MACHINE SCIENCE

ISSN: 2227-6912
E-ISSN: 2790-0479

2024, № 2 Pages 50– 58

FAILURES IN CENTRIFUGAL COMPRESSORS

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https://doi.org/10.61413/FCBE3989

Abstract: Centrifugal flash gas compressors are mechanisms that convert the kinetic energy of gas into pressure energy, playing a crucial role in compressing and transporting associated gases in the oil and gas industry. These compressors operate on the principle of centrifugal force and are widely used in key industrial sectors. They are considered essential equipment for compressing and transporting gases in fields such as the oil and gas industry, chemical production, power generation, and cooling systems. Capable of handling high flow rates and large volumes, centrifugal compressors use impellers to increase the gas velocity, while the diffuser converts this velocity into pressure. As a result, gas compression occurs within the compressor, ensuring the continuous operation of industrial processes. Although centrifugal compressors offer high performance and durability, they can fail under certain conditions due to various reasons. Failures and breakdowns can lead to serious production issues, significant financial losses, and even safety risks. Let's now examine the causes of these compressor failures.

Keywords: *compressor, failures, wear, abrasion, corrosion, surge, dry gas seal, buffer gas.*

Failures and Breakdowns in Centrifugal Compressors

Centrifugal flash compressors are used to increase the pressure of gases and liquids through high-speed rotating rotors. Dynamic machines make use of rapidly rotating impellers to accelerate the gas to high speed. By changing the direction and decelerating the gas much of its kinetic energy is converted to pressure energy [2].

Centrifugal compressors use the same operating principle as centrifugal pumps. They can be single stage or multiple stages. A casing can have multiple rotors, but the casing can be one stage in a multi-stage process. The word "stage" usually refers to the stage in a process. The part of the centrifugal compressor that moves the gas is the impeller. The gas enters through the eye of the impeller and the rotating impeller accelerates the gas towards the outer rim. When the gas reaches the tip of the impeller blades it is at its maximum velocity and possesses the maximum amount of energy. As the gas leaves the impeller it is pushed into passageways called diffusers. The flow area in the diffuser is larger than that in the impeller so the velocity of the gas begins to decrease. This causes the gas pressure to increase. The diffuser converts the kinetic energy of the gas to increased pressure.

These compressors are highly efficient and have a wide range of applications, but certain failures (malfunctions) can occur in their operation. The main types of failures include [1]:

Wear and Erosion – Wear is one of the most common causes of failure in centrifugal compressors. High-speed rotating impellers and other mechanical parts are subjected to wear over time. This leads to reduced equipment efficiency, increased energy consumption, and eventually the need for extensive repairs. Erosion, on the other hand, results in material loss from parts that come into contact with the gas passing through the compressor. During the compression process, gas particles can erode the surfaces of the impeller and diffuser, which diminishes the compressor's operational capability. (Fig. 1).

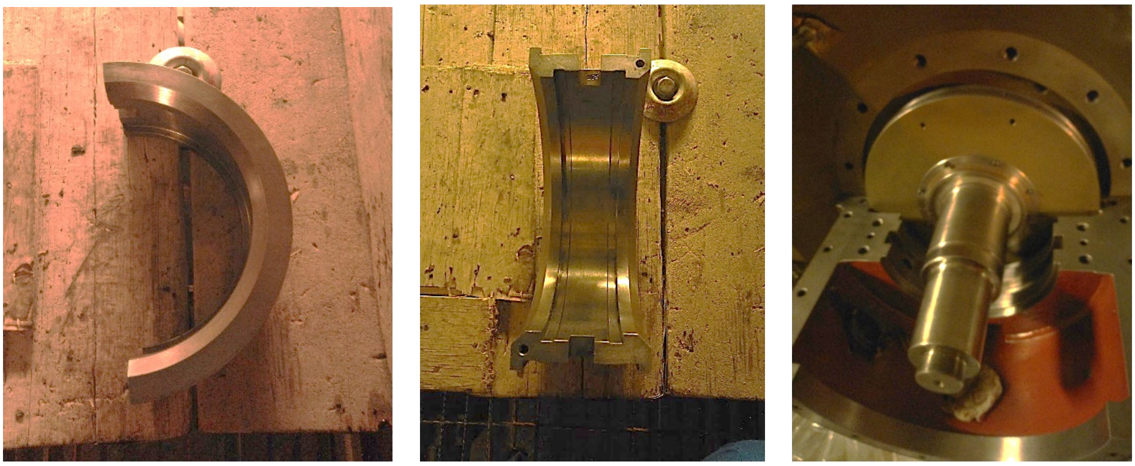

Figure 1. Friction Bearing Pads and Shaft

Failure of Bearings and Sealing System – Bearings used in compressors can fail over time due to high speed and loading conditions. Bearing malfunction leads to the disruption of the equipment's rotational balance and the formation of vibrations. This can also cause improper functioning of the impellers. A lack of lubrication, wear, or mechanical damage in the bearings can result in the compressor stopping. When the bearings do not function properly, the rotor becomes unstable, which can lead to serious malfunctions. [1]

Bearings: Describe different types of bearings (e.g., ball bearings, roller bearings) and their functions.

Sealing Systems: Explain types of seals (e.g., mechanical seals, O-rings) and their purpose in preventing contamination and fluid leakage.

Causes of Failure -Wear and Tear: Explain how prolonged use can lead to failure.

Contamination: Discuss how dirt, moisture, or foreign particles can damage the bearings and seals.

Improper Lubrication: Explain the effects of insufficient or excess lubrication.

Misalignment: How misalignment of components can increase wear and lead to failure.

Thermal Issues: Discuss the impact of excessive heat on bearing and seal performance.

Seals are crucial for preventing gas leakage. When seals fail, gas leakage can occur, leading to reduced efficiency, compromised safety, environmental pollution, and energy losses. Leaks in the sealing elements, valves, or pipes in the compressor system can result in pressure loss and decreased performance, which in turn also creates safety risks(Fig. 2).

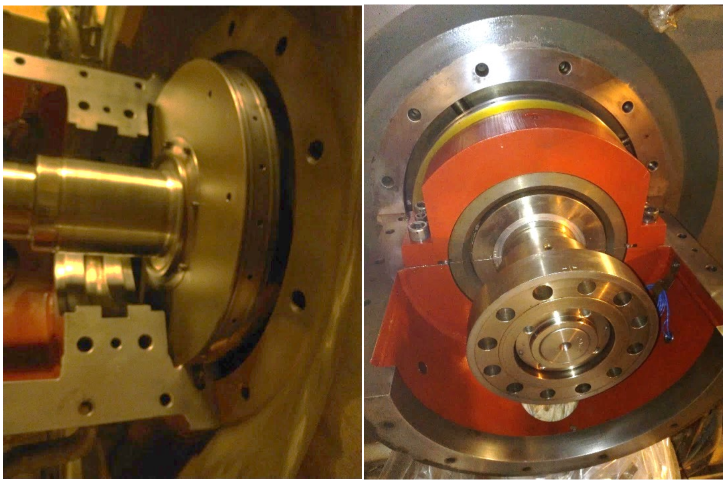

Figure 2. Dry Gas Mechanical Seals

Surge Instabilities and Resonance – If unstable flow conditions develop inside the compressor, this can impose additional load on the impellers. During hydrodynamic resonance, a mismatch occurs between the rotational speed and the flow velocity, which can lead to severe vibrations and malfunction of the mechanism. These issues often arise from design flaws or incorrect operating conditions.

Centrifugal compressors can enter a condition known as stall or surging under certain flow conditions. During stall, the flow stops in a specific part of the compressor, causing vibration and performance loss. Surging, on the other hand, is a malfunction characterized by periodic fluctuations in pressure during compressor operation, and it can cause significant damage to the compressor [2,3]

Vibration and Imbalance – Imbalance and vibration in high-speed rotating impellers are common issues. Vibrations can cause significant damage to the mechanical parts of the equipment, which not only reduces operational continuity but also increases repair costs. Imbalance typically arises from improper assembly of the impellers, material defects, or erosion. Disruption of rotor balance leads to vibrations in the compressor, which can damage both the compressor and the piping system. This situation occurs due to changes in the rotor's center of gravity, wear, or fractures. If the filtration systems are malfunctioning, dust or other contaminants can accumulate on the rotor blades. This results in rotor imbalance and reduced performance. High vibration can occur due to rotor imbalance, bearing issues, or resonance, which can damage mechanical components and cause the equipment to be out of 0 peration (Fig. 3).

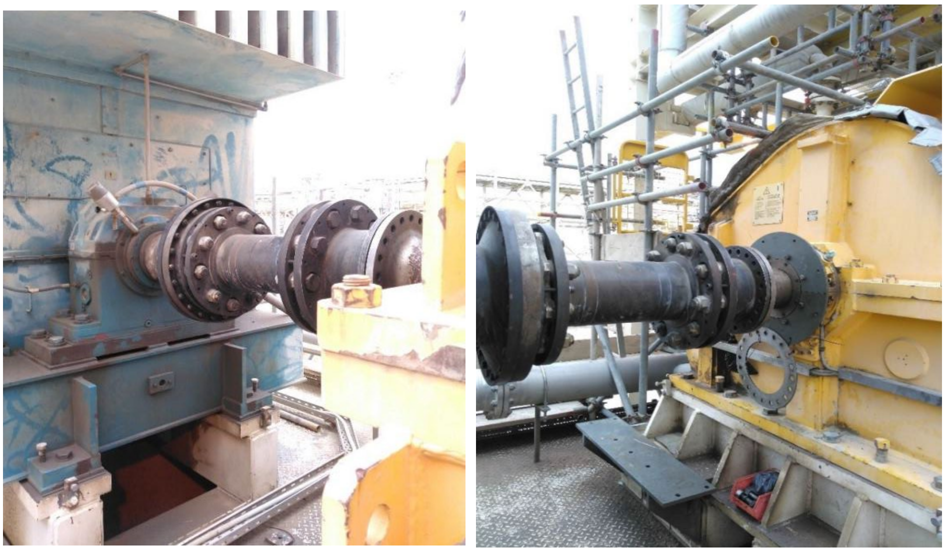

Figure 3. Gearbox and Compressor Shaft Transmission Coupling

Thermal Fatigue and Disruption of Thermal Balance – When centrifugal compressors operate at high temperatures, the thermal expansion of components may occur unevenly, leading to material fractures, cracking, or deformation. If a fault occurs in the compressor's cooling system, the temperature will rise, resulting in thermal fatigue. Thermal fatigue develops due to the repeated effect of high temperatures on components, which reduces the strength of the metal. [4,5]

Lubrication System Failures – Any malfunction in the compressor's lubrication system can have disastrous consequences for the bearings, rings, and other mechanical components. Without proper lubrication, friction increases, leading to the rapid failure of components and causing the equipment to stop(Fig. 4).

Figure 4. Lubrication System Failures

Preventive Measures:

Regularly monitor vibration levels, temperature, and pressure.

Perform routine maintenance and inspections for bearings, mechanical seals, and rotors.

Ensure proper filtration to prevent contamination.

Implement control systems to protect against surge damage resulting from sudden gas flow reduction.

Check and properly balance rotating components.

By implementing a strong maintenance strategy and utilizing condition monitoring systems, most of these failures can be detected early, preventing significant damage.

In this regard, the power consumed is determined by the characteristic optimal mode of the compressor unit, that is, the efficiency, temperature, nominal power and pressure distribution in stages, in accordance with the manufacturer's instructions. In this case, the degree of compression of the gas in the compressor cylinders in stages becomes normal, the consumed nominal power increases to 1350 hp. and the efficiency increases by maintaining the number of crankshaft revolutions at the level of 300 rpm. In practice, the operation of the GMC should be constant in such a mode, and in this case, the efficiency can be increased to 95÷100% in accordance with the technical instructions. At the same time, it should be taken into account that if the operation of the GMC in such a mode is constantly continued in gas lift and gas transportation systems, the wear limit in the friction areas of nodes and parts will be normal, premature wear will be eliminated and the unit's repair time will be extended. When the technical-technological-thermodynamic regime is violated in the operation of the compressor unit, the economic and energy regime of the unit is seriously violated, see table 5.

It is more clear from table 5 that if the clearance in the friction areas of the main nodes and details of the compressor unit exceeds the permissible clearance according to the manufacturer's instructions, the technical and economic indicators of that unit decrease. Of course, in such an operating mode, if the technical parameters of the lubrication system of the compressor unit do not comply with the manufacturer's instructions, wear increases and the number of idle stops increases in the event of an accident.

Therefore, engineers and technicians operating the compressor unit must constantly take into account that as the permissible clearances in the friction areas of nodes and details increase, the most important economic parameters of the units decrease significantly. This means that the reliability and efficiency of the compressor unit decreases, productivity decreases, and the cost of compressed gas increases. It is known from mining practice that compressor units in GKS and SKS are often operated with changing loads. As a result, it can be said that frequent changes in the pressures of low-pressure side oil gas entering the compressor cylinders and high-pressure compressed gas at the outlet lead to a corresponding change in the number of crankshaft revolutions. As a result, difficulties arise in regulating the power and compressor cylinders, and ultimately, dynamic forces increase [6,7,8]. Therefore, as a result of the increase in dynamic forces in the compressor and power cylinders, the thermodynamic process in the cylinders is disrupted, and, accordingly, the normal operation of pistons, piston rings and valves is seriously changed. Therefore, as a result of the influence of dynamic forces in the compressor and power cylinders, the clearances in their nodes and details increase, and the probability of an accident increases. Therefore, the main technical and technological parameters of the operated compressor units must be maintained in accordance with the manufacturer's instructions, and a comparison of the distances that can be left in the wear areas of the nodes and details in the manufacturer's technical instructions with the practically measured distances is shown in Table 1 (several nodes and details are listed as examples):

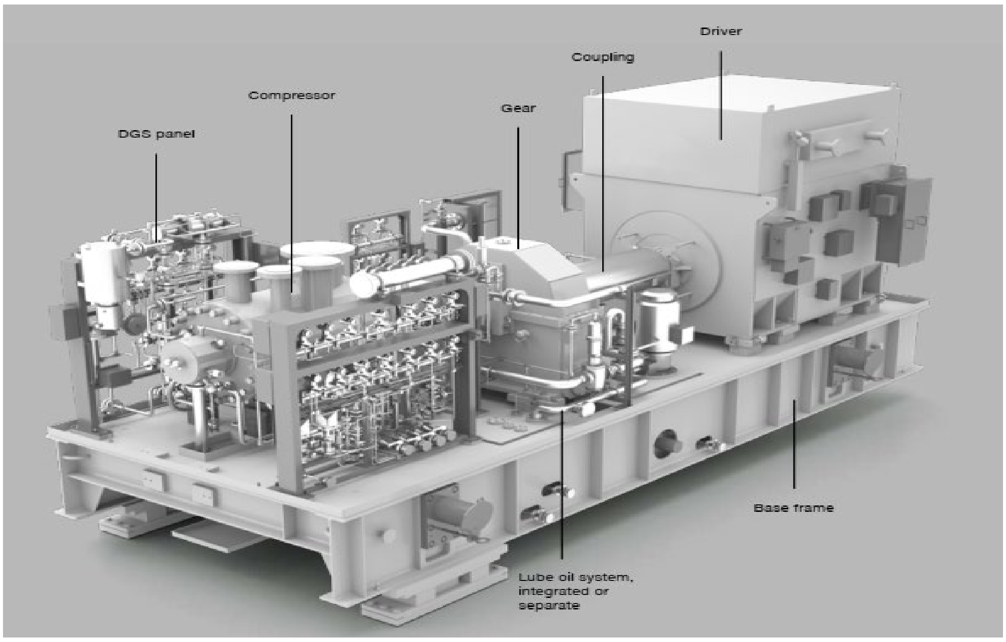

Figure 4. General Diagram of a Centrifugal Compressor

Table 1

№	Names of components and details	Allowable diametrical clearance, mm (normal)	Practical diametrical measured clearance	As a result of wea	
				Nominal power	Productivity
11	Distance between cylinder and piston of power cylinders	1,5	2÷2,5	8÷10% reduces	12÷15% reduces
22	Distance between cylinder and piston of 1st stage compressor	1,0÷12%	1,5÷1,8	10÷12% reduces	1,5÷1,8 reduces

Based on the conducted studies, it can be concluded that the selection of risers and their effective operation in wells depends on three main factors:

1) Despite the theoretical calculation, in production, the energy in the well is determined by a practical method, in addition to the correct and effective working agent (compressed high-pressure associated petroleum gas), and in the best case, with the help of oil to be produced according to the technological regulations;

2) The diameter of the risers should fully correspond to the maximum power of the protected oil production;

3) The depth of the compressor risers in the well should be as great as possible, and for this it is possible to install the f.i.e. of the risers.

It is known that the most widespread risers in the OGPD consist of two-row pipes:

1) Injection of compressed high-pressure gas;

2) Formation of the liquid with compressed gas. This also occurs with the main energy of the gas rising upwards.

The main reason for this is that the compressed high-pressure gas injected into the riser moves in the direction of the lowest pressure, that is, from the shoe to the wellhead.

During the movement of the gas-liquid mixture in the riser pipes to the wellhead, the pressure of the mixture must be such that it both overcomes friction in the distance from the point of formation of the mixture to the wellhead, and also overcomes any movement in front of it during its movement. At the same time, it is necessary to obtain that there is no exact calculation of the riser pipes in the central gas lift system.

During the operation of gas lift wells, small diameter pipes are selected to have a large annular area. Through these pipes, the injection of compressed oil-pressured associated gas is ensured at the gas lift compressor station. However, the diameter of the pipes cannot be reduced too much, as a very large pressure loss may occur. In mining practice, this is achieved by selecting the diameter of the riser pipes according to the operating column.

For this purpose, the dimensions of the riser pipes are taken depending on the diameter of the operating column and the depth of discharge. If the operating diameter is 203.2mm (8″), then the pipe for shallow penetration is 76.2mm (3″), for deeper penetration, 63.5mm (2.5″) or 50.8mm (2″), 1.4mm (6″) diameter increases the effect of only 50.8 (2″) pipes on gas lift wells. Now, for example, to ensure the optimal productivity of a gas lift well and the pressure in the well bottom zone in accordance with this productivity, the length of the riser pipes, the length of the riser pipes, the required daily supply of compressed high-pressure gas (working agent).

It is known in mining practice that when the gas factor of the formation decreases, it becomes very difficult to lift the fluid to be produced to the wellhead, and in this case, high-pressure associated oil gas compressed in an additional gas lift compressor station is injected from the wellhead to the bottom zone, and then, starting from the bottom zone, artificial oil production in the well passes into the fountain form.

As a result, the operating conditions in the gas lift riser pipes become the same as those of the fountain method, and this can be determined by the following formula [2,9]:

$$Q_{ef'} + R_{0.v.r.} \geq R_0 \,, \tag{1}$$

Here $Q_{e.f.}$ is the effective gas factor; $R_{0v.r}$ is the specific consumption of gas injected to the bottom of the well; R_0 is the specific consumption of the required gas.

The total efficiency of the compressor gas lift system is equal to the product of the total energy of this system and the energy distributed in individual areas of the system [2]:

$$\eta_{k.q.s.} = \eta_{q.m.} \cdot \eta_{p.k.} \cdot \eta_{m.q.x.} \cdot \eta_{q.b.} \cdot \eta_{p.q.x.} \cdot \eta_{q.} \tag{2}$$

where $\eta_{k.q.s.}$ – efficiency of the compressor gas lift system; $\eta_{q.m.}$ – efficiency of the gas engine; $\eta_{p.k.}$ – efficiency of the piston compressors in the oil well; $\eta_{m.q.x.}$ – efficiency of the high-pressure main gas line in the field; $\eta_{q.b.}$ – efficiency of the battery distributing h_{igh}-pressure gas to the wells; $\eta_{p.q.x.}$ – efficiency of the gas distribution lines to the wells; $\eta_{q.}$ – efficiency of the gas lift unit.

For this, we assume the following data: well depth $H = 1470m$; formation pressure $P_1 = 66atm$, productivity factor $K = 6t/day \cdot \leftarrow atm$; allowable depression pressure, ΔP=16atm; diameter of the production casing $D = 7''$ (177.8mm); percentage of water with oil from the formation is 20%; specific gravity of oil $\gamma_h = 0.9$; relative specific gravity of water $\gamma_h = 1$; natural gas factor $G_0 = 50m^3/ton$; gas solubility coefficient corresponding to 1atm pressure, $a = 0.53m/t.atm$; gas working pressure $P_{i.t.} = 37.5atm$; P_y at the wellhead.

Using the data, let's determine the optimal productivity of the gas lift well [4,10]:

$$Q_{opt} = K \cdot \Delta p = 6 \cdot 16 = 96m/day \tag{3}$$

Knowing the optimal productivity of the well, we determine the pressure in the well bottom zone.

$$P_{q.d.} = P_1 - \Delta p = 66 - 16 = 50atm \tag{4}$$

Considering that the pressure in the well bottom zone is greater than the working pressure, then the length of the riser pipes is calculated not according to the depth of the well, but only according to the working pressure.

In this case, the length of the riser pipes is determined according to the working pressure as follows.

$$L = H - \frac{10(P_{i.t.} - P_b)}{\gamma} \tag{5}$$

Here, first, let's determine the pressure in the shoe (P_b). For this, it is known from mining practice that the pressure loss in the pipes, taking into account the assumption of $P_1 = 4atm$, should be subtracted.

Then, knowing the pressure loss, we determine the pressure in the shoe:

$$P_b = P_{i.t.} - P_1 \tag{6}$$

Then we determine the average specific gravity of the liquid mixture between the wellbore zone and the shoe of the riser pipes.

$$\gamma = \frac{\gamma_{q.d.+}\gamma_1}{2} \tag{7}$$

It should be noted that in the formula - is the specific gravity of the liquid, and we determine it as follows.

$$\gamma = \frac{80_\gamma + 20\gamma_b}{100} = \frac{80 \cdot 0{,}9 + 20 \cdot 1}{100} = 0{,}92$$

However, knowing that it is 20% water, the yield is found based on the liquid.

The diameter of the riser pipes is calculated as follows for the optimal well productivity regime:

$$d = 0.235\sqrt{\frac{1}{\varepsilon}} \cdot \sqrt[3]{\frac{Q}{(1-\varepsilon)\cdot\gamma}} \tag{9}$$

In this case, taking into account that gas is dissolved in oil and that oil contains 20% water, we determine the specific consumption of compressed high-pressure associated oil gas required to lift one ton of oil.

$$R_{0_{su}} = R_0 - \left[G_0^1 - \frac{a}{\gamma}\left(\frac{P_b + P_y}{2} - 1\right)\right]\left(1 - \frac{\pi_b}{100}\right) \tag{10}$$

We determine the dynamic level that can be generated in the well, corresponding to the daily gas consumption:

$$h_0 = h - \frac{10(P_b - P_y)}{\gamma} = 1285 - \frac{10(34.5 - 1.2)}{0.92} = 923m$$

The report once again shows that other required parameters can be calculated in advance for each gas lift well in accordance with the technological regime predetermined by the geological and well development departments of the OGPD.

It is known from mining practice that the amount of product extracted from a gas lift well depends largely on the volume and pressure of compressed high-pressure associated petroleum gas injected into the well. This dependence varies depending on the depth of the risers, the depth of the pipes, the diameter of the pipes and the back pressure in the well discharge line.

Conclusions

Failures that occur during the operation of centrifugal compressors can lead to serious problems. Various mechanical, thermal, and hydrodynamic causes result in faults and breakdowns in compressor performance. Regular maintenance, balancing, and the application of proper operating conditions help prevent these issues.

Taking into account the above, in order to ensure the operation of compressor units in accordance with the instructions of the manufacturer, to improve their economic indicators and increase their reliability, it is proposed to carry out the following innovative technical and technological works at the N. Narimanov Oil and Gas Production Department's GKS and SKS:

1. By improving the low-pressure associated oil gas collection system, maintain the gas pressure directed to the GKS and SKS at a constant level of 4.2÷4.5 atm;

2. Deeply clean the internal surface and gas cleaning parts (metal meshes and plates) of the separator head units installed in the GKS and SKS once a year;

3. By fully restoring the operation of the separator head units, cleaning the low-pressure associated oil gas entering the 1st stage compressor cylinders from mechanical impurities, especially sand particles and large and medium-sized liquid hydrocarbon particles, it is possible to structurally protect the surface of the inner mirror part of the cylinder from deep scratches and abrasions;

4. Taking an oil sample from each operating GMC every two months and solving the issue of changing the oil in the crankcase by checking the mechanical mixture, water and at least its color change in the laboratory (if it is darkened);

5. Eliminating serious technical malfunctions that may occur by ensuring the distribution of gas pressures in the compressor cylinders in accordance with the manufacturer's instructions;

6. Maintaining the permissible clearances in the friction areas of the GMC, especially in the engine section, by constantly monitoring the lubrication pressure and oil temperature in accordance with the manufacturer's instructions;

7. At the intake of the 1st stage compressor cylinders of the gas turbine, by maintaining the pressure of the low-pressure associated oil gas at 4.2÷4.5 atm, ensure the overall productivity of the compressor unit in accordance with the manufacturer's instructions;

8. When the number of revolutions of the crankshaft in the gas turbine is less than the manufacturer's instructions, i.e. 260÷270 revolutions/min., the clearance in the friction areas of the nodes and details is 1.5÷2 times greater than the permissible norm. To prevent this, maintaining the number of revolutions of the crankshaft in accordance with the instructions (300 revolutions/min) increases productivity and is very profitable.

9. By maintaining the technical-technological-thermodynamic parameters of the gas turbine in operation in accordance with the instructions, it is possible to reduce the number of operating compressor units. As a result, the cost of compressed gas can be reduced.

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Received: 24.07.2024
Accepted: 12.10.2024