ПОВЫШЕНИЕ БЕЗОПАСНОСТИ ЭКСПЛУАТАЦИИ КОМПРЕССОРНЫХ АГРЕГАТОВ ЗА СЧЕТ УРАВНОВЕШИВАНИЯ РОТОРОВ

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INCREASE OF SAFETY OF OPERATION OF COMPRESSOR UNITS DUE TO BALANCING OF ROTORS

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Аннотация

Рассматриваются причины повышенного шума и вибрации при работе компрессорных агрегатов на предприятиях стройиндустрии. Предлагаются вибрационные методы и средства измерения статической и моментной неуравновешенности жестких роторов. В отличие от существующих аналогов предложенные средства не требуют предварительной настройки, обладают более высокой точностью измерения за один пуск, являются более безопасными и имеют меньшую стоимость.

Abstract

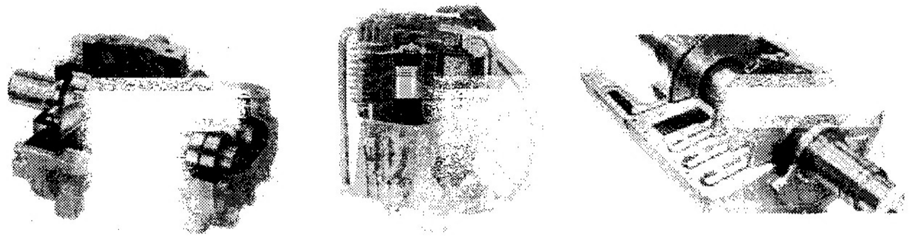
The reasons of the increased noise and vibration at work of compressor units at the building enterprises are considered. Vibration methods and means of measuring the static and moment imbalance of rigid rotors are proposed. In contrast to the existing analogues, the proposed tools do not require pre-setting, have a higher measurement accuracy for one start, are safer and have a lower cost.

Ключевые слова: компрессор, ротор, шум, вибрация, дисбаланс, маятниковая рама, свободные колебания.

Keywords: compressor, rotor, noise, vibration, imbalance, pendulum frame, free oscillations.

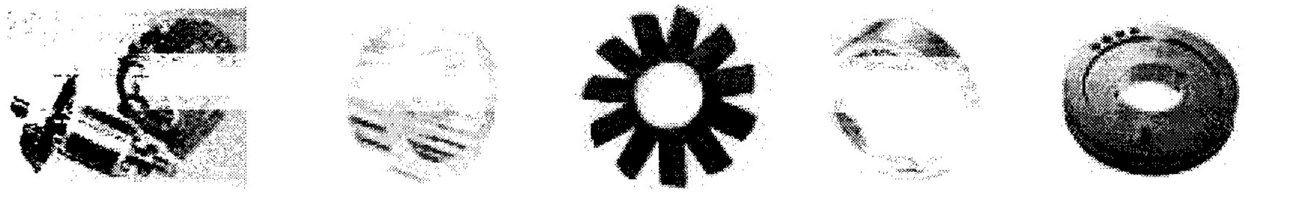
Problem statement. The work of compressor units in construction companies is often associated with high levels of noise and vibration. These factors are the cause of occupational diseases, occupational injuries and reduced productivity [1, 2]. Approximately 19 % of the cases of occupational diseases in Ukraine falls on vibration disease and diseases of hearing organs.

The most common types of compressors in the construction industry are: screw, piston and centrifugal. Their work is accompanied by high levels of noise and vibration. Among noise is dominated by the noise of mechanical origin. The main sources of these factors are air compression units (Fig. 1). There are also other sources (Fig. 2).



a b c

Fig. 1. Blocks the compression of air: a – helix; b – piston; c-centrifugal



a b c d e

Fig. 2. Additional sources of vibration and noise: a – rotor (left) of the induction motor; b and c – electric fan impellers; d – under-stud; e – flywheel

In all considered sources unbalance of rotors is the cause of vibration and noise. The occurrence of vibration during the rotation of the unbalanced rotor is explained by the presence of vibration forces, the frequency of which coincides with the speed of rotation, and the module is proportional to the amount of unbalance (imbalance) [3, 4]:

$$\left|F_{VIBR}\right| = D\mu\omega^2, \tag{1}$$

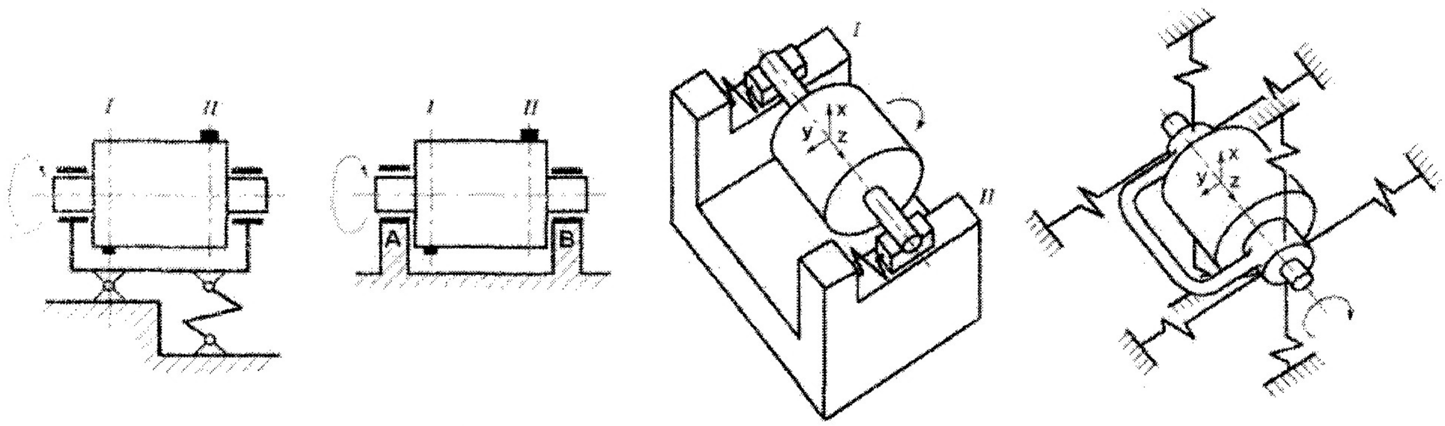
where D – imbalance, kg·m, μ – the coefficient of dynamic; ω – cyclic frequency.

The noise level from the vibrating surface depends on its shape, area and vibration velocity. The sound power from a vibrating flat (according to the law of sine) of a surface equal to:

$$W_{SOUND} = \frac{\rho\omega S^2 v^2}{8\pi c}, \tag{2}$$

where ρ – density of medium, kg/m³; S – surface area, m²; V - vibration velocity, m/s; c – the speed of sound in the medium, m/s.

There are several types of rotor unbalance: static, torque and dynamic [5, 6]. For balancing of rotors of various methods, which essentially boils down to the adjustment of the unbalanced masses. This can be achieved by removing or adding a specific mass in the correction planes by drilling, tapping, soldering, welding or gluing. This process is called balancing. Currently used several types of balancing machines, which carry out the measurement of the unbalanced masses. The main diagrams of these machines are shown in Fig. 3.



a b c d

Fig. 3. Schemes of machines for dynamic low-frequency balancing in two correction planes: a – with fixed supports of the balanced rotor; b,c – with a fixed axis of oscillation of the rotor; d – with a fixed plane of oscillations

In the first scheme, the rotor has two connections with the base: rigid and elastic. Unbalance is determined by the amplitude of oscillations of the rotor during its rotation. If the unbalance is in plane I, it does not affect the unbalance in plane II.

In the second scheme, the rotor is connected to the base by means of rigid bearings (Fig. 3b). To determine the unbalance of the rotor, dynamic reactions of the supports are measured using force sensors. Operation of such machines is possible in pre-resonant mode.

In the third scheme, the rotor oscillates in a fixed (horizontal) plane, (Fig. 3c). Vibration amplitudes in vertical planes I and II are measured to determine unbalance. The work of these machines is possible in the resonance mode.

In the fourth scheme, the rotor has no rigid connections with the environment, Fig. 3d).

All the schemes have shortcomings that limit their effectiveness and use in practice. The first three schemes require pre-setting the machine, which reduces labor productivity with frequent changes in the nomenclature of the rotors. These schemes limit the accuracy of measurement and correct unbalance in a single start. The increase in the number of starts leads to an increase in the cost of individual rotors and compressor units as a whole. The high speed rotation of the rotor in the balancing process is the cause of high risk of injuries. These machines have a high cost due to the presence of rotation drives. As a result, the rotors of the compressor units have a relatively high residual imbalance, which is the main cause of increased noise of mechanical origin and vibration.

The aim of the article is to develop and introduce into production effective and safe methods and means of measuring the unbalance of rotors, which will allow to achieve a more effective reduction of noise and vibration of compressor units in the sources of occurrence - unbalanced rotors.

Presentation of basic material. Currently, vibration methods and means of measuring the unbalance of rotors based on measuring the frequency of free damping vibrations of the pendulum frame have been developed and patented [7-10].

Figure 4 shows a diagram of a device for measuring static rotor unbalance, which is a pendulum frame.

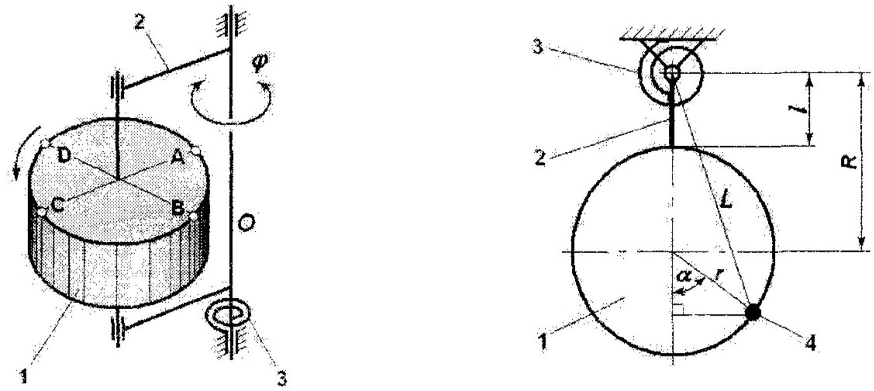


Fig. 4. Simplified diagram of a device for measuring static unbalance (top view and overview)

Rotor 1 is mounted on the pendulum frame 2, which is connected to the fixed base by means of hinges and torsion spring 3. The rotor has an unbalanced mass of 4. Rotor 1 can be rotated around its axis and fixed in four positions (points A, B, C, D). Frame 2 can make free damping vibrations relative to the O axis. The oscillation sensor and frequency meter are used to measure the oscillation frequency (not shown in the diagram).

The method of measuring static unbalance (imbalance) is as followsThe rotor 1 is mounted on the frame 2. In this position, the rotor is rotated to the axis of the point A. Excite and measure free damping oscillations. Then turn the rotor on 90° anticlockwise. In this position it will be rotated to axis O by point B. Similarly, measure the oscillation frequency and repeat the procedure for other positions of the rotor (points C and D).

The value of static unbalance (imbalance) is calculated by the formula

$$D = mr = \frac{G}{16\pi^2 R}\sqrt{\left(\frac{1}{\nu_A^2} - \frac{1}{\nu_C^2}\right)^2 + \left(\frac{1}{\nu_B^2} - \frac{1}{\nu_D^2}\right)^2} =$$

$$= \frac{G}{16\pi^2 R}\sqrt{\left(T_A^2 - T_C^2\right)^2 + \left(T_B^2 - T_D^2\right)^2}, \quad (3)$$

where m – the magnitude of unbalanced mass; G – the stiffness coefficient of the spring 3 torsion; ν_A-ν_C и T_A-T_C – the measured frequencies and periods of free vibrations of the frame, respectively R – the shoulder frame.

The angle α imbalance is calculated using the algorithm in Fig. 5.

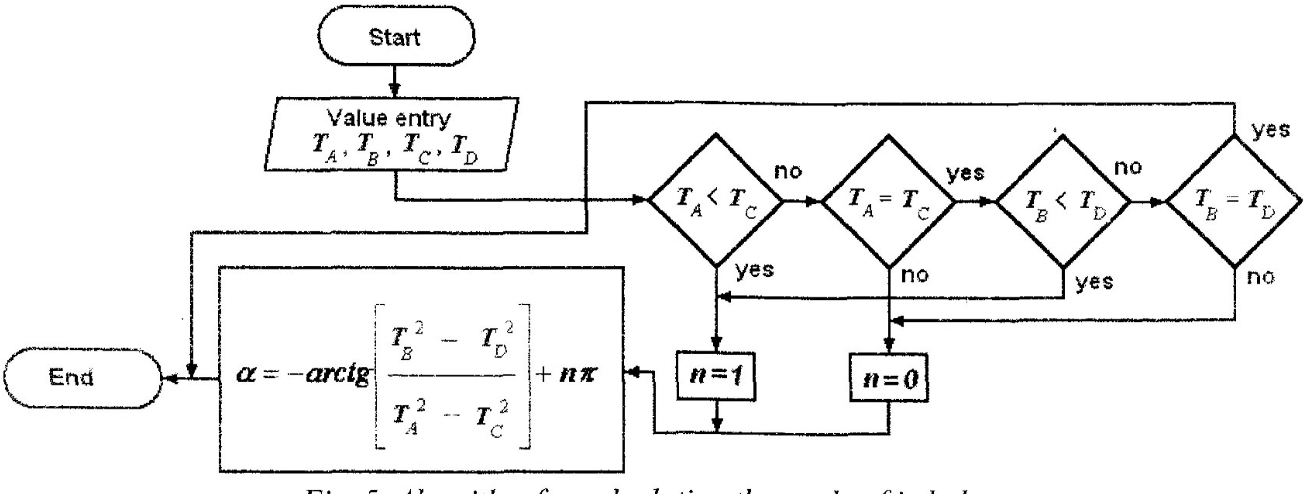
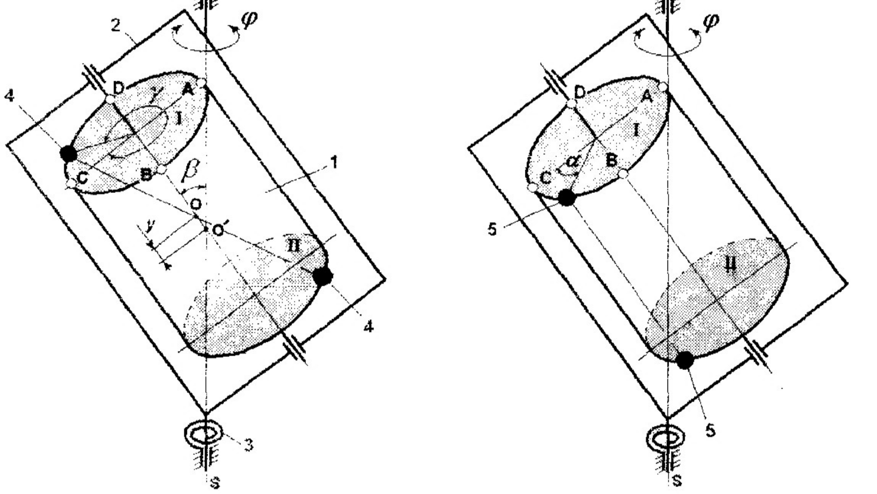


Fig. 5. Algorithm for calculating the angle of imbalance

Figure 6 shows a diagram of the device for measuring the torque unbalance of the rotors. Its device and principle of operation are similar to the scheme in Fig. 4. The difference of this device is that the frame is tilted to a vertical axis at an angle of β (π/4).



a *b*

Fig. 6. A simplified diagram of the device for measuring torque unbalance: a – rotor with the torque unbalance 4; b – rotor with static unbalance 5

The method of measuring the moment unbalance is similar to the previous method, and also involves measuring the free damping oscillations of the pendulum frame in different positions of the rotor relative to its axis. The value of the moment unbalance is calculated by the formula

$$M_D = \frac{1}{\sin 2\beta} \times$$

$$\times \sqrt{\left[\frac{G}{4\pi^2}\left(T_{*A}^2 - T_{*C}^2\right) - 2Dy\sin 2\beta\cdot\cos\alpha\right]^2 + \left[\frac{G}{4\pi^2}\left(T_{*B}^2 - T_{*D}^2\right) + 2Dy\sin 2\beta\cdot\sin\alpha\right]^2} \quad , (4)$$

where y – distance between points O and O' (O – a point equidistant from the correction planes I and II; O' – point at the intersection of the rotor axis and the axis S-S).

The angle γ of the moment unbalance is calculated using the algorithm in Fig. 7.

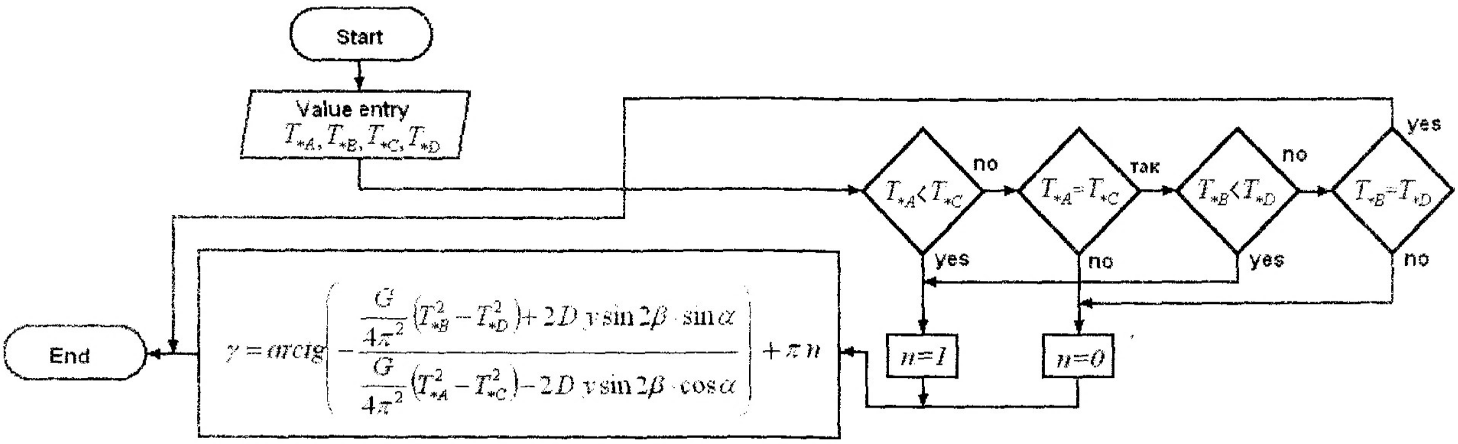


Fig. 7. The algorithm for angle calculation torque unbalance

To measure unbalance, you do not need to adjust the device based on the location of the measurement planes. In the process of measurement there are no distortions and the output of unbalanced mass from the plane of measurement. There is no acceleration, the rotation of the braking rotor. This saves energy, increases productivity and increases safety. The device does not have an electric motor drive, which reduces its cost.

The proposed methods and means can be implemented not only in enterprises that produce rotor assemblies, but also in the repair areas of construction companies.

increased levels of noise of mechanical origin and vibration. The main sources of these factors are unbalanced rotors. Existing methods and tools for measuring imbalances have a number of disadvantages that limit their effectiveness. To solve this problem vibration methods and means of measurement of unbalance have been developed and patented, which in the opinion of the authors are not inferior to analogues in efficiency and are safer. Implementation of the proposed methods and tools will improve the quality of rotor balancing compressor units and thereby reduce their noise and vibration levels.

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