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NEW TECHNOLOGIES FOR PNEUMOENERGY PRODUCTION IN THE UNDERGROUND MINES WITH THE HELP OF THE BB AND УКГШ COMPRESSORS

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НОВІ ТЕХНОЛОГІЇ ВИРОБКИ ПНЕВМОЕНЕРГІЇ В ПІДЗЕМНИХ УМОВАХ ШАХТ ЗА ДОПОМОГОЮ КОМПРЕСОРІВ ВВ І УКГШ

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НОВЫЕ ТЕХНОЛОГИИ ВИРАБОТКИ ПНЕВМОЭНЕРГИИ В ПОДЗЕМНЫХ УСЛОВИЯХ ШАХТ С ПОМОЩЬЮ КОМПРЕССОРОВ ВВ И УКВШ

Abstract. A new mine screw compressor unit УКГШ with better fire safety than of previously used units is designed and have already integrated into the coal industry of Ukraine. During the whole period of their operation, there was no fire, which usually occurs with compressor units of other types. One more compressor unit BB is designed, which is equipped with microprocessor control system, high-voltage electric motor, compressor assembly, effective system of air and oil filtration, effective system for vibration reduce, pre-heating device, unloaded system startup and shutdown. Causes of compressor fault due to the failure of some assemblies were analyzed.

Examples of reliability calculations are presented for compressor units and compressor machines in total. Guidelines for improving compressor reliability are: upgrading of compressor de-

sign; use of new technology of their exploitation; optimization of their operating modes; use of rapid diagnostic of the compressor state; improvement of preventative maintenance.

Keywords: compressors, new technologies, pneumatic energy, underground mining conditions, reliability and safety.

Energy efficiency, reduction of accident rate and man-caused impacts on the environment are the most pressing problems for the coal mines. In order to be successful, the industry should speed up its technical upgrading and complex renewal of the mine fixed asset. It should be noted that operation life of the Ukrainian mines is quite long, therefore, investments into their modernization are urgently required.

Improvement of compressed-air supply systems in the mines is one of the key guidelines for saving energy in the coal industry. Significant reserves for energy saving in the compressed-air production for the coal mines lie in reduction of its production cost and improvement of pneumatic system for compressed air supplying. An alternative to the existing production technology, which assumes installation of powerful compressor stations on the earth surface, is creation of modular underground compressor stations on the base of mobile screw compressor units with their allocation directly in the face, including in the dead ends, optimally close to the underground consumers of the compressed air [1, 2].

The screw compressor unit.

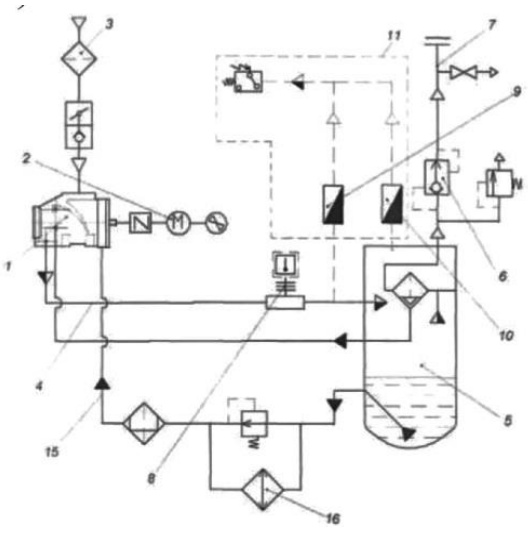


Figure 1 - Pneumohydraulic scheme of screw compressor unit

A pneumohydraulic circuit of the designed screw compressor unit [3] is shown in Fig. 1, and its vertical and horizontal sections are shown in Fig. 2. The screw compressor unit works as follows. When the unit works, air is sucked through the air filter 3 into the compressor 1, to where the cooled oil also flows from the cooler 16 through the line 15. This cooled oil is needed for cooling the compressed air, sealing gaps between the working bodies of the compressor and lubricating the bearings. The oil is mixed with the air and forms an oil-air mixture, which is compressed in the compressor 1 to the set operating pressure and then enters the oil separator 5. On two levels of the oil separator 5, the air is separated from the oil and then is supplied to the customer through the minimal pressure valve 6 and distribution valves on the dispensing tube 7.

Sensors of automation systems and connected with them devices force the automatic system to response when operating parameters of the unit exceed the boundary values. Two temperature sensors 8 and 9 of the automation system are installed in the injection line 4 after the screw compressor 1; they are designed on different physical principles of operation and provide reliable response when the oil-air mixture temperature exceeds the set parameters.

The temperature sensor 10 of the automation system protection line 11 is installed in the space of the oil separator 5 and ensures more reliable response when oil temperature in the oil separator 5 reaches critical values.

When temperature of the drive cover exceeds the set values, a temperature sensor 12, which is installed on the drive cover, emergently switches the compressor 1 off. In event of a fire risk, the temperature sensor 13 of the fire suppression system, which is installed above the oil separator 5, switches the device 14, which is installed over the oil separator 5, and which feeds fire extinguishing agents and effectively localizes a possible fire in the area of the main element of the shaft compressor unit, and which contains the most part (90 %) of fire-safe substance. In event of critical increase of methane concentration, the methane sensor 17 switches the automation system on; the sensor 17 is installed on the top of the compressor unit casing, and such location ensures its operation in area with initial methane accumulation in the upper part of the casing.

The main stages of the mobile shaft compressor unit УКГШ designing are as follows:

1. To receive from the MacNDI an expert's conclusion concerning compliance of the high-risk equipment with requirements of regulations on labor protection and industrial safety, and to get a permit for testing the equipment in the Ukrainian mines. The received expert's conclusion states that the unit УКГШ-7,5/7В5 is in harmony with the relevant requirements of regulations and it is permitted to test the unit (approval test and operation) in the underground dead ends, including mines with the risk of high gas and dust content, in accordance with the "The Safety Rules For the Coal Mines".

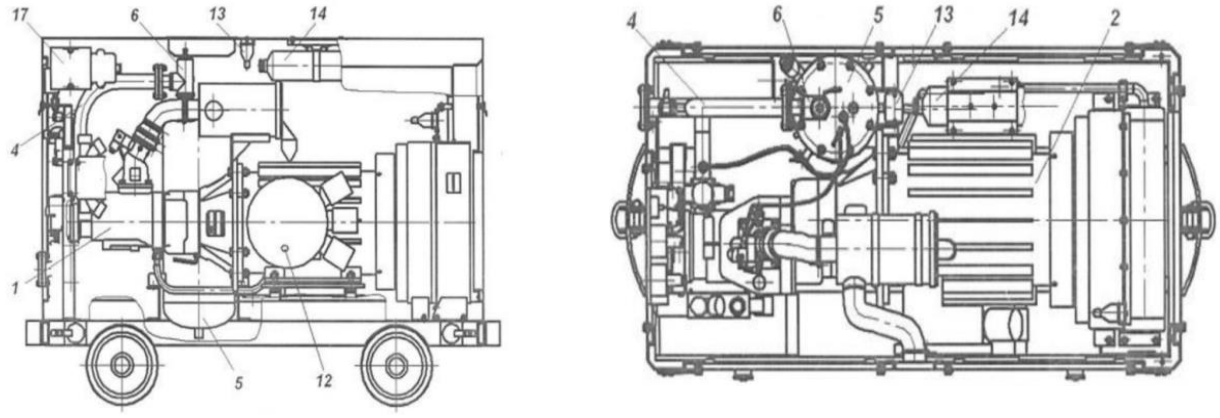


Figure 2 - Screw compressor unit: a) horizontal and b) vertical section

2. To develop and approve Technical Specifications.

3. To conduct, together with the M.M. Fedorov NIIGM and NIIHS "Respirator", acceptance tests of the unit prototype at the Dobropolska Mine of the SE Dobropolyeugol.

4. To obtain from the Donetsk Technical Expert Centre of the Derzgirpromnaglyad of Ukraine (DTEC) an expert's conclusion on the high-risk equipment compliance with requirements of regulations on labor protection and industrial safety.

5. To obtain, on the basis of the DTEC conclusion, a permit for the units putting into operation in the Ukrainian mines.

6. To put into operation a docking series with further widespread implementation of the mobile shaft compressor units УКГШ in the Ukrainian mines.

In 2012, the certificates of conformity with technical regulations on the safety machinery and equipment were received on the basis of certification study protocols and periodic testing protocols for the units УКГШ-5/7 УКГШ-7.5 / 8 УКГШ-15/7.

Assessment of and ways for improving reliability of the compressor units and assemblies.

The Ukrainian coal producers have already implemented more than 1148 compressor units УКГШ-7.5/7; УКГШ 10/7; УКГШ-15/7 designed by NIKMAS Concern. Their productivity is 7,5-15 m^3/min. The units are in operation since 2001.

The shaft compressor units УКГШ have higher level of fire safety than previously used units ШВ-5. During the whole period of their operation, there was no fire, which usually occurs with compressor units of other types [4-6].

Figure 3 – The shaft screw compressor unit УКГШ-10/7 А У2 with electric protection system

Design of the shaft screw compressor units was improved (Fig. 3), and statistics of failures of the compressor modules and assemblies was gathered for the whole period of their operation in the coal mines. The systematic analysis shows that the key destabilizing factors affecting the compressors technical and economic parameters is wear of the loaded assemblies, which is accompanied by increased power consumption by the drive system or by termination of their operation. Especially critical is wear of the screw pairs, because any increase of clearance between them leads to significant reduction of their efficiency.

Dimension types of the shaft screw compressor units are shown in the Table 1.

In order to provide more effective air cleaning in the dusty mines, the units are equipped with advanced filtration system and, in particular, air filter of the oil-inertial type, which ensure operation of the unit at dust content up to 100 mg/m^3. The compressor units of the ВВ-25/8 М1 У2; ВВ-32/8 М1 У2; ВВ-32/8 Т2 types are used as an integral part of the drilling equipment (Fig. 4, 5).

In the process of parameter optimization for the first series of machines, design of the unit ВВ-32/8М1У2 was essentially improved by integration of additional equipment: vertical separator-oil filter, thanks to which oil drainage does not exceed 3 mg/m^3 and interval for the oil relubrication is 3500 hours; thermostat, which simplifies process of starting and heating; and electric motor of special design for boring machine.

The compressor block and electromotor are connected with each other by a common casing and are installed on the shock absorbers, therefore, periodic alignment is not needed any more and load on the bearings and vibration rate are reduced; besides,

design of minimal-pressure valve and drain valve was improved in terms of their reliability; oil cooler was upgraded (its weight and dimensions were reduced); more reliable temperature sensors and solenoid valves were installed; performance control system was modernized: now electric motor starts when compressor is unloaded, thus, reliability of the electric motor and starting equipment is improved; the compressor unit was modified by way of integration of the controller.

Table 1 – Specification of the shaft screw compressor units

Parameters and design features	УКГШ-4/7	УКГШ-5/7	УКГШ-6/7	УКГШ-7,5/7	УКГШ-10/7	УКГШ-11/7	УКГШ-15/7	УКГШ-20/7
Compressible working agent	Air							
Volumetric productivity, calculated for the initial conditions, m^3/min	4,0	5,0	6,15	7,5	10,0±1,0	11,0±0,5	14,5±0,72	20,0±1,0
Initial pressure, nominal, kg/cm^2	1,03							
Final pressure, nominal, kg/cm^2	6,0±7,0	6,0±7,0	6,0±7,0	6,0±7,0	6,0±7,0	6,0±8,0	6,0	6,0
Initial temperature maximal, ^{0}C minimal, ^{0}C	+35 -5	+35 -5	+35 -5	+35 -5	+40 -5	+40 -5	+35 -5	+35 -5
Final temperature, ^{0}C, not higher than without final cooler with final cooler	100 20^0 higher than the intake air temperature							
Power consumed by the compressor, kW	25	31	37	47	54±57	73	not more than 90	not more than 110
Specific power consumption, kW m^3/hour	6,25	6,2	6,17	6,27	$5,7_{-0,3}$	6,63	6,2	5,8
Power of the installed electric motor, kW (asynchronous, three-phase, explosionproof)	30	37	45	55	55 or 75	75	90	110
Oil consumed for the air drainage, g/m^3 of air, not higher than	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

Sound level at a distance 1 m, dB, not higher than 7 m, dB, not higher than	89 80	89 80	89 80	89 80	90 80	93 80	93 80	93 80
Synchronous speed, s^{-1} (rev/min)	25 (1500)	25 (1500)	25 (1500)	25 (1500)	25 (1500)	25 (1500)	25 (1500)	25 (1500) or 50 (3000)
Supply voltage, V	380/660	380/660	380/660	380/660 або 660/1140	380/660	380/660	380/660	380/660 or 660/1140
Possible starter installation in the unit body	+	+	+	+	+	+	+	+
Starter type	ПВІ125	ПВІ125	ПВИ125	ПВІ125	ПВІ160	ПВІ160	ПВІ250	ПВІ250
Protection system	ПГЗ* or УЗКВ** or microprocessor							
Overall dimensions	2200	2200	2200	2200	2800	2800	3140	3200
without starter: length	1050	1050	1050	1050	1100	1150	1140	1140
without starter: width	1500	1500	1500	1500	1400	1485	1600	1640
With integrated starter: length	2600	2600	2600	2600	3200	2800	3200	3200
With integrated starter: width	1050	1050	1050	1050	1100	1150	1140	1140
With integrated starter: height	1500	1500	1500	1500	1400	1485	1600	1640
Weight, kg	1500	1500	1500	1500	3000	3000	2900	3000
Base of the transport trolley, mm/rail, mm	1250/600 (900)	1250/600 (900)	1250/600 (900)	1250/600 (900)	1650/600 (900)	1650/600 (900)	1650/600 (900)	1650/600 (900)
Cleaning of the intake air (efficiency) I variant - dry filter	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)	+ (10 to 30 mg/m^3)
II variant - combined (dry + oil inertial filters)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)	+ (up to 100 mg/m^3)
Mobile, on wheels	+	+	+	+	+	+	+	+
Stationary	+	+	+	+	+	+	+	+

Note: * ПГЗ - version with pneumohydraulic protection system;
** УЗКВ - version with electrical protection system

The microprocessor control unit makes possible to control all compressor unit operations. The controller is equipped with independent powerful memory, which can store the compressor current settings and modes and operator's actions for a long period of time.

Figure 4 – The compressor unit for drilling machine

Figure 5 - Drilling machine СБШ- 250МНА-32КП with compressor unit ВВ-50/8У2

The compressor unit ВВ-50/8У2 is equipped with microprocessor control system, high-voltage electric motor, compressor assembly, effective system of air and oil filtration, system for effective vibration reduction, pre-heating device, system for unloaded starting and shutdown.

A block diagram of the unit with elements and components, which impact on the compressor machine reliability, is shown in Fig. 6.

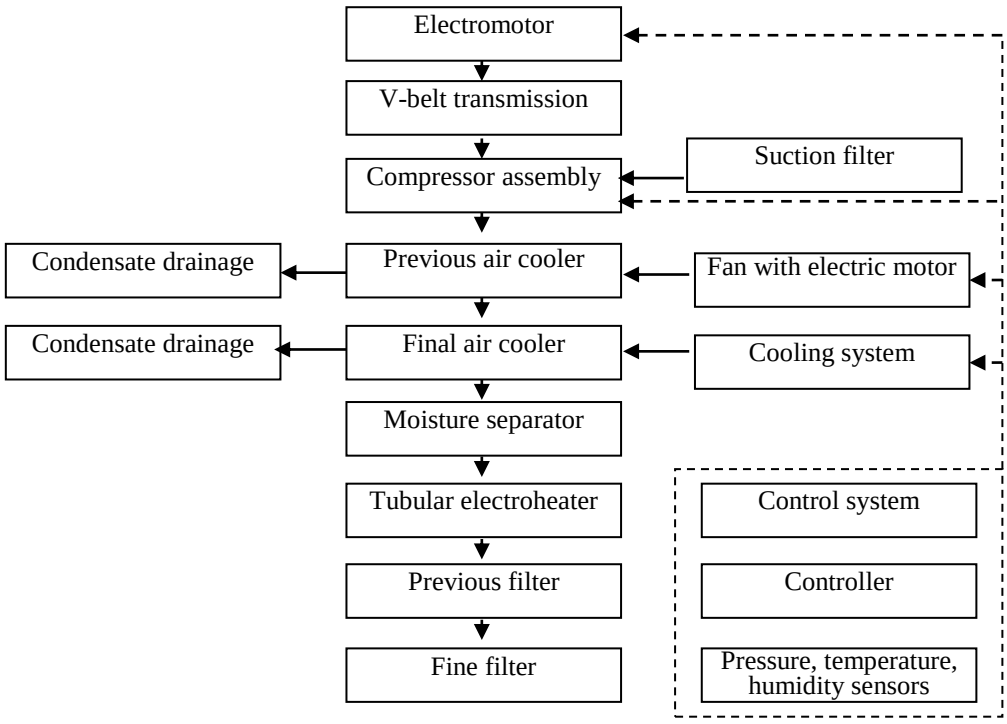


Figure 6 - The hierarchical structure of the compressor machine

Calculations of reliability of compressor assemblies and compressor machine in total are shown in Table 2. The obtained life per elements is from 2107 hours to 13,162 hours, which is much better than values specified in the Technical Specification. Probability of the element failure-free operation ranges between 0.975 and

0.9995. Probability of failure-free operation during the specified system life is 0.9434. Average operation period till some element failure ranges between 20 000 hours and 125 000 hours. Probability of the element failure-free operation ranges between 0.827 and 0.998.

Table 2 - Estimated reliability of the compressor elements

№ p / p	Item	Average interval between the failures, hours	Density of probable failure	Probability of failure-free operation	Intensity of failure	The obtained failure-free operation period
1	Controller	39 736	$1{,}78\cdot10^{-5}$	0,827	$2{,}03\cdot10^{-5}$	
2	Air supply unit	85 969	$9{,}2\cdot10^{-8}$	0,9975	$9{,}22\cdot10^{-8}$	9057
3	Previous air cooler	50 000	$5{,}27\cdot10^{-7}$	0,995	$8{,}99\cdot10^{-7}$	5288
4	Condensate drainage	30 000	$2{,}2\cdot10^{-6}$	0,987	$2{,}23\cdot10^{-6}$	3160
5	Coarse filter	100 000	$2{,}03\cdot10^{-8}$	0,998	$2{,}03\cdot10^{-8}$	10 536
6	Fine filter	100 000	$2{,}03\cdot10^{-8}$	0,998	$2{,}03\cdot10^{-8}$	10 536
7	Electric heater	25 000	$4{,}04\cdot10^{-6}$	0,978	$4{,}13\cdot10^{-6}$	2634
8	Pressure sensor	125 000	$8{,}7\cdot10^{-8}$	0,9975	$8{,}71\cdot10^{-8}$	13 162
9	Temperature sensor	20 000	$8{,}9\cdot10^{-7}$	0,96	$8{,}94\cdot10^{-7}$	2107

Fig. 7 shows guidelines for improving the compressor machine reliability, which were realized in this research. Failures of some subsystems of the compressor park are random variables. Causes of compressor failures due to the failure of individual blocks were analyzed (Fig. 8).

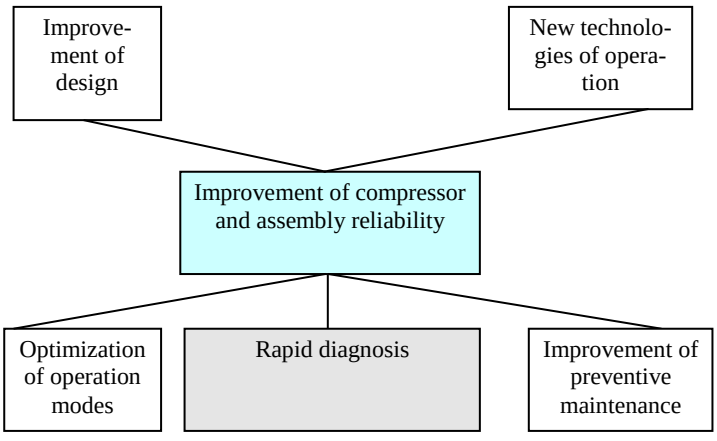
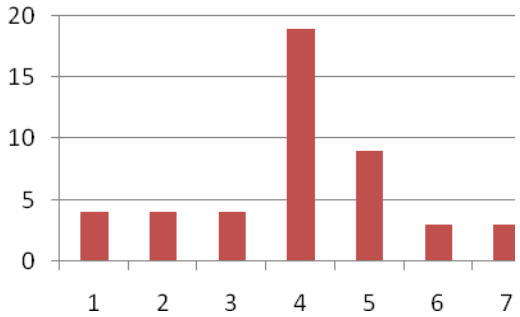


Figure 7 – Guidelines for improving reliability of the compressor machines



1 - oil filter; 2 - thermometer; 3 - compressor assembly; 4 - controller; 5 - electric motor; 6 - suction valve; 7 - temperature controller

Figure 8 - Histogram of relative frequency of failure of the compressor assemblies and parts in process of their operation in the coal mines

Conclusions.

1. A new shaft screw compressor unit was designed. When the unit operates, air is sucked through the air filter into the compressor, to where the cooled oil also flows from the cooler. The oil is mixed with the air and forms an oil-air mixture, which is compressed in the compressor to the set operating pressure and then enters the oil separator. On two levels of the oil separator, the air is separated from the oil and then is supplied to the customer through the minimal pressure valve and distribution valves on the dispensing tube.

2. The Ukrainian coal producers have already implemented more than 1148 compressor units УКГШ-7.5/7; УКГШ 10/7; УКГШ-15/7 designed by NIKMAS Concern. Their productivity is 7,5-15 m^3/min. The units are in operated since 2001. The shaft compressor units УКГШ have higher level of fire safety than previously used units ШВ-5. During the whole period of their operation, there was no fire, which, which usually occurs with compressor units of other types.

3. Calculations of reliability of compressor blocks and compressor machine in total are shown in Table 2. The element life is from 2107 hours to 13,162 hours, which is better than values specified in the Technical Specification. Probability of the element failure-free operation ranges between 0.975 and 0.9995. Probability of failure-free operation during the specified system life is 0.9434. Average operation period till any element failure ranges between 20 000 hours and 125 000 hours. Probability of the element failure-free operation ranges between 0.827 and 0.998.

4. The key guidelines for improving the compressor reliability include: improvement of design; new technologies of operation; optimization of operation modes; rapid diagnostic of technical state; improvement of preventive maintenance system.

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Анотація. Створена гвинтова шахтна компресорна установка УКГШ. На підприємствах вугільної промисловості України впроваджені установки компресорні шахтні УКГШ, які мають більш високий рівень пожежної безпеки, ніж застосовувані раніше установки. За час експлуатації не було зафіксовано жодного випадку загоряння, що мало місце при експлуатації компресорних установок інших типів. Розроблена компресорна установка ВВ оснащена мікропроцесорною системою управління, високовольтним електродвигуном, компресорним блоком, ефективною системою фільтрації повітря і масла, ефективною системою зниження вібрації, пристроєм передпускового підігріву, системою розвантажувального пуску і зупинки. Виконано аналіз причин відмови роботи компресорних машин через несправність окремих вузлів. Наведено розрахунки показника надійності вузлів і компресорних машин в цілому. Основними напрямками підвищення надійності компресорних машин є удосконалення конструкції, використання нових технологій експлуатації, оптимізація режимів роботи, використання оперативної діагностики стану, удосконалення системи ППР.

Ключові слова: компресори, нові технології, пневмоенергія, підземні умови шахт, надійність і безпека.

Аннотация. Создана винтовая шахтная компрессорная установка УКВШ. На предприятиях угольной промышленности Украины внедрены установки компрессорные шахтные УКВШ, которые имеют более высокий уровень пожарной безопасности, чем применяемые прежде установки. За время эксплуатации не было зафиксировано ни одного случая загорания, что имело место при эксплуатации компрессорных установок других типов. Разработанная компрессорная установка ВВ оснащена микропроцессорной системой управления, высоковольтным электродвигателем, компрессорным блоком, эффективной системой фильтрации воздуха и масла, эффективной системой снижения вибрации, устройством предпускового подогрева, системой разгрузочного пуска и останова. Выполнен анализ причин отказа работы компрессорных машин из-за неисправности отдельных узлов. Приведены расчеты показателя надежности узлов и компрессорных машин в целом. Основными направлениями повышения надежности компрессорных машин является усовершенствование конструкции, использование новых технологий эксплуатации, оптимизация режимов работы, использование оперативной диагностики состояния, усовершенствование системы ППР.

Ключевые слова: компрессоры, новые технологии, пневмоэнергия, подземные условия шахт, надежность и безопасность.

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