УДК 681.5.017
МРНТИ 50.43.15

GAS TRASPORTING UNIT OPERATION MODES MODELING

N.A. BATAYEV[1], A.R. KUZYRGALIYEV[2]

[1]*Kazakh National Research Technical University after K.I. Satpayev*
[2]*"Zeinet&SSE" LLP*

Abstract: *Modern Oil and Gas facilities are requiring control systems applications, upon which exclusive standards of quality, and reliable work of hardware and software are imposed. Gas and steam turbines, high-pressure boilers, oil and gas handling, storage and refining systems refer to such facilities. The main objectives of this article are the description of the software designed to simulate of multistage gas compressor operation modes with associated equipment. A check is made of the adequacy of software to real data, checking the response of the system to external influences and changes in system parameters also performed.*

Keywords: *Centrifugal Gas compressor, gas turbine, anti-surge control, multistage compressor, mass flow rate*

ГАЗ ТАСЫМАЛДАУ АГРЕГАТТЫҢ ЖҰМЫС РЕЖИМДЕРІН МОДЕЛЬДЕУ

Аңдатпа: *Заманауи мұнай-газ қондырғылары ерекше сапа стандарттарын, аппараттық және бағдарламалық сенімді жұмысын қамтамасыз ететін басқару жүйелерін пайдалануды талап етеді. Осындай нысаналарға газ және бу турбиналары, жоғары қысымды қазандықтар, тасымалдау жүйесі, мұнайды сақтау және өңдеу системалары жатады. Бұл мақалада көп сатылы газ компрессорының және қосалқы қондырғыларын модельдеу үшін арналған бағдарламалық қамтамасыздандыру баяндалған.*

Түйінді сөздер: *газ компрессор қондырғысы, газ турбинасы, тасымалдау жүйесі, антипомпаждық бақылау*

МОДЕЛИРОВАНИЕ РЕЖИМОВ РАБОТЫ ГАЗОПЕРЕКАЧИВАЮЩЕГО АГРЕГАТА

Аннотация: *Современные объекты нефтегазовой отрасли требуют применения систем управления, на которые накладываются исключительные стандарты качества и надежная работа аппаратного и программного обеспечения. В данной статье приводится описание программного обеспечения (ПО), предназначенного для моделирования режимов работы многоступенчатого газового компрессора и сопутствующего оборудования, используемого на современных компрессорных станциях. Приводится проверка адекватности программного обеспечения реальных данных, проверка реакции системы на внешние воздействия и изменения параметров системы.*

Ключевые слова: *центробежный газовый компрессор, газовая турбина, антипомпажное регулирование, многоступенчатый компрессор, массовый расход*

INTRODUCTION

Natural gas is one of the most common sources of energy in the modern world. Gas is transported from production sites to consumers by gas compressor stations, which makes it possible to increase gas pressure for subsequent transportation via a gas pipeline. An integral part of any compressor station is a centrifugal supercharger and a gas turbine. Depending on the model, the centrifugal compressor is able to increase the gas pressure by 1.2-1.5 times.

Compressors are generally divided into two categories: Positive Displacement Compressors and Dynamic Compressors. Positive displacement compressors in essence work by entrapping a volume of gas and subsequently reducing this volume which in turn increases the pressure. Positive displacement compressors will not be covered further in this article.

Dynamic compressors generally work by transferring movement to the gas; i.e. kinetic energy is transferred from the machines internals to the gas. By subsequent reduction of this velocity the kinetic energy is converted into potential energy – pressure. The two main types of dynamic compressors are: Axial Compressors and Centrifugal Compressors.

Axial compressors transfers movement to the gas in the axial direction. This is done by a series of rotors similar to those seen at the air intake in the front of jet-engines. Each rotor is followed by a stator where the kinetic energy, transferring to the gas by the rotor, is converted into pressure. Centrifugal compressors, on the other hand, work by transferring movement to the gas in radial direction by an impeller. This outward velocity is then converted into pressure in a diffuser.

Based on the theory for centrifugal compressors and control theory a control strategy has been applied to the model based on the available equipment. The model has been used to investigate how the gas compression system responds to changes in the compressor inlet flows and conditions. The concept of using the model of the compressor and the compressor control system model.

The main task of the compressor station is the uninterrupted operation of gas pumping units for supplying gas to various settlements and plants. In this regard, the task of modeling, troubleshooting and diagnostic of gas pumping units is very important. Like any other equipment, gas turbine parts wear out over time. It is very important to prevent damage in due time. And it is best to make a forecast of future faults in time to eliminate them. The sources describe various methodologies for modeling [1]–[8] and diagnostics of gas turbine engines [9]–[14]. Fault classification using machine learning methods are given in the source [15]–[17].

This paper describes the software designed to simulate of gas transporting unit's operation modes with associated equipment.

METHODS

The considered software is an interface that allows users to create various technological schemes involving elements such as gas compressor, heat-exchanger, gas-liquid separator, valve, anti-surge control line. User can select these elements from the library and generate the required schemes by connecting elements to each other in any sequence. The user is prompted to select required gas components from library. The main window of the software is shown in Fig. 1.

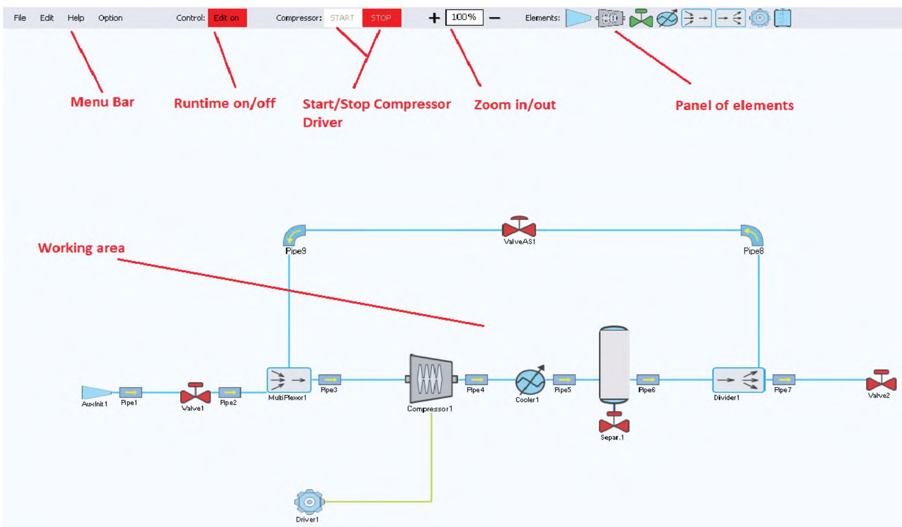

Fig. 1. The main interface of the developed software

The application consists of the number of different objects which simulates the real equipment. The main objects are: compressor – is the mathematical model of the real gas compressor; separator – is the mathematical model of the real gas-liquid (2 stage) separator (knock-out drum); heat exchanger – is the mathematical model of the real gas heat exchanger (as the cooling liquid is used water); valve – is the mathematical model of the real valve; compressor driver, gas flow input, gas mixer (multiplexor) and tie (divider).

Compressor one of the main equipment in simulated model. It is possible to build different structures with compressor: parallel, serial, parallel-serial, etc. Each compressor has own parameters such as compressor curve, nominal speed, polytropic efficiency, capacity. Fig. 2 is the Dialog box for enabling compressor parameters. The tab “Main parameters” contains inlet and outlet parameters of the compressor, the tab “Gas composition” shows current gas composition through compressor. These two tabs are the same for all other objects (the same number and type of parameters).

In order to draw compressor curve user should enter Flow array and corresponding Polytropic Head array; these parameters will be different for different types of compressors. These arrays will draw red line at the curve. Then the special function inside of this block will calculate polynomial coefficients (a,b,c,d) of the function dx^3+cx^2+bx^1+a which will approximate red line, at the curve the light blue line is the approximation function. The approximating coefficients array [a,b,c,d] sends to a corresponding compressor, where using these coefficients calculates Polytropic Head for current volumetric flow through the compressor by the next equation:

$$H_n = d \cdot Q^3 + c \cdot Q^2 + b \cdot Q + a \quad (1)$$

This dialog box also allows to users to save compressor curve arrays to file (“Save as” in menu), *.txt format is recommended, and to upload earlier saved arrays from file (“Upload” in menu). Further Polytrophic Head is used for calculation of compressor’s discharge temperature and pressure.

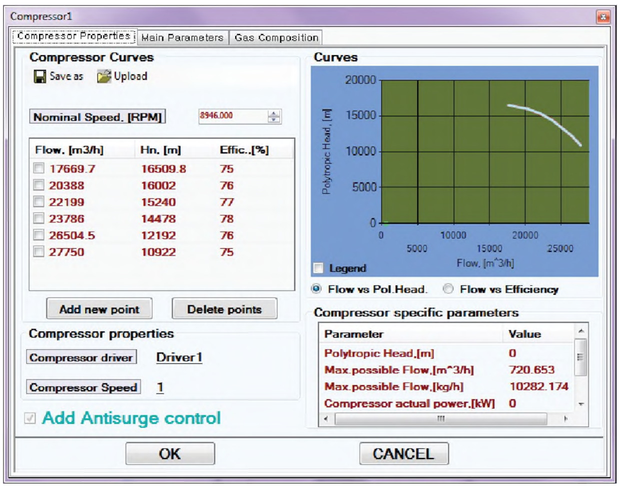

Fig. 2. Centrifugal gas compressor dialog box

Gas-liquid separator is used to separate gas and water vapor. In *Fig. 3* is shown Dialog box for gas-liquid separator.

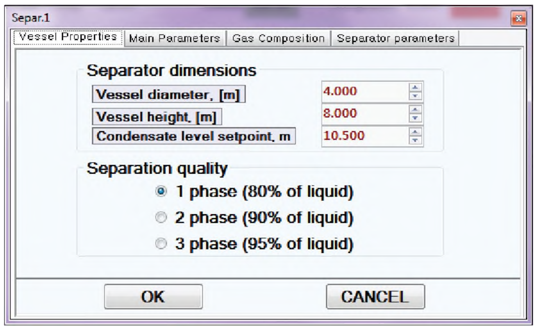

Fig. 3. Dialog box for separator

From dialog box user can set parameters for separator: Vessel diameter, Vessel height, Condensate Level set-point, Separation quality. Level set-point is compares with the current condensate level, if the set-point is more than the current value liquid drain valve is opens. Number of separation phases is the parameter which simulates the separation process efficiency: “1 phase” – means that the 80% of the condensate will removed, “2 phase” - means that the 90% of the condensate will removed, “3 phase” - means that the 95% of the condensate will be removed. If the gas composition will not contain water, the separator’s condensate level will be unchanged. The tab “Separator parameters” contains calculated specific parameter of the separator.

The application contains two main types of valve: common valve and an anti-surge one.

Common valve could be chosen directly from object panel, anti-surge valve could be added from compressor's dialog box by enabling "Add Anti-Surge Control" check box. In Fig. 4 is shown Dialog box for common valve. In the "Valve Properties" tab user can choose appropriate parameters for valve:

"CV value" – CV value for valve or capacity of the valve in US GPM.

"C1 value" – C1 value according to valve's passport data.

"Const. press. drop" – constant pressure drop at valve in [bar].

"Shutdown valve" – if this check box enabled after pressing stop button valve will go to fully close position (0%)

"Valve pos." – manual value for valve position from 0 to 100%

"Valve opening time" – time in seconds required to change the position of valve from 0% to 100% or versa from 100% to 0%.

"Disch. Press." – enabling of this checkbox allows to keep the discharge valve's pressure at constant pressure, "Const. press. drop" will be disabled.

"Flow Charact." – allows to choose valve's capacity characteristic: Linear, Quick Opening or Equal Percentage.

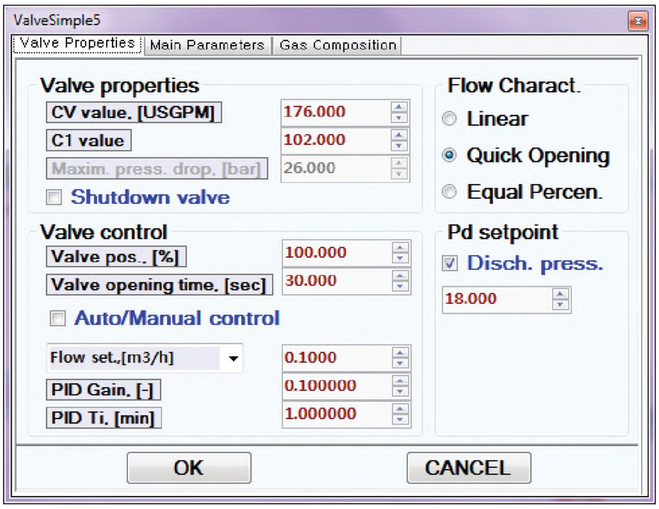

Fig. 4. Dialog box for valve

"Auto/Manual control" – if this checkbox disabled valve will open according to setpoint indicated in "Valve pos." field. If this checkbox enabled valve will opened or closed in order to keep the setpoint of outlet volumetric flow or temperature indicated in the field below.

"PID Gain" – is the proportional gain for valve position regulator (applicable if "Auto/Manual control" enabled)

"PID Ti" – is the integration time coefficient for valve position regulator (applicable if "Auto/Manual control" enabled)

RESULTS AND DISCUSSION

To validate the results, software has been tested. Two stage gas compressor has been modeled in startup sequence [18]. This mode involves acceleration of compressors and reaching of rated speed with fully open anti-surge valves. One of the important parameters for this simulation mode is the time required to accelerate compressors to nominal speed. For simulated and real systems this time is 60-70 seconds. Fig. 5 - Fig. 7 are shows changings of volumetric flow, pressure and temperature during compressors' start sequence.

As seen on trends the character of the volumetric flow-rate changing smoothly while the anti-surge valves are fully open, as anti-surge valves closing the character of flow changing.

The Fig. 6 shows that the character of pressure changing without high fluctuations. The pressure difference between the outlet of the first compressor and inlet of the second compressor for simulated system is greater than for the real one, as well as in the simulated system between the first and the second stages the valve is mounted with the constant pressure drop. The

Fig. 5. Volumetric flow-rate of gas during the compressors' start sequence

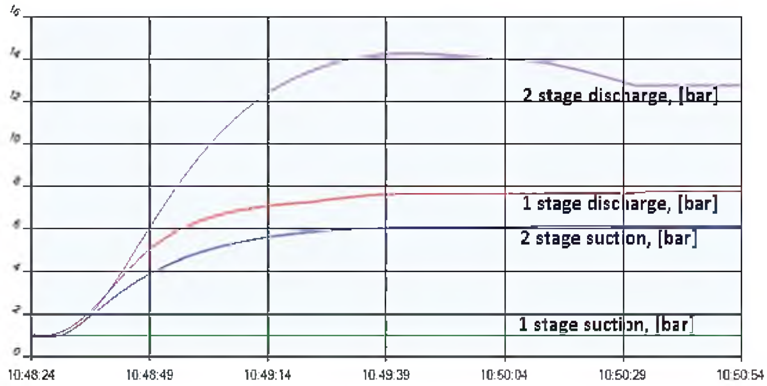

Fig. 6. Pressure of gas during the compressors' start sequence

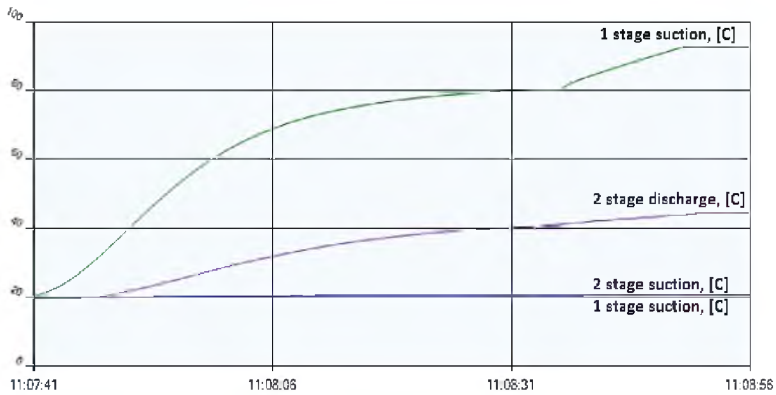

Fig. 7. Temperature of gas during compressors' start sequence

gas pressure at the 2 stage discharge is rises then decreases.

Temperature trends for compressor's start sequence shows slight differences between the simulated and the real systems. For the simulated system the initial values of temperatures are 20 °C, for the real system the initial temperature for the second compressor is 40°C. This is due to the fact that the software is not modeled heat accumulation on the walls of the compressor.

CONCLUSION

Within this article there was presented a description of software for simulating multistage gas compressor operation modes; carried out a series of tests to verify the adequacy of the software to real data and reaction of the system to external influences. According to test results, we can conclude that the simulated system for different operating modes and parameters gives results close to real. It can be suggested that considered software allows to estimate real processes in equipment such as gas compressor, heat-exchanger, gas-liquid separator, gas valve, pipe; presented calculations are based on real data and show the practical significance of the obtained results; each equipment described by mathematical model with corresponding formulas which leads the model to the real technological process; given software takes into account factors affecting the real process of gas compression; simulation algorithms adequately reflect the real processes in the present equipment.

REFERENCES

1. V. Dragan, I. Malael, and B. Gherman, "Development of a very high pressure ratio single stage centrifugal compressor," *Int. Rev. Model. Simulations*, vol. 8, no. 3, pp. 347–353, 2015. DOI:10.15866/iremos.v8i3.6020.
2. K. Jones, A. Cortinovis, M. Mercangoez, and H. J. Ferreau, "Distributed Model Predictive Control of Centrifugal Compressor Systems," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 10796–10801, 2017. DOI:10.1016/j.ifacol.2017.08.2343.
3. R. A. Stanley and W. R. Bohannan, "Dynamic Simulation of Centrifugal Compressor Systems," *Proc. sixth Turbomach. Symp.*, pp. 123–132, 1977.
4. H.-K. Li, X.-F. Wang, J.-G. Yang, P.-F. Zhao, and Y. Liu, "The effect of impeller–diffuser interactions on diffuser performance in a centrifugal compressor," *Eng. Appl. Comput. Fluid Mech.*, vol. 10, no. 1, pp. 565–577, 2016. DOI:10.1080/19942060.2016.1210028.
5. R. Matas, T. Syka, and O. Luňáček, "Numerical and experimental modelling of the centrifugal compressor stage – setting the model of impellers with 2D blades," *EPJ Web Conf.*, vol. 143, p. 02073, 2017. DOI:10.1051/epjconf/201714302073.
6. V. V. N. K. S. Koyyalamudi and Q. H. Nagpurwala, "Stall Margin Improvement in a Centrifugal Compressor through Inducer Casing Treatment," *Int. J. Rotating Mach.*, vol. 2016, pp. 1–19, 2016. DOI:10.1155/2016/2371524.
7. H. Dehnavifard, G. Radman, and M. Kalyan, "Design and comparison of high-speed induction machine and high-speed interior permanent magnet machine," *Int. Rev. Model. Simulations*, vol. 11, no. 3, pp. 151–157, 2018. DOI:10.15866/iremos.v11i3.14112.
8. K. K. Botros, P. J. Campbell, and D. B. Mah, "Dynamic Simulation of Compressor Station Operation Including Centrifugal Compressor and Gas Turbine," *J. Eng. Gas Turbines Power*, vol. 113, no. 2, p. 300, 2008. DOI:10.1115/1.2906563.
9. D. Gašparovič, M. Výžinkár, J. Žarnovský, and J. Blata, "Turbine Modification of Nuovo Pignone Gas Turbine," *Acta Technol. Agric.*, vol. 20, no. 3, pp. 74–77, 2017. DOI:10.1515/ata-2017-0015.
10. J. L. Pérez-Ruiz, I. Loboda, L. A. Miró-Zárate, M. Toledo-Velázquez, and G. Polupan, "Evaluation of gas turbine diagnostic techniques under variable fault conditions," *Adv. Mech. Eng.*, vol. 9, no. 10, pp. 1–16, 2017. DOI:10.1177/1687814017727471.
11. M. Rahman, V. Zaccaria, X. Zhao, and K. Kyprianidis, "Diagnostics-Oriented Modelling of Micro Gas Turbines for Fleet Monitoring and Maintenance Optimization," *Processes*, vol. 6, no. 11, p. 216, 2018. DOI:10.3390/pr6110216.
12. M. Benrahmoune, A. Hafaifa, M. Guemana, and X. Q. Chen, "Detection and modeling vibrational behavior of a gas turbine based on dynamic neural networks approach," *Stroj. Cas.*, vol. 68, no. 3, pp. 143–166, 2018. DOI:10.2478/scjme-2018-0032.
13. F. Lu, J. Jiang, J. Huang, and X. Qiu, "An iterative reduced KPCA hidden markov model for gas turbine performance fault diagnosis," *Energies*, vol. 11, no. 7, pp. 1–21, 2018. DOI:10.3390/en11071807.
14. M. Adamowicz and G. Zywica, "Advanced gas turbines health monitoring systems," *Diagnostyka*, vol. 19, no. 2, pp. 77–87, 2018. DOI:10.29354/diag/89730.

15. N. Batayev, “Gas turbine fault classification based on machine learning supervised techniques,” in *14th International Conference on Electronics Computer and Computation, ICECCO 2018*, 2019. DOI:10.1109/ICECCO.2018.8634719.
16. N. Batayev, “Forecasting and Diagnostic of Gas Turbine Driven Gas Compression Unit Parameters,” in *Materials of the IV International Scientific-Practical Conference. Sapporo, Japan*, 2019, pp. 186–191.
17. N. Batayev and A. Onbayev, “Prediction of Gas Turbine Parameters based on Machine Learning Regression Methods,” *Proc. 6th Int. Virtual Conf. Adv. Sci. Results*, vol. 6, pp. 217–221, 2018. DOI:10.18638/scieconf.2018.6.1.495.
18. J. Liedman, “Dynamic simulation of a centrifugal compressor system,” Chalmers University of Technology, 2013.