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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
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ИЗВЕСТИЯ

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OPTIMIZATION OF TECHNICAL MEANS AND TECHNOLOGICAL PROCESSES OF GAS COMPRESSION FOR THE MINING INDUSTRY OF THE REPUBLIC OF KAZAKHSTAN

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Abstract. Modern air compressors used in the mining industry have a high margin of safety when operating in difficult conditions: This includes uneven terrain, high temperature differences and work underground. Scientific research, complex of theoretical and experimental studies, is carried out in order to obtain sound initial data, to find principles and ways to create a new generation of compressors for use in a mining field.

Air compressors are used in deep mines, including supplying clean air, since there may not be enough air in the mine. The compressor can take in outside air, compress and filter it, then feed it into the tunnel. It is necessary to choose compressor equipment for use in mines very carefully; there are many potential risks and limitations. The basic problem, its relevance – in this paper, the issues related to the device, operation and the possibility of optimizing the design of a screw compressor, gas compressor station in the mining industry are considered. The methods used. The modeling of processes and the construction of flowcharts were carried out using programs MathCad, Drawio, MS PP. A simplified mathematical model of a screw compressor is obtained.

Key hypotheses and conclusions. Of the work carried out, the optimal regulator capable of controlling the system with minimal energy consumption has been determined. Originality. The relevance of the topic is explained by the fact that in

Kazakhstan and other developing countries special attention is paid to the issue of energy conservation. This requires an increase in the efficiency of gas compressor equipment in general and compressor stations in particular.

The practical value is an optimal regulator capable of controlling the system with minimal energy consumption.

Keywords: mining industry, screw compressor, gas compression, compression, energy efficiency.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ ТАУ КЕН ӨНДІРУ ИНДУСТРИЯСЫ ҮШІН ГАЗДАРДЫ СЫҒЫМДАУДЫҢ ТЕХНИКАЛЫҚ ҚҰРАЛДАРЫ МЕН ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСТЕРІН ОҢТАЙЛАНДЫРУ

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Аннотация. Тау-кен өнеркәсібінде қолданылатын заманауи ауа компрессорлары қиын жағдайларда жұмыс істегенде жоғары қауіпсіздік маржасына ие болуы керек: бұл біркелкі емес рельеф, температураның жоғары өзгеруі, жер астында жұмыс істеу болып табылады. Ғылыми-зерттеу жұмыстары теориялық және эксперименттік зерттеулер кешені ретінде негізделген бастапқы деректерді алу, жаңа буын компрессорларын құрудың принциптері мен жолдарын іздеу мақсатында жүзеге асырылады. Тау-кен кен өнеркәсібінде қолданылады.

Ауа компрессорлары карьердегі терең шахталарда, сонымен қатар жер асты шахталарын таза ауамен қамтамасыз ету үшін қолданылатын негіхгі әрі маңызды жабдық болып табылады. Компрессор сыртқы ауаны алып, оны қысып, сүзіп, содан кейін туннельге жібере алады. Шахталарда қолдануға арналған компрессорлық жабдықты таңдауға өте мұқият қарау керек, өйткені көптеген ықтимал қауіптер мен шектеулер бар. Жұмыстың *өзектілігі* – бұл жұмыста тау-кен өнеркәсібіндегі газ компрессорлық станцияның бұрандалы компрессорының құрылымын оңтайландыру құрылғысына, жұмысына және мүмкіндігіне байланысты мәселелер қарастырылады.

Қолданылған әдістер. Процестерді модельдеу және блок-схемаларды құру Mathcad, Draw io, MS PowerPoint және т.б. бағдарламаларын қолдана отырып жүргізілді. *Негізгі гипотезалар мен қорытындылар.* Жүргізілген жұмыстың нәтижесінде жүйені минималды энергия шығындарымен басқаруға қабілетті оңтайлы реттеуші анықталды. Өзіндік ерекшелігі. Тақырыптың өзектілігі Қазақстанда және басқа да дамушы елдерде энергия үнемдеу мәселесіне ерекше көңіл бөлінетіндігімен түсіндіріледі. Бұл жалпы газ компрессорлық жабдықтың және атап айтқанда кен орындардығы компрессорлық станциялардың тиімділігін арттыруды талап етеді.

Практикалық мән - бұл жүйені минималды энергия шығындарымен басқаруға қабілетті оңтайлы реттеуші.

Түйін сөздер: тау-кен өнеркәсібі, бұрандалы компрессор, газды сығымдау, газды қысу, энергия тиімділігі.

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ОПТИМИЗАЦИЯ ТЕХНИЧЕСКИХ СРЕДСТВ И ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ КОМПРИМИРОВАНИЯ ГАЗОВ ДЛЯ ГОРНОДОБЫВАЮЩЕЙ ИНДУСТРИИ РЕСПУБЛИКИ КАЗАХСТАН

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Аннотация. Современные воздушные компрессоры, используемые в горнодобывающей индустрии, должны иметь высокий запас прочности при работе в сложных условиях: это и неровный рельеф, высокие перепады температур, работа под землей. Научные исследовательские разработки, как комплекс теоретических и экспериментальных исследований, проводится с целью получения обоснованных исходных данных, изыскания принципов и путей создания компрессоров нового поколения для использования в горнодобывающем месторождении.

Воздушные компрессоры используются в глубоких шахтах в том числе и для подачи чистого воздуха, поскольку в шахте его может не хватать. Компрессор может забирать наружный воздух, сжимать и фильтровать его, а затем подавать в туннель. Необходимо очень тщательно подходить к выбору компрессорного оборудования для использования в шахтах, поскольку существует множество потенциальных рисков и ограничений. Базовая проблема, ее актуальнось – в данной работе рассматриваются вопросы, связанные с устройством, работой и возможностью оптимизации конструкции винтового компрессора газокомпрессорной станции в горнодобывающей индустрии.

Применяемые методы. Моделирование процессов и построение блок-схем велось с использованием программ MathCad, Drawio, MS PowerPoint и др. Получена упрощенная математическая модель винтового компрессора.

Ключевыегипотезыивыводы.Врезультатепроведеннойработыопределены оптимальный регулятор, способный управлять системой с минимальными затратами энергии. Оригинальность. Актуальность темы объясняется тем, что в Казахстане и в других развивающихся странах уделяется особое внимание вопросу энергосбережения. Это требует повышения эффективности работы газокомпрессорного оборудования в целом и компрессорных станции в частности.

Практическим значением является оптимальный регулятор, способный управлять системой с минимальными затратами энергии.

Ключевые слова: горнодобывающая индустрия, винтовый компрессор, сжатие газа, компримирование, энергоэффективность.

Introduction

In order to transport gas in large volumes and over long distances, it is necessary to compress the gas before feeding it into the main pipeline. Nowadays, gas compression is energetically costly at any plant - that is why it is necessary to optimise the operation of compressor equipment.

Optimisation of complex processes is one of the most important tasks in improving the performance and efficiency of equipment. In recent years, screw compressors have become popular in gas production, oil refining and chemical production systems. The screw compressor (SC) is the most modern technological solution for gas compression, which will replace the outdated noisy and energy-intensive piston units (Zubarev, et al., 2016).

Screw compressors are being actively adopted in the oil and gas industry. However, gas compression consumes a significant amount of electricity, so it makes sense to optimise the operation of screw compressors to ensure minimum power consumption (Mikhailov et al., 1989). Optimisation will be performed by means of inputting an optimal regulator into the system, which will allow to regulate power consumption at changing input and output values.

One of the methods for calculating the optimal controller is the minimum energy control problem, the calculation of which will provide a controller capable of controlling the system with minimum energy consumption, in the case of overshoot, which can often occur at booster compressor stations (BCS). Since booster compressor stations are mostly located in places where there is no electricity supply, and electricity is produced by generators, which work on gas passing through the pipeline, so the issue of power consumption at the stations is very important (Bezzubov, et al., 2002).

The aim of this work is: development of an optimal pressure regulator at the outlet of a screw compressor, providing minimum energy consumption for gas pumping. Comparative analysis of existing analytical methods of optimisation in the sense of integral energy consumption in the presence of constraints on the regulated variables.

In order to achieve the set goal, the following tasks should be solved:

- analysing the device of the screw compressor
- analysing the technology of the screw compressor
- selection of the main elements of the system
- selection of the method of optimisation of the developed system to reduce the energy consumption;
- determination of optimality criterion and essential restrictions;
- development of a simplified model of the screw compressor;

Methods and Materials. This work is the first stage of a large cycle of research and design works on creation and development of gas pumping and compressing capacities for gas-industrial enterprises of the Republic of Kazakhstan. At the first stage it is necessary to define the scheme of used gas pumping stations (GPS) and the type of used gas pumping units (GPU).

In the course of this work the state of research in the direction of design of gas pumping station structures and screw compressor devices has been analysed. World leading databases Scopus and Web of Science were used for the analysis. The basic block diagram of the gas compression unit was drawn up. With the help of statistical information from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan the optimal characteristics of units and assemblies of the gas compressor station, which can be applied to the enterprises of the Republic of Kazakhstan, were determined. Modelling of processes and construction of block diagrams was carried out with the use of MathCad, Drawio, MS PowerPoint and other programs. A simplified mathematical model of a screw compressor was obtained.

Results and discussion. Selection of gas compressor unit type

Gas compressor stations (GCS) play a key role in the long distance transport of natural gas. Compressors, being the 'heart' of the GPS, are responsible for increasing the gas pressure to overcome pipeline resistance and ensure uninterrupted gas supply to consumers. There are different types of compressors used in gas compressor stations, each of which has its own advantages and disadvantages (Bykov, 2014, Aimbetova, et al., 2023). The choice of gas compressor units (GCU) is an extremely important stage in the design of gas compressor stations. This choice will largely determine the further possibility of energy optimisation and reduction of energy consumption of both the plant as a whole and the whole production chain.

The most common type of compressor units is the reciprocating type, the principle of operation of which is to compress the gas due to the reciprocating motion of the piston. Piston compressor, has a simple design, due to which not high price, on the other hand, it is less efficient at high gas flow rates. The operation of the reciprocating compressor is quite noisy, the supply of compressed gas is carried out by pulses, for smoothing which receivers are used, it has high energy consumption, at high compression speed the system heats up (Internet resource, Tu, Julius, 2020).

Gas compression by a centrifugal compressor is carried out in the following way: due to rotation of the impeller blades the gas moves from the centre to the edge of the wheel and as a result the gas velocity increases and compression takes place, further the gas velocity decreases and re-compression takes place in the circular diffuser where the kinetic energy of the gas changes into potential energy. The centrifugal compressor has high capacity and no gas supply pulsations, but there is a high probability of pomp, large size and high noise level of the blades, as well as low efficiency of the compressor (Planovskiy, et al., 2015).

Compared to reciprocating and centrifugal compressor, screw compressor has a number of advantages and disadvantages (Stosic, et al., 2005, Yanchik, 2018):

- the screw compressor saves energy by approximately 30% due to the screw units and automatic gas supply control;

- in comparison with the reciprocating piston compressor, where gas is compressed by reciprocating motion of the piston, and centrifugal compressor, where gas is compressed by centrifugal force, the screw compressor compresses gas by reducing its volume in the screw pair, due to which it has small size, low noise and vibration level;

- screw units have excellent technical characteristics: efficiency up to 95%. No need to convert the rotary motion of the motor into reciprocating motion of the pistons, as well as a lower coefficient of friction significantly increase the efficiency of the screw compressor.

- The screw compressor does not require a special foundation or a separate room, which saves on installation and commissioning costs. The screw unit should be serviced after 4000-8000 hours, while reciprocating compressors should be serviced after every 500 hours of operation;

- long service life. Due to the simple lubrication and cooling system, as well as the absence of a valve system, a screw compressor can operate for several years without repair. As practice shows, the units can work without screw pair replacement for 7-8 years, when during this time in the same conditions it is necessary to change 5 reciprocating compressors of similar capacity;

The screw compressor has some disadvantages, viz: - high price of the unit, due to the structural complexity of the compressor, thus spare parts are much more expensive (Novoselov, 2020);

- due to the lubrication system there is a need for a bulky oil separation system, leading to an increase in the cost of manufacturing, weight and dimensions of the compressor components;

- screw compressors should not be used for aggressive gases;
- wear of the screw pair, when used in a dusty environment.

Based on the above advantages and disadvantages, we can conclude that screw compressors have greater reliability, because it has a minimum number of rubbing parts, energy consumption economy: the savings depends on the regulation system, has a high resource and efficiency of work, because they are serviced after 4000-8000 hours of operation.

Due to the presence of a bulky oil separator, the cost of the system, its weight and dimensions increase significantly. Also, the type of gas to be compressed should be taken into account, and the necessary conditions for its operation should be created (Fleming, et al., 2015).

In all other cases, the rational choice is a screw compressor. Screw compressors are the most common type of compressors for GPS due to their high efficiency, low noise and vibration levels, and compact size. It is these compressors that are suitable for implementation within the energy industry of the Republic of Kazakhstan.

Design of the compression unit circuit using a screw compressor

Screw compressor is a horizontal single-stage machine driven by an electric motor, its design consists of a casing, driving and driven rotors and mechanical seal. The main difference of this type of compressor is that the rotors are in meshing with each other. The principle of compression is that when the screw pair rotates as the paired cavities are released, the compressor working cavity is filled with gas through the suction window. Due to the fact that the gas fills the hollows of the driving rotor, the gas is compressed by the driven rotor (Scientific peer-reviewed journal, 2019).

The screw compressor is chosen for implementation in the oil and gas industry of the Republic of Kazakhstan due to its best characteristics, such as a wide range of load variation, operating range, as well as low maintenance costs, so the development of the project with the use of this type of compressor in the system with minimal energy consumption is certainly relevant.

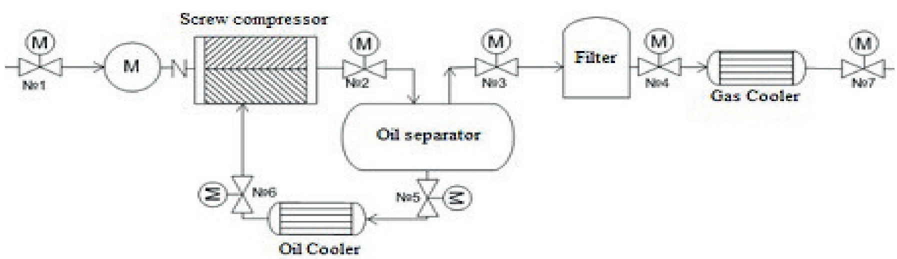


Figure 1 shows the developed scheme of GPS using screw compressor.
Fig.1. Schematic diagram of the gas compression unit

From the separation plants, the purified gas enters the screw compressor through the electric valve No. 1. The drive is connected to the compressor via a coupling. Oil is injected into the working area of gas compression through the electric valve

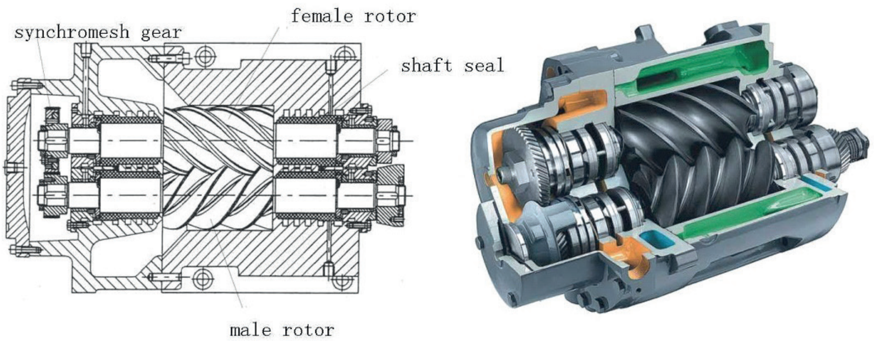
No. 6, which cools the gas and provides lubrication of the rotors upon contact, as well as their sealing. The mixture of gas and oil from the compressor through valve No. 2 enters the oil separator (separator), where the gas is separated from the oil, then enters the filter, where it undergoes additional oil purification, then enters the gas cooler, then goes to its destination. The oil separated from the gas goes through the cooling stage and is injected again into the screw compressor to lubricate the bearings of the screw block. The oil and gas are cooled to the recommended temperature in a special water cooler.

In case of failure of the screw compressor, the oil system is under pressure, in this case, a shut-off valve No. 6 is provided, blocking the oil inlet to the compressor. A shut-off valve is necessary to prevent oil from entering the compressor when it is stopped, otherwise oil may fill the working cavity of the compressor, which will make it difficult to start the installation later and may lead to a hydraulic shock (Aimbetova, et al., 2024).

There are a small number of rubbing parts in the design of the screw compressor and oil is used to prevent friction.

As a result of the oil supply to the working cavity of the compressor, the feed coefficient increases, the compressor design is simplified and it becomes possible to reduce the rotation speed.

Unlike oil-free compressors, in oil-fed compressors, part of the heat released during compression of the gas is transferred to the oil, which significantly increases the compression process. However, the oil coming out of the bearings helps to heat the suction gas, therefore, the power of the machine decreases. In addition, the gas, mixing with the oil, dissolves in it, which creates a number of adverse effects, such as low volumetric efficiency and deterioration of the properties of the oil. Thus, when calculating the characteristics of a screw compressor, it is necessary to take into account the miscibility of the gas in the oil.



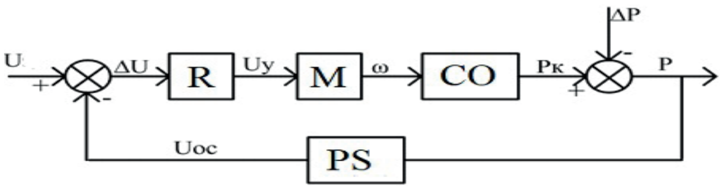
The design of a screw compressor for compressing associated petroleum gas is shown in Figure 1.2.
Fig. 2. Design diagram of a screw compressor

The screw compressor is a volumetric type machine, since the gas compression process occurs due to a decrease in the closed volume. The compressor consists of a housing with a suction and discharge nozzles located diagonally. Cylindrical bores are made in the housing and cover of the screw compressor for the drive and driven screws of the compressor, which intersect with each other, the shaft of the drive screw is connected to the electric motor. The teeth of the rotors are made with different run–in profiles, the leading screw has more convex wide teeth, the driven one is narrow and concave. To preserve the bilateral lateral gaps between the teeth of the screws, their shafts are connected by synchronizing gears, which eliminates the possibility of mutual contact of the screws, preferably for non-oil-filled compressors.

In small compressors, rolling bearings are used, which are necessary to reduce the axial forces acting on the screw pair, on the side of the electric motor - support bearings, after the screw pair - angular contact bearings. Sliding bearings are used in large compressors. Metal-ceramic seals of the stuffing box type are used as seals of the screw shafts (GOST 24.104-85, 1985).

Design of the compression unit circuit using a screw compressor.

Before proceeding to the description of the GPA, it is necessary to present a functional system for optimal control of the system, which provides for monitoring and regulating the gas pressure at the compressor outlet. The functional diagram of the system is shown in Figure 3.



R - regulator; M - motor; CO- control object; PS- pressure sensor.

Fig. 3. Functional diagram of the system

On the basis of this functional scheme the characteristics of the main elements of the GCU system are selected. Technical requirements for the system with screw compressor are formed on the basis of the technical process flowing in GCU. The basis for the selection of parameters of the GCU system, shown in Table 1, was the data on the needs of energy enterprises of the Republic of Kazakhstan (data of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan).

Table 1 - Technical requirements for a screw compressor system

Number	Parameter	Value
1	Supply voltage	380 V +10%
2	Frequency	50 Hz
3	Operating temperature range,	-15
4	Pressure control range, MPa	0,4 to 0,7
5	Regulation time, not more than, s	5

6	Over-regulation	shall not be allowed
7	Static error at pressure change within 0.5 MPa, not more, %	2

The technical requirements for the motor are formed on the basis of the compressor in terms of power consumption, it is also necessary to take into account the operating conditions, as it is used in gas compression system, the motor must be made in explosion-proof version. Selected screw compressor should be, based on the operating conditions, oil-filled type machine. It should provide compression of associated petroleum gas with a maximum discharge pressure of 0.7 MPa and a capacity of 20-22 m3/min. Full requirements to the technical characteristics of the compressor are presented in Table 2.

Table 2 - Compressor performance requirements

Compressible gas	Capacity, m3/min,	Suction pressure, MPa	Discharge pressure, MPa	Rotor speed, r/pm.	Engine type	Power, kW
Природный газ	22	0,2	0,7	3000	ЭД	200

The oil-injected screw compressor (OIC) has low circumferential speeds (30 to 50m/s), therefore rolling bearings are used. In the suction and discharge chamber, roller bearings are used to take radial loads and angular contact ball bearings are used for axial loads. This compressor is low maintenance and has a long service life of about 40000 motor hours, after which major overhaul is required. Asynchronous three-phase AC motor with squirrel cage rotor AIR315M2 was chosen as the drive of the screw compressor. This type of motor is made in explosion-proof version. In order for the compressor drive to provide minimum energy consumption it is necessary to perform optimal regulation. Within the framework of this work, such a calculation will be made in the next step.

Conclusions

In this paper, the design and working principle of screw compressor has been analysed in depth. It is a type of compressor that utilises two screw rotors rotating in opposite directions to compress gas efficiently and smoothly. The main elements of a screw compressor such as rotors, housing, control mechanism and lubrication system were discussed. The key advantages of the screw compressor over other types of compressors such as reciprocating compressors and centrifugal compressors were highlighted. Screw compressors have high compression ratio and low energy consumption, making them more economical to operate. Screw compressors are characterised by low noise levels due to the smooth compression process. Due to their simple design and the absence of friction between the rotors, screw compressors have a long service life and require minimal maintenance. Screw compressors can operate over a wide range of pressures and capacities, making them versatile for a variety of applications. Based on the performance data obtained for the screw compressor, the main elements of the gas compressor system were selected. It was important to ensure that the specifications of the gas compression system were matched. As a result of the analysis, it was decided to use an asynchronous motor with squirrel cage rotor. This type of motor is characterised by its simple design, reliability and relatively low cost. It also has a high power output, which is essential for the efficient operation of the screw compressor.

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