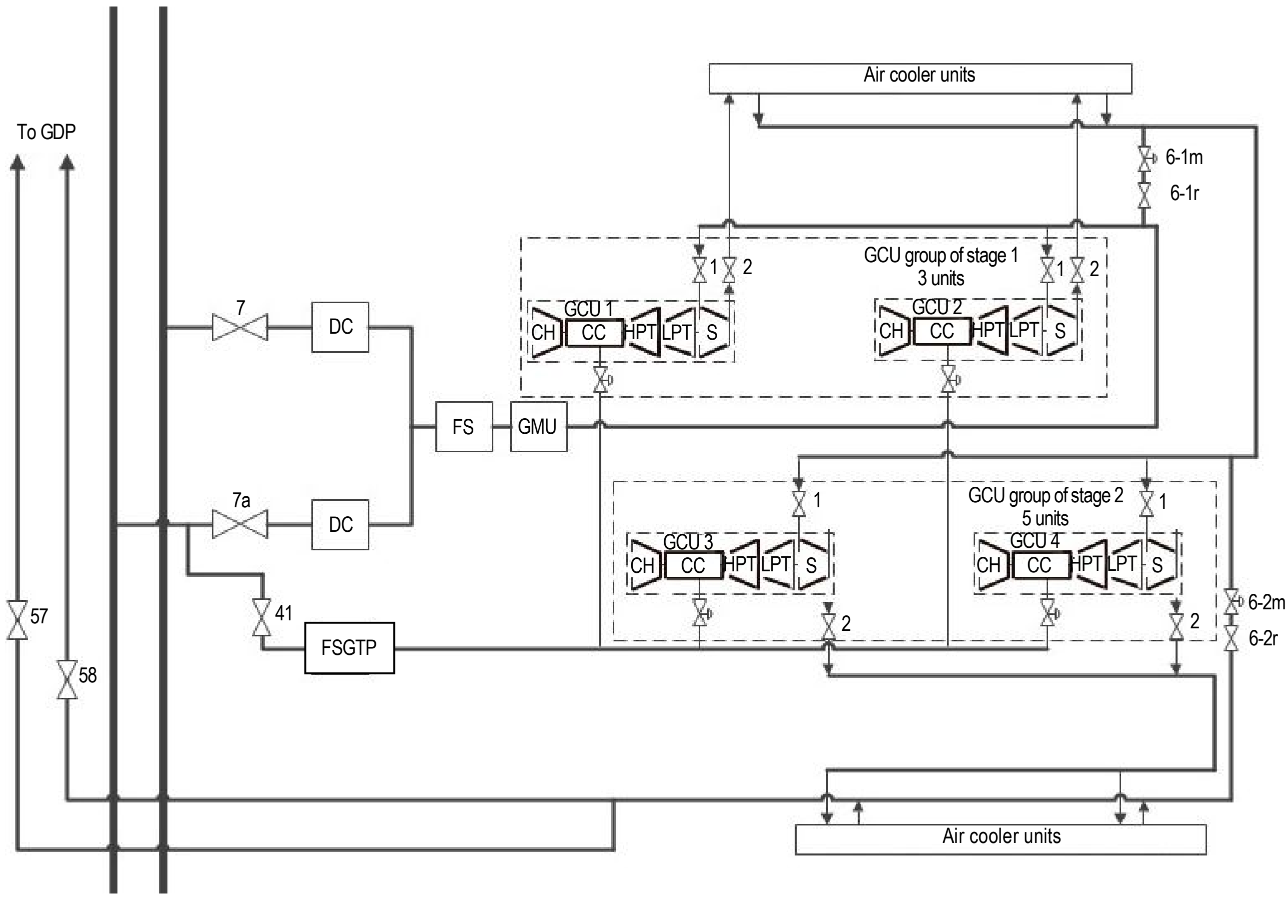

Fig.1. GCS simplified basic circuit scheme
GDP – gas-distributing plant; DC – dust collectors; FS – filter-separators; FSGTP – fuel and start-up gas treatment plant; GMU – gas metering unit; CC – combustion chamber

After treatment, gas enters first stage GCU inlet collector of the GPA-C-6.3 type (NCV-50/1.45). At the first stage, gas is compressed to 4.5–5.1 MPa, cooled to a temperature of 30-40 °C in gas air cooler units (ACU), and fed to inlet collector of the second stage.

At the second stage (5 GCU of GPA-C-6.3 (NCV-100/2) type), gas is compressed to 8.0-12.5 MPa, cooled to a temperature of 38-42 °C in gas ACU.

Cooled gas through head collectors enters GDP, where distribution among wells and gas injection into formation is carried out [4, 11, 12].

At automation of gas transportation process, structure of the system should be strictly hierarchical [2, 3, 6, 7]. At the top step is the task of transporting required volume of gas with ensuring the running of the technological process with the highest possible efficiency. At a lower level of the hierarchical structure is the task of managing diverse executing mechanisms, i.e. of more local plan. At the top level, one of the tasks is to determine required volumes of gas transportation. Based on solutions provided by system for this task, necessary setting of transportation power is determined. Chief dispatcher is responsible for this task, who makes a decision based on information on amount of gas transported in trunk gas pipelines adjacent to the station, as well as gas demand of the population. This level of control gives a value that will be used in our system as a setting.

Compressor station level manages through distribution of capacities between compression groups in order to ensure maximum possible efficiency of compressor units. This hierarchical level performs following tasks:

- treatment of various types of gas (fuel, start-up);

- physical connection of trunk gas pipeline and compressor workshop;
- control of turbines' rotation frequencies in gas compressor units;
- proper load distribution between gas compressor units;
- workshop regulation.

Each level of hierarchical structure has its own management tasks and their solution allows developing requirements for moving to a lower level of hierarchy. However, quality of entire system depends on solution of the tasks set at the lowest level; therefore, sustainable operation of all levels of the structure, including local control objects in gas compressor units, cannot be neglected [6]. That is why we will begin consideration of the compressor workshop's functional scheme with local control objects.

Methodology. Gas compressor units of GPA-C-6.3 type – block, complete automated installations with a gas turbine aviation drive NCV-50/1.45 with power of 6.3 MW – are designed to transport natural gas through trunk gas pipelines, and can also be used on booster compressor stations as a control element for pumping fluid into formation.

Gas compressor unit is unified and, depending on design of supercharger's flow part, can be used at a final pressure of 5.6 (56) MPa. Unit ensures normal operation at ambient temperature from 233 to 318 K (from – 40 to 45 °C).

Compressed gas – natural, non-corrosive, explosive. Composition and thermodynamic properties of rated natural gas are given in GOST 54404-2011. Dust content of gas entering the supercharger should not exceed 5 mg/m^3, size of mechanical particles should not exceed 40 μm.

Maximum humidity corresponds to a saturation state in the absence of drip moisture. Suction gas temperature varies from 233 to 318 K (– 40 to 45 °C).

Type of compressor is a two-stage centrifugal supercharger with a vertical connector, designed for parallel operation in a group or for a single unit. Main parameters of the supercharger are given in GOST 54404-2011.

Transported gas enters inlet of a two-stage centrifugal supercharger through gas pipeline by the means of suction pipe, where it is compressed and discharged through the discharge pipe into trunk gas pipeline.

As supercharger drive, a stationary gas turbine engine NCV-50/1.45 of an aviation type, working on the transported gas, is used. Engine is made according to a two-shaft scheme with a free power turbine.

Air, which is purified in the unit's air-cleaning device, enters axial compressor of the engine, where it is compressed and enters the combustion chamber. At the same time, fuel (natural gas) is supplied to combustion chamber through the working nozzles. From the chamber, hot gases are sent to compressor turbine blades, and then through gas pipeline to power turbine.

Power of the turbine's compressor is spent on rotation of compressor itself and the drives of the units, and power of the power turbine is used to drive the supercharger rotor and drive its units. Mechanical connection between power turbine and supercharger rotor is done through a hollow torsion shaft. Exhaust gases through the scroll, exhaust device and exhaust silencer are emitted into the atmosphere. Unit is equipped with various auxiliary systems that ensure reliability of its operation if installed in open areas and ambient temperature from 233 to 318 K (from – 40 to 45 °C) [8-10].

In order to develop SCADA component of selected compressor station of trunk gas pipeline, it is important to determine its internal infrastructure connections between individual components. For this, representations of its macro- and microstructures are necessary. Macrostructure for selected compressor station CS-17 specifies global processes taking place in considered section of trunk gas pipeline. Nodes of microstructure can be used to determine output values, and by them – technological structure of considered CS-17. Based on the information received, a technological and functional scheme is compiled.

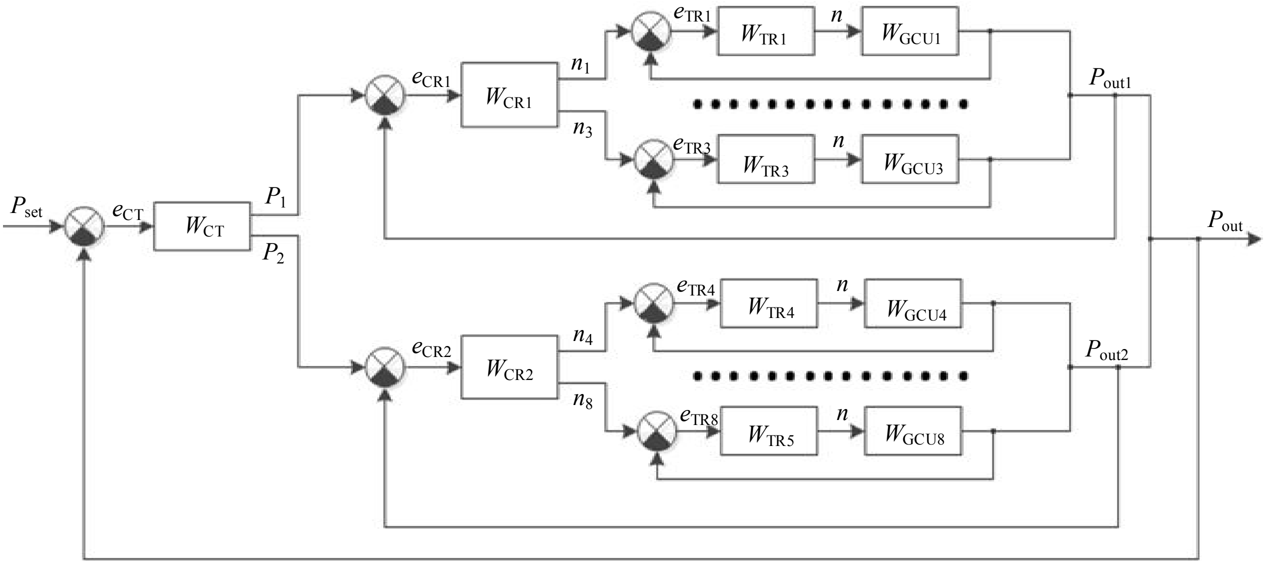

Fig.2. Structural scheme of compressor station

Technological scheme is a standard unified document containing information, instructions used by the personnel of the organization performing a certain technological process or maintenance of a technological object.

Cascade regulator synthesis. Management of compressor station has several distinctive features:

- Steadiness of technological process.
- Time lag. Compressor workshop injects compressible gas into part of gas pipeline, which has the characteristics of an integral link with saturation and a large delay. This fact negatively affects the quality of regulation, reaction to control action may occur after a long period of time.
- Load distribution between units. There are three schemes of compressor workshop operation: in parallel, in series and in series-parallel. In our case, series-parallel operation of the workshop is used, which is typical for underground gas storages, since a high degree of compression is required.

Structural scheme of compressor station is shown in Fig.2. Consideration of structural scheme of the regulator system will begin with the internal circuit. Control object is a gas compressor unit, which increases pressure by means of a supercharger. If principle of operation is considered in a simplified manner, it can be said that regulating body in this case will be the fuel control valve, opening degree of which affects the amount of fuel entering GCU combustion chamber, which directly affects speed of the supercharger, and hence pressure change in output circuit.

Presented gas compressor units do not differ from each other fundamentally, i.e. they have same characteristics, mathematical models, and therefore regulators.

Internal circuit is considered as a combination of fuel regulator and gas compressor unit, since these objects are controlled in the ACS of GCU.

Before proceeding with direct identification of control object, it is necessary to form an input and output data array. First of all, functional relationship between opening percentage of the fuel control valve and increase in speed of low pressure turbine is determined. Data used to identify the object are taken from performance characteristics of GTK-10I turbine.

Input data for our system is position of turbine control valve (TCV), output data is low-pressure turbine (LPT) rounds.

To build an identification model, interactive graphic program IDENT is used, which is part of the System Identification Toolbox package in Matlab software.

Autoregression algorithm is taken as an identification algorithm. To characterize degree of model adequacy to the object, rms criterion is selected, according to which such evaluations of parameters are sought that provide minimum average square of the difference between output signals of the model and the object under the same input action [13]. Autoregressive model is described by the following equation:

$$A(q)y(n) = B(q)u(n) + e(n),$$

where $A(q) = 1 + \sum_{i=1}^{n} a_i q^{-i}$, $B(q) = \sum_{i=1}^{n} b_i q^{-1}$, $e(n)$ – obstacle.

Based on the conducted identification, transfer function is obtained, connecting the opening degree of TCV with an increase in speed of LPT:

$$W(s) = \frac{k}{(1+T_{p1}s)(1+T_{p2}s)}.$$

Substituting numerical values, following transfer function is obtained:

$$W(s) = \frac{3}{95s^2 + 25s + 1}.$$

Resulting model was tested in bench tests conducted at Research and Production enterprise «Sistema-Servis».

For the object under consideration, link that provides necessary correction of linear amplitude characteristic (LAC) should have a transfer function (TF) of following type:

$$W_{\text{cor}} = \frac{K_{\text{cor}}\left(\tau_{\text{cor}}s + 1\right)}{s}$$

or

$$W_{\text{cor}} = \frac{K_{\text{cor}}\left(\tau_{\text{cor}1}s + 1\right)\left(\tau_{\text{cor}2}s + 1\right)}{s}.$$

Consider transfer functions corresponding to PI and PID regulators:

$$W_{\text{cor}} = \frac{K_{\text{cor}}}{s} + K_{\text{cor}}\left(\tau_{\text{cor}1} + \tau_{\text{cor}2}\right) + K_{\text{cor}}\tau_{\text{cor}1}\tau_{\text{cor}2}s$$

or

$$W_{\text{cor}} = \frac{K_{\text{integ}}}{s} + K_{\text{prop}} + K_{\text{dif}}s;$$

$$K_{\text{integ}} = K_{\text{cor}};$$

$$K_{\text{prop}} = K_{\text{cor}}\left(\tau_{\text{cor}1} + \tau_{\text{cor}2}\right);$$

$$K_{\text{dif}} = K_{\text{cor}}\tau_{\text{cor}1}\tau_{\text{cor}2}.$$

Regulator gain coefficients K_{prop}, K_{integ}, K_{dif} are represented in transfer functions as time constants τ_1, τ_2 and coefficient K, therefore when adjusting regulator, one can distinguish components that affect compensation of TF poles and speed. For example, one can first adjust compensation, and then gradually increase gain coefficient and thereby – system speed to required level. Regulator is softwarily implemented in the form of following difference equations:

$$d = \frac{K_{\text{cor}}\tau_{\text{reg}1}\tau_{\text{reg}2}(x_k - x_{k-1})}{cycle};$$

$$i = i + K_{\text{cor}}cycle\frac{x_k + x_{k-1}}{2};$$

$$y_k = x_k K_{\text{cor}}(\tau_{\text{reg1}} + \tau_{\text{reg2}}) + d + i,$$

where x – input signal (regulation error); y – regulator output; indices k and $k-1$ correspond to current and previous counts; *cycle* – cycle duration of control program call.

In steady state, regulator output is equal to the integrating component. Therefore, to initialize regulator, $i = y$ is used.

Regulator must ensure transition of control object to a given operating point with a positioning error of not more than 0.5 s and transfer processes without overregulation with a transient time of not more than 0.4 s.

Reaction rate to deviation of controlled quantity from the setting depends on the gain coefficient of proportional component K_{p}.

Response of system to rate of change of controlled quantity is determined by the gain coefficient of differential component K_{d}: differential component will work faster than proportional, and will compensate for sharp deviation of the value from setting.

At change of setting, accuracy of its implementation is determined by integral component of regulator.

Transfer function of regulator can be written as follows:

$$W_{\text{reg}} = K_{\text{p}} + K_{\text{d}}s + K_{\text{i}}\frac{1}{s},$$

where K_{p} – transfer coefficient of regulator proportional component; K_{d} – transfer coefficient of regulator differential component; K_{i} – transfer coefficient of regulator integral component.

For our case, it is necessary that function takes following form:

$$W_{\text{reg}} = K_{\text{reg}}\frac{T_{\text{OY}}^2 s^2 + 2T_{\text{OY}}\zeta s + 1}{s},$$

where K_{reg} – total transfer coefficient of regulator.

In this case, LAC “correction” of original OY will occur, and LAC of open-loop system with regulator will have a slope of 20 dB over its entire length. Depending on value of K_{reg}, this LAC will move along the ordinate axis.

If K_{reg} value changes, time of transfer process and overregulation value will change. This implies a subtask – it is necessary to find range of K_{reg} values at which the requirements for transfer process time (not more than 0.4 s) and overregulation (zero) will be met. Solution to this problem is found experimentally – system with a regulator will be simulated for various K_{reg} values in Simulink software.

Numerical example. Simulation scheme of system with regulator is shown in Fig.3, and transfer function graph is shown in Fig.4.

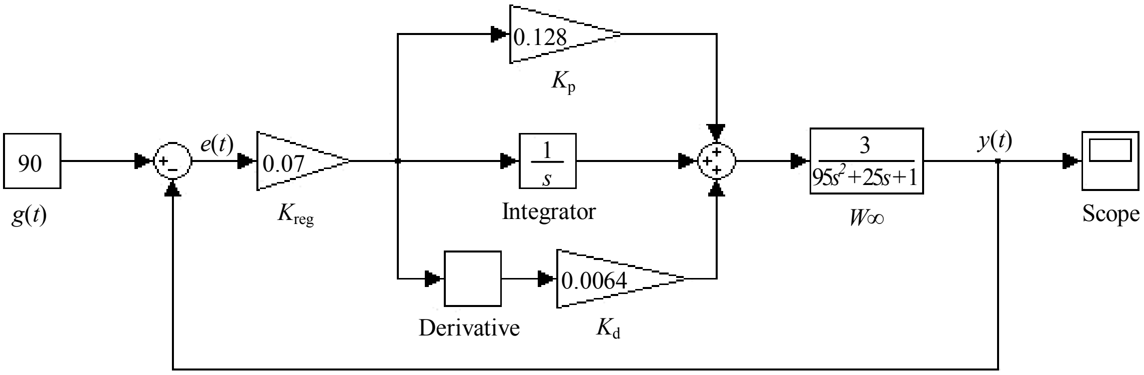

Fig.3. Simulation scheme of corrected system

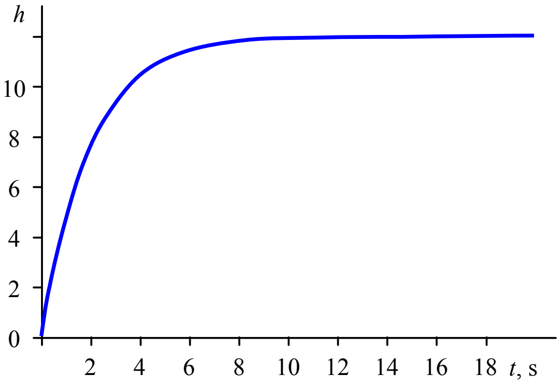

Fig.4. Transfer process of corrected system
h – function value depending on time *t*

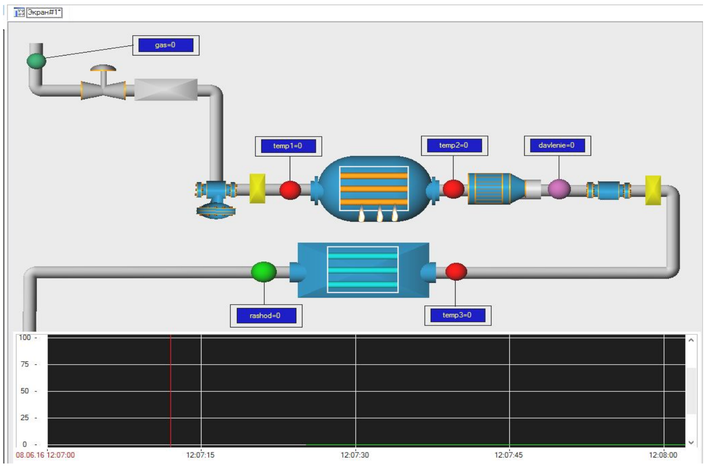

Fig.5. Project's main screen

Thus, resulting system shows a transition process taking into account all disturbing influences.

To develop graphical interface for AWP, graphical editor of integrated development environment will be used. In accordance with functional scheme of compressor station, a common screen for displaying information on sensors will be composed. During development of graphic part of the system, built-in library of graphic elements can be used, which must be moved from program folder to the folder «C:\ProgramData\AdAstra\TraceModeIDE6\ tmdevenv.tmul». Obtained result is shown in Fig.5.

After studying all connections between elements of the system and specifying all channels necessary for input and output information, development of programs, for which these elements will work in the environment Trace Mode, can begin.

Then, after compiling and writing default values for program arguments, cycle execution for an indefinite number of times to check operability of the program code is started.

Thus, development of a software package for managing gas compressor station is done.

Discussion. Modern development of gas industry in Russia is characterized not only by a rapid increase in production volumes, which is due to the need for natural gas on external and internal markets, but also by reconstruction of functioning gas fields. Automation of gas production units as the lowest links in management structure of the Unified system of Russian gas supply is a powerful incentive to increase product quality and reliable gas supply of consumers.

For improvement and introduction of latest gas production equipment and commissioning of the investigated field, it is important to provide integrated automated control systems (ACS). Implementation of technological equipment upgrades and introduction of ACS at gas fields by technological processes (TP) is explained by high demand for quality of natural gas for its transportation and increased reliability of technological equipment due to continuous organization of production, as well as tendency to improve the operation modes of wells and integrated gas treatment plants (IGPP).

Conclusion. Conducted studies have shown the importance of developing applied methods for modeling and controlling various processes in demand in gas industry. Practical value of the results lies in obtained mathematical models, which allow predicting behavior of structure with changing parameters that determine operating modes of the system.

Object of compressor workshop, obtained as a result of SCADA operation, is universal and can be used for objects with identical parameters.

However, use of this component has a number of limitations that are associated with correction factors obtained in synthesis of transfer function. At the same time, obtained component fulfills the task of modeling and managing compressor workshop.

REFERENCES

1. Galkin A.F. Complex Use of Heat-Exchange Tunnels. *Zapiski Gornogo instituta*. 2017. Vol. 224, p. 209-214. DOI: 10.18454/PMI.2017.2.209 (in Russian).

2. Gryazev M.V., Kachurin N.M., Vorobiev S.A. Mathematical Models of Gas-Dynamic and Thermophysical Processes in Underground Coal Mining at Different Stages of Mine Development. *Zapiski Gornogo instituta*. 2017. Vol. 223, p. 99-108. DOI: 10.18454/PMI.2017.1.99 (in Russian).

3. Il'yushin Yu.V., Pershin I.M. Method of Controlling the Temperature Field on the Basis of the Green's Function. *Journal of Mining Institute*. 2015. Vol. 214, p. 57-70 (in Russian).

4. Il'yushin Yu.V., Trushnikov V.E. Development of pulse control for drilling augers' temperature field for the extraction of hot mineral water at Kislovodsk narzan deposit. *Gornyi informatsionno-analiticheskii byulleten'*. 2014. N 2, p. 172-181 (in Russian).

5. Kazanin O.I., Sidorenko A.A., Sirenko Y.G. Numerical study of the air-gas dynamic processes when working out the Mosshny seam with longwall faces. *Journal of Engineering and Applied Sciences*. 2018. N 13(4), p. 1534-1538.

6. Kazanin O.I., Sidorenko A.A., Vinogradov E.A. Substantiation of the technological schemes of intensive development of gas-bearing coal beds. *Journal of Engineering and Applied Sciences*. 2017. N 12(7), p. 2259-2264.

7. Kolesnikov A. Nonlinear Oscillations Control. Energy Invariants. *Journal of Computer and Systems Sciences International*. 2009. N 48(2), p. 185-198. DOI: org/10.1134/S1064230709020038

8. Kolesnikov A., Zarembo Ya., Zarembo V. Discharge of a Copper-Magnesium Galvanic Cell in the Presence of a Weak Electromagnetic Field. *Russian Journal of Physical Chemistry*. 2007. N 81(7), p. 1178-1180. DOI: org/10.1134/s003602440707031x

9. Pleshivtseva Y., Rapoport E. The Successive Parameterization Method of Control Actions in Boundary Value Optimal Control Problems For Distributed Parameter Systems. *Journal of Computer and Systems Sciences International*. 2009. N 48(3), p. 351-362. DOI: org/10.1134/S1064230709030034

10. Rapoport E. Structural Parametric Synthesis of Automatic Control Systems with Distributed Parameters. *Journal of Computer and Systems Sciences International*. 2006. N 45(4), p. 553-566. DOI: org/10.1134/S1064230706040071

11. Sidorenko A.A., Sirenko Yu.G., Sidorenko S.A. Influence of face advance rate on geomechanical and gas-dynamic processes in longwalls in gassy mines. *Eurasian Mining*. 2018. N 1, p. 3-8. DOI: 10.17580/em.2018.01.01

12. Zarembo V., Kiseleva O., Kolesnikov A., Burnos N., Suvorov K. Structuring of Inorganic Materials in Weak Rf Electromagnetic Fields. *Inorganic Materials*. 2004. N 40(1), p. 86-91. DOI: org/10.1023/B:INMA.0000012184.66606.59

13. Zarembo V., Kolesnikov A. Background Resonant Acoustic Control of Heterophase Processes. *Theoretical Foundations of Chemical Engineering*. 2006. N 40(5), p. 483-495. DOI: org/10.1134/s0040579506050058

***Authors*: Yury V. Ilyushin,** *Candidate of Engineering Sciences, Associate Professor, ilyushin_y@bk.ru (Saint-Petersburg Mining University, Saint-Petersburg, Russia),* **Olga V. Afanaseva,** *Candidate of Engineering Sciences, Associate Professor, ovaf72@gmail.com (Saint-Petersburg Mining University, Saint-Petersburg, Russia).*

The paper was received on 15 April, 2019.

The paper was accepted for publication on 17 September, 2019.