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## NamMTI ILMIY-TEXNIKA JURNALI TAHRIR HAY'ATI A'ZOLARI

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# OPERATIONAL CHARACTERISTICS OF CENTRIFUGAL PUMPS IN THE MINING INDUSTRY

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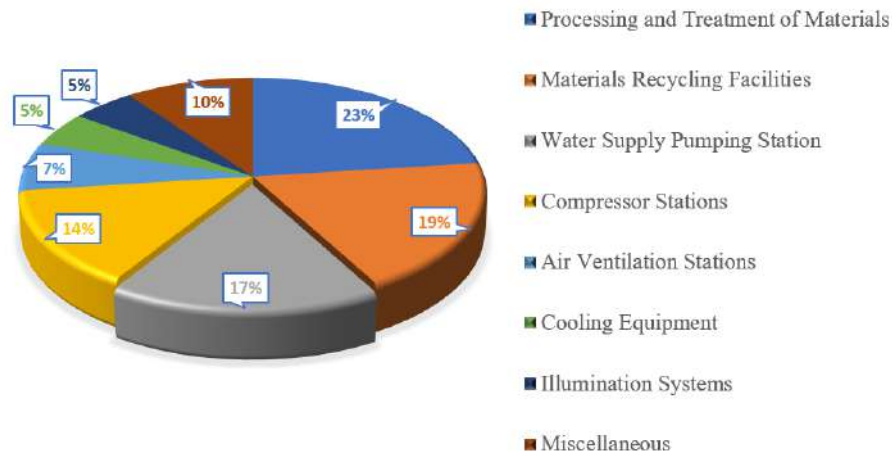
**Abstract:** Pump stations at mining industry enterprises represent a critical infrastructure component that ensures the continuous and reliable operation of technological processes. Their efficient performance plays a decisive role in the stable transportation of mineral resources, including uranium raw materials and processed products, from extraction sites to processing and consumption points. Pumping equipment used in mining enterprises constitutes an integral and essential element of technological processes related to the transportation and processing of minerals. These processes are characterized by high energy intensity and account for a significant share of the total electrical energy consumption of the enterprise. This study analyzes the functional structure of pump stations employed in mining production, the operational characteristics of their main and auxiliary systems, the types of pump units, as well as their performance and operational indicators.

**Keywords:** pump, pump station, centrifugal pump, engine, electric motor, internal combustion engine, impeller, pump casing, drive system, efficiency coefficient.

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**Introduction.** The pumping station is one of the key structural elements of mining enterprises. Its reliable and stable operation ensures the continuous transportation of extracted minerals, including uranium products, from mining sites to end users. In the context of modernization and the implementation of advanced equipment at pumping stations, it is necessary to have a comprehensive understanding of the operation of both primary and auxiliary systems, the classification and operating principles of pumps, the types of monitoring and measurement instruments used, as well as the technological operating modes of these facilities.

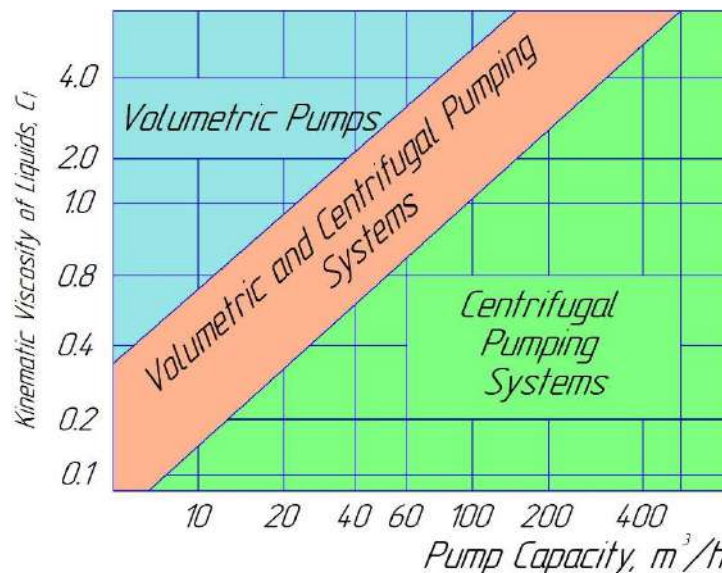
Pump installations used in mining enterprises represent a critical component of the technological chain for the transportation and processing of mineral resources. The processes associated with the movement and treatment of extracted materials are among the major consumers of electrical energy. Mine dewatering systems constitute one of the largest energy-consuming units, accounting for approximately 17% of the total electricity consumption. The distribution of energy consumption within mining operations is illustrated in Figure 1 [1].



**Figure 1.** Structure of energy consumption in the mining industry

**Materials and methods.** At mining enterprises, the existing systems used for mine water removal can be classified according to specific operational and functional characteristics.

In general, the fields of application and operating principles of various types of pumps are presented in Figure 2. The analysis shows that centrifugal pumps can be effectively used for pumping liquids with a wide range of viscosities.



**Figure 2.** Application areas of different types of pumps

Centrifugal pumps are among the most widely used types of equipment for liquid handling and transportation. They are extensively applied for mine dewatering, as well as for pumping highly abrasive hydraulic mixtures—such as sand, gravel, and slag—at mineral processing and beneficiation plants. These pumps enable the lifting of fluids to

considerable heights and ensure their reliable transportation over long distances through pipeline systems.

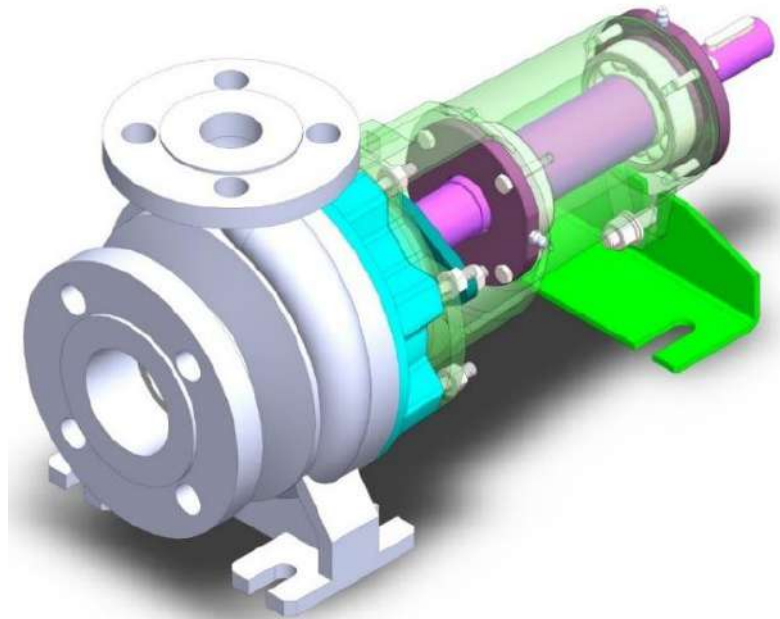


Figure 3. Centrifugal pump type

Various types of centrifugal pumps are widely used in mining and mineral processing plants, mining and metallurgical enterprises, thermal power stations, cement production facilities, and gold extraction operations, as well as in mineral beneficiation processes.

The main classification of centrifugal pump types is presented in Figure 4.

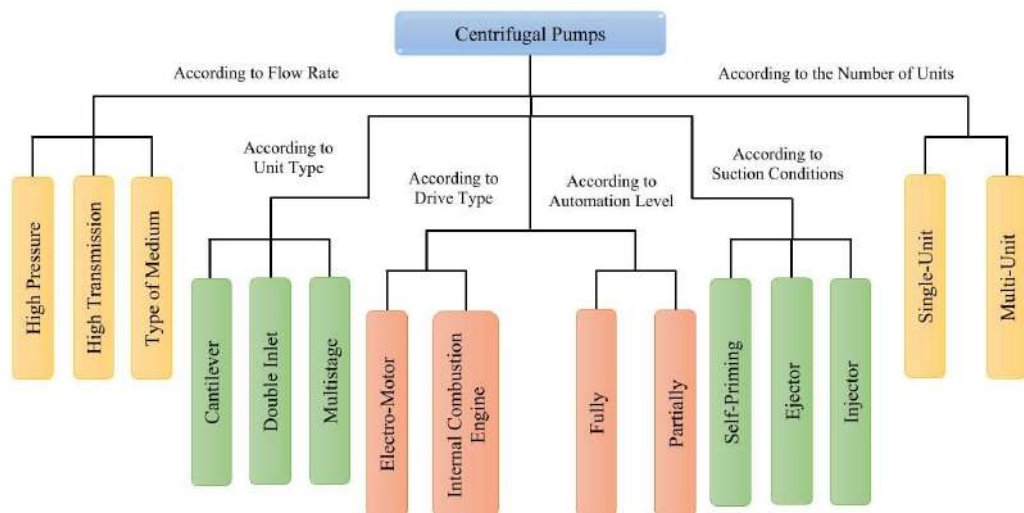
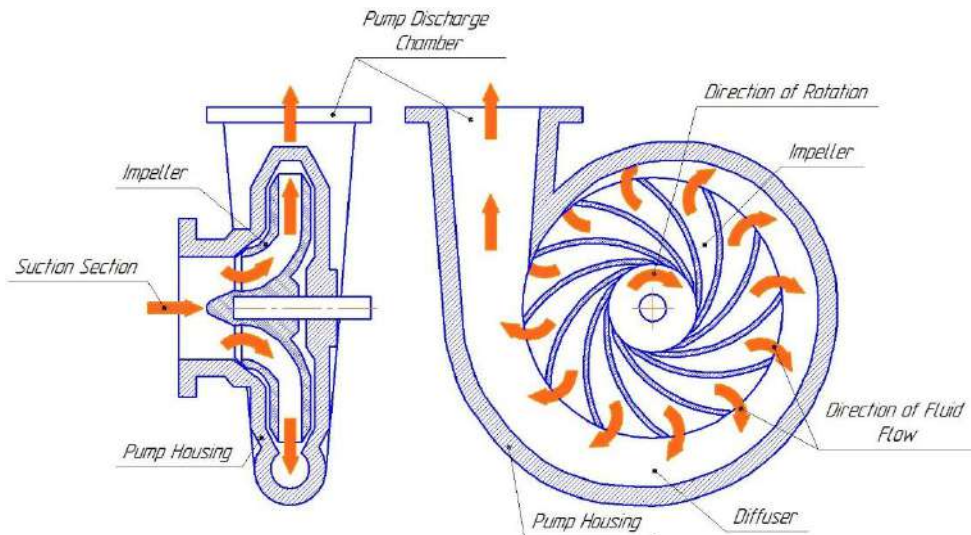


Figure 4. Classification of centrifugal pumps

**Operating principle of a centrifugal pump.** The operating mechanism of this type of pump is based on the following process. The pumped liquid or liquid mixture enters

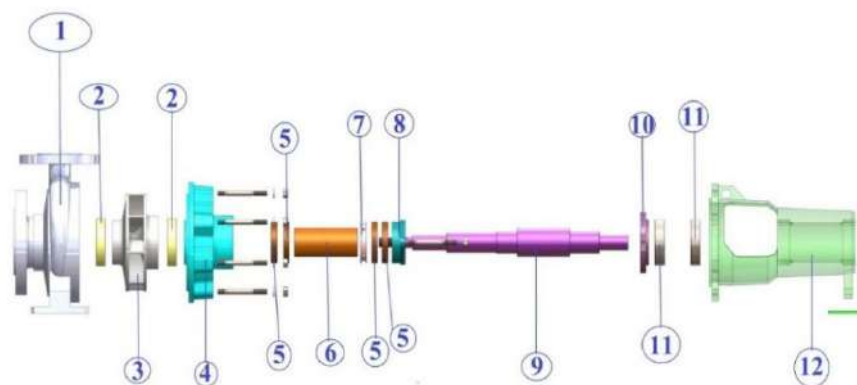
the pump through a cylindrical suction inlet and is directed to the impeller. As the impeller rotates, centrifugal forces generated by its blades impart kinetic energy to the fluid. Under the action of these forces, the hydraulic mixture is accelerated and discharged through the outlet pipeline (see Figure 5).



**Figure 5.** Operating principle of a centrifugal pump

**Main section.** Centrifugal pumps are equipped with high-pressure hydraulic components, which allows them to be used not only for suction of liquid mixtures but also for their transportation over long distances. The above-mentioned advantages demonstrate that centrifugal pumps are highly efficient and reliable devices for handling and conveying liquid mixtures. Typically, a centrifugal pumping unit consists of the pump itself and a drive system. The drive is usually provided by an electric motor or, in some cases, by an internal combustion engine.

These centrifugal pumping units are characterized by high operational efficiency, which can reach up to approximately 75%. To ensure reliable operation under demanding conditions, high-power drive motors are used, with an average rated capacity of up to 650 kW.



**Figure 6.** Design of a single-stage centrifugal pump. 1 – pump casing; 2 – wear rings; 3 – impeller; 4 – coupling; 5 – stuffing box seals; 6 – seal chamber; 7 – lubrication ring; 8 – stuffing box chamber; 9 – shaft; 10 – bearing cover; 11 – bearings; 12 – cast bracket

The design of a centrifugal pump consists of a main casing and the working components installed inside it. The primary internal elements include the impeller (3), wear rings (2), stuffing box seals (5), and the shaft (9) (see Figure 6).

All centrifugal pumps are also equipped with auxiliary flushing or cleaning systems designed to prevent clogging and to ensure stable and reliable operation during the pumping of contaminated or abrasive fluids.

The materials used for the hydraulic (flow) components of the pump—such as the impeller, pump casing, and protective discs—are manufactured from the wear-resistant alloy IZrCr28H2, which provides high resistance to abrasion and mechanical wear. The flow section of a centrifugal pump consists of inner and outer casings, within which a closed-type centrifugal impeller is installed to ensure efficient energy transfer to the pumped fluid. The rotating element of the pump is the shaft, which is mounted on rolling-element bearings. The impeller is installed on the cantilevered end of the shaft and is securely fixed using a locking nut to ensure reliable operation during rotation. The stuffing box assemblies are located in the rear cover of the casing and serve to protect the shaft from abrasive wear and the ingress of solid particles, thereby increasing the service life and operational reliability of the unit.

The operational features and selection of the hydraulic flow components in centrifugal pumps are determined by key technical parameters, including head, flow rate, rotational speed, efficiency, and power. The design of the discharge section should ensure the transformation of the flow conditions downstream of the impeller—specifically the reduction of velocity and the increase of pressure—with minimal hydraulic losses.

Based on the analysis of flow pressure characteristics and spectral data, the levels of noise and vibration over the entire operating range of a centrifugal pump can be evaluated. Such analysis makes it possible to identify the nature of mechanical and hydrodynamic forces acting within the unit, as well as the factors that subsequently cause their occurrence.

For centrifugal pumps, the main mechanical forces include the following:

- centrifugal forces caused by the imbalance of rotating rotor components;
- kinematic forces resulting from the interaction of contact surfaces, primarily due to irregularities and friction at bearing interfaces, as well as at the surfaces of throttling elements and stuffing box seals.
- parametric forces associated with the variable stiffness component caused by defects or imperfections in the centrifugal pump shaft;
- impact forces arising from the interaction of individual friction elements, accompanied by elastic deformations, as well as other related dynamic effects.

The origin of hydrodynamic forces is associated with pressure forces exerted by the fluid flow on the impeller blades during rotation, as well as on the walls of the discharge channels and flow passages [2, 3, 4, 5].

To modify the specific speed coefficient  $n_s$  of a centrifugal pump, it is necessary to significantly change the geometric configuration of the impeller. In addition, the volumetric flow rate—one of the key performance indicators of the pump—can be increased by optimizing the geometric parameters of the discharge flow elements.

The stationary flow components are located downstream of the impeller and typically include the following sequence: an annular diffuser, guide vanes, a spiral (volute) casing, and a conical diffuser section [6].

**Results and Discussion.** Each of these elements performs, to a certain extent, the function of converting the kinetic energy of the fluid flow into pressure energy. At the same time, they ensure flow uniformity and form the required flow passage that provides the desired direction for the velocity vectors of fluid particles.

The entire process must ensure minimal pressure losses of the fluid flow as it moves through the internal passages of the pump hydraulic components.

The vortex formation factor in the fluid flow also has a significant influence on the technological performance of pumping equipment. Flow vortices arise due to the non-uniform distribution of velocity and irregular changes in the direction of the fluid stream. In practice, circular or swirling flow structures are most often observed near the pump, particularly at the suction zone and at the narrowest sections of the inlet passage. The direction of vortex motion may either coincide with or oppose the direction of impeller rotation. If the swirl direction matches the direction of the impeller rotation, the overall efficiency of the pump operating mode decreases. Conversely, if the vortex rotates in the opposite direction to the impeller, it can lead to deviations from nominal performance, including an increase in power consumption and a reduction in the available cavitation margin.

The presence of flow swirl is a critical factor that contributes to accelerated wear of moving components, increased vibration levels, and a reduction in flow pressure within pumping equipment.

Axial and radial loads also have a significant impact on the optimal and reliable operation of pumping equipment. During pump operation, when the fluid passes through the impeller, axial forces are generated due to the pressure difference between the suction and discharge sides of the pump. The magnitude of the axial force depends on the developed head, as well as on the design type and dimensions of the impeller. As the pump head increases, the magnitude of the axial force correspondingly rises. In addition to axial loading, the impeller of a centrifugal pump is also subjected to radial forces. These radial loads arise due to pressure non-uniformity around the impeller circumference, as well as the asymmetric distribution of the spiral (volute) passages within the pump casing.

In addition, a significant imbalance may occur in the rotating components of the pump, which can lead to mechanical failures such as cracking, shaft deflection, and

damage to bearings and other structural elements. The following forces act on the shaft and bearings of centrifugal pumping equipment: the torque transmitted from the drive motor to the impeller; transverse and normal forces acting on the pump shaft due to the self-weight of the impeller; lateral forces generated when the axial symmetry of the flow around the impeller is disturbed as a result of hydraulic effects.

Axial forces generated by the fluid flow passing through the impeller and its internal cavities;

A bending moment caused by the combined effect of the impeller's self-weight and centrifugal force, which occurs during rotation due to misalignment between the impeller's center of mass and the geometric axis of the shaft (see Figure 7).

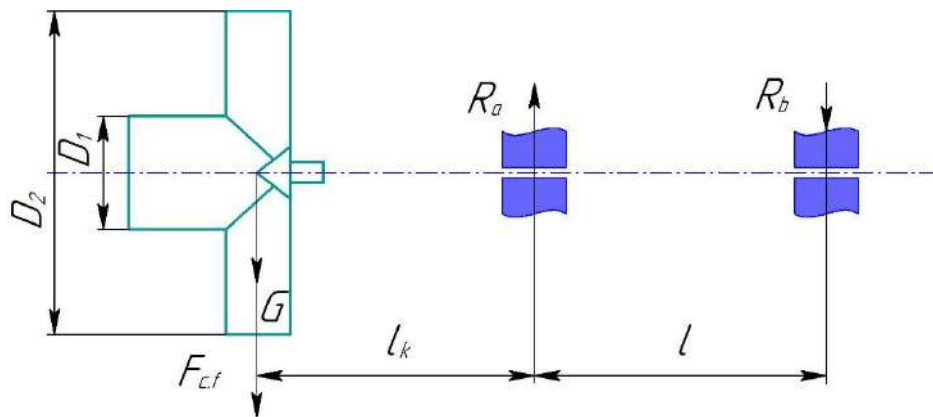


Figure 7. Scheme for calculating shaft deflection

The magnitude of mass eccentricity resulting from non-uniform wear of the impeller is determined as follows:

$$e_{mass} \approx (0,005 \dots 0,01) \cdot D_2$$

The permissible deflection of the end section of the shaft on which the impeller is mounted can be determined using the following inequality:

$$y \leq 0,001 \cdot l_k$$

Where  $l_k$  is the length of the shaft cantilever, i.e., the distance from the center of gravity of the impeller to the center of the first bearing.

The total eccentricity is defined as follows:

$$e = e_{mass} + y$$

The centrifugal force is determined as follows:

$$F_{c.f} = \frac{G \cdot e \cdot n^2}{900}$$

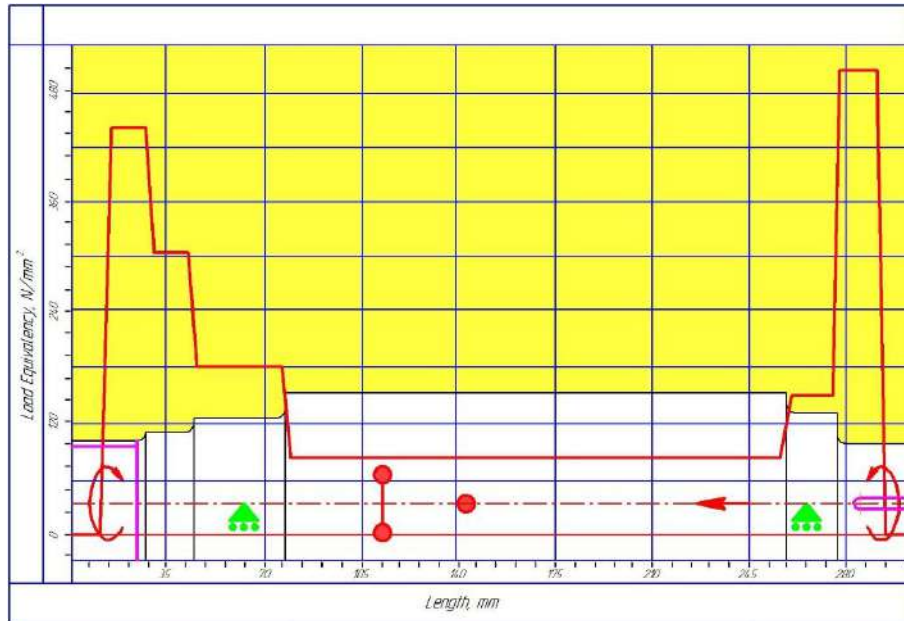
where  $G$  is the weight of the impeller, expressed in newtons (N).

According to the scheme shown in Figure 8, the deflection of the end section of the shaft can be determined using the following expression:

$$y = \frac{(G + F_{c.f}) \cdot (l + l_k) \cdot l_k^2}{3 \cdot E \cdot I}$$

where  $E$  is the modulus of elasticity of the shaft material, Pa;  $I$  is the moment of inertia of the shaft cross-section,  $kg \cdot m^2$ .

Calculations performed using these formulas tend to provide a slightly overestimated value of shaft deflection. However, this approach makes it possible to obtain an approximate assessment of the initial imbalance that occurs in the shaft as a result of wear of the working elements [7, 9, 11].



**Figure 8.** Analysis of the shaft of centrifugal pumping equipment

As shown in Figure 8, the maximum loads occur in the regions of the bearing supports. Therefore, it is necessary to develop diagnostic measures to determine the service life and to prevent operation under conditions of increasing vibration levels in the pump shaft. An increase in hydro-abrasive wear of pump units leads to a significant rise in vibration intensity.

**Conclusion.** The theoretical and experimental studies aimed at identifying the main factors affecting the service life of centrifugal pumping equipment have shown that hydro-abrasive wear of the impellers is one of the primary causes of pump failure. When the wear of the impellers exceeds standard and permissible limits, it leads to an increase in vibration levels of the pump unit. Therefore, the vibration characteristics of centrifugal pumping equipment can be considered as key diagnostic indicators of the technical condition and remaining service life of pump units.

The design of the pump discharge system is carried out taking into account all the above-mentioned elements and operational factors. In addition, the geometry of the discharge flow components is optimized using three-dimensional modeling in order to minimize hydraulic pressure losses and to improve the overall technical performance of the pumping equipment.

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