**SUMMARY**

of the PhD Thesis

on the specialty 6D070200 – «Automation and Control»

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on the topic of research «Modeling and research of gas transporting unit's operation modes»

**Topicality of the research.** Over the past few centuries, fossil fuels as the primary source of energy have been essential for global economic growth. During the Industrial Revolution in Europe in the 19th century, coal played a key role in supporting technological progress in agriculture, manufacturing, and transport. In the 20th century, oil replaced coal in many energy sectors and is an important factor in supporting the economy.

However, at present, a constant and indiscriminate increase in oil prices, combined with a significant reduction in reserves and the requirements of many countries to switch to cleaner energy sources, have led to an increase in demand for natural gas, which is a cleaner and more economically attractive type of fuel. Thus, natural gas is a strategic fossil fuel that increases current global energy supplies and, to some extent, mitigates some of the possible consequences of the use of petroleum products.

The development of gas fields and the transportation of natural gas is one of the priority areas for the development of industry in the Republic of Kazakhstan. The rapid growth of hydrocarbon exports in recent years is primarily due to the rise of industry in Western Europe and China. For more than a quarter century since Kazakhstan gained independence, the country has made significant progress in the fuel and energy sectors. In terms of natural gas reserves, the Republic of Kazakhstan is among the top thirty countries in the world. The gas industry of Kazakhstan has gained rapid development since the 1970s. As of 2015, according to the State Commission on Mineral Reserves, the explored reserves of natural gas in Kazakhstan are estimated at 4.0 trillion $m^3$, where the share of gas dissolved in oil is 2.3 trillion $m^3$, and the share of free gas is 1.8 trillion $m^3$. The major share of the country's gas reserves is located in the western regions of Kazakhstan. Natural gas is produced in three main fields: Karachaganak, Kashagan and Tengiz. The annual gas production in Kazakhstan is about 23 billion $m^3$.

Due to the production of huge volumes of gas, the question arises of the further transportation of natural gas to places of final consumption. In this regard, the role of modeling systems of natural gas compression units is relevant.

One of the main reasons for reducing the performance of the gas compression unit is the contamination of the axial compressor of the gas turbine engine due to air pollutants. Given the fact that pollution leads to high fuel consumption, lowering the pressure of the injected air of the axial compressor and increasing the temperature of the exhaust gases, the development of a method for detecting compressor degradation will prevent such problems.

**The aim of the research.** The main goal of this work is to describe the methodology, the proposed calculation algorithms and the developed software, the purpose of which is to simulate the operating modes of a gas compressor and related equipment. To develop a methodology for identifying the degree of deterioration of the efficiency of a gas compression unit.

**The main idea of the research.** Development of an application to implement the proposed algorithms for modeling a natural gas compression system by individually modeling each component of the system, such as a gas compressor, valve, cooler, gas-liquid separator, etc. Based on the theory of a centrifugal gas compressor and practical skills, apply an anti-surge control strategy to the model for a timely response and to prevent surges. To conduct a study of the main operating modes of the gas compressor unit and propose a methodology for detecting a drop in the efficiency of gas compressor units.

**Research objectives.** In accordance with the goal, the following tasks are identified that need to be solved in this work:

- perform an analysis and identify technological problems of modeling of gas compression units (GCU) operation modes;
- develop mathematical models of various system nodes used in the natural gas compression process, such as, gas compressor, gas-liquid separator, cooler, valve, flow collection/separation nodes;
- develop an algorithm for the modeling system and implement an anti-surge strategy for a gas compressor;
- calculation of the main gas parameters at each point of the circuit and solving the problem of the distribution of gas flow;
- develop library model elements in the form of separate modular blocks;
- introduce the developed models into a single software package and develop an application for modeling the operating modes of a gas pumping unit;
- implement the logic of automatic and manual control of the gas compressor;
- check the adequacy of the algorithms;
- to investigate the operating modes of the gas compressor and to develop a methodology for detecting the degree of degradation of the axial compressor.

**The object of the research.** The object of research is the technological process of compressing natural gas at a compressor station, where the main equipment is a gas compression unit.

**Methods of the research.** The tasks were solved by conducting theoretical and practical research. In the study of the tasks set, the theory of automatic control, data processing methods, physical formulas for calculating gas parameters, as well as machine learning methods to determine the effectiveness of a gas compression unit were used.

As tools for modeling and software development, modern application software packages were used: LabView, Microsoft Visual Studio, Jupyter Notebook.

**Scientific outcomes.** Based on the studies performed, the following results were obtained:

- an analysis of the operation of the gas compression unit was performed and algorithms for modeling the main GCU equipment were developed;
- an algorithm has been developed for the formation of volumetric gas flow for the selected list of equipment;
- an algorithm has been developed for calculating the main parameters of a gas compressor;
- developed a composite algorithm for calculating the mass and volume balance of gas for the selected equipment sequence;
- an analysis of the reasons for the drop in the efficiency of the gas compression unit was performed and a method for detecting the degree of degradation of an axial compressor was proposed.

**Statements of the defense:**

- the algorithmic structure of the formation of volumetric gas flow;
- algorithms for calculating compressor parameters and calculating the mass and volume balance of gas;
- developed software for modeling the operating modes of the natural gas compression system;
- algorithm for detecting the degree of decline in the efficiency of the gas compression unit;
- the obtained test results of the developed algorithms and applications for modeling the operating modes of the gas compression unit.

**Practical significance of the research outcomes.** The proposed algorithms for calculating equipment parameters, calculating the mass and volume balance of gas, and calculating the current volumetric flow rate of a gas compression system are implemented in a single application that allows to simulate a user-selected device sequence in dynamic mode. A series of tests were carried out to verify the adequacy of the software, tests were conducted to verify how the system assembled in this application responds to external influences and changes in its main parameters. Based on the test results, the simulated system for various operating modes and parameters produces adequate results. The practical value of this application is:

- this application allows to evaluate the real processes in the natural gas compression system;
- each device is described by a mathematical model with the corresponding formulas;
- the proposed software takes into account factors affecting the process of real gas compression in gas compressors;
- the logic of modeling algorithms adequately reflects the real technological processes in the presented equipment.

The practical application of this application is the possibility of its implementation for educational purposes for the study of processes occurring under various operating modes of a gas compressor.

**Practical contribution of the PhD student** in obtaining scientific results is:

- formulation of research tasks and methods for their implementation;
- development and construction of mathematical models of the main equipment of the compressor station;
- development of algorithms for the formation of volumetric gas flow rate and calculation of mass and volumetric gas balances;
- practical implementation of the proposed algorithms in the developed application for modeling the operating modes of the gas compression unit;
- study of parameters of GCU efficiency and development of a methodology for detecting a drop in GCU efficiency.

**Approbation of the thesis outcomes.** The main results of the study were reported and discussed at international conferences: «The 16th International Conference Information Technologies and Management» held in 2018 in Latvia (Riga); «The 6th International Virtual Conference on Advanced Scientific Results», held in 2018 in Slovakia; «Global Science and Innovations», held in 2018 in Kazakhstan (Astana); «International Conference on Electronics Computer and Computation», held in 2018 in Kazakhstan (Almaty); «Integration of the Scientific Community to the Global Challenges of Our Time. The IV International Scientific-Practical Conference», held in 2019 in Japan (Sapporo).

**Publications.** On the topic of the study, 12 works have been published, which are 6 papers and abstracts at international conferences, 4 papers in the journals recommended by Ministry of Education of the Republic of Kazakhstan, 2 articles were published in foreign journals included in the international citation database Scopus.

**Volume and structure of the thesis.** The thesis consists of an introduction, five sections of the main content, conclusion and appendices, a bibliography of 71 titles and contains 102 pages, 77 figures and 4 tables.

**The first section** describes the process of compressing natural gas at modern compressor stations. The main types of gas pipeline systems and the main differences between them are described. The state of gas transmission networks in the Republic of Kazakhstan is described. The principle of the operation of natural gas compression systems is described. A review of the methods and tools of modeling systems performed.

**The second section** describes the sequence of development of a mathematical model. A detailed description of creating models of a gas compressor, valve, cooler, gas-liquid separator, pipe, engine is given. An algorithm for generating a volumetric flow rate of natural gas for a selected sequence of elements of a gas compression scheme, an algorithm for calculating the mass balance of a scheme, an algorithm for calculating the compressor output parameters are described.

**The third section** describes the phenomenon of compressor surge, which is one of the main threats to a gas compressor. The principle of action and the requirement to use an anti-surge regulator is described. The principles of the law of regulation are disclosed, the principle of use and the purpose of the anti-surge regulator are described in detail. Based on practical skills, a model of anti-surge regulator is developed.

**The fourth section** describes the testing results of the developed application. The process of modeling a natural gas compression system is described using the example of a single-stage gas compressor. The adequacy of the model in the stationary and dynamic modes of the gas compressor unit was checked. The sequence of testing the anti-surge regulator is described.

**The fifth section** proposes a method for detecting the degradation of the axial compressor of a gas turbine unit for the case of a gas compression unit with a gas turbine engine as a driver. The calculation of power parameters and efficiency of the shaft of a centrifugal gas compressor described. An approach to assessing the performance of GCU on the basis of the machine learning forecasting model is shown. The adequacy of the model is tested on operational parameters.

**In the conclusion** of the thesis, the main conclusions of the work are formulated based on the obtained results.

**The appendix** contains information about the practical implementation of the given algorithms and application.