ГЕОТЕХНОЛОГИЯ. ГОРНЫЕ МАШИНЫ

DOI: 10.21440/0536-1028-2023-6-9-17

Dynamics of mine drainage centrifugal pumps technological development

Evgenii O. Churakov[1], Vladimir N. Makarov[2], Nikolai V. Makarov[2]*, Rustam G. Akhmetov[3]

[1] OOO SMNP Ekspertnaladka, Ekaterinburg, Russia

[2] Ural State Mining University, Ekaterinburg, Russia

[3] Kostanay Minerals JSC, Zhitikara, the Republic of Kazakhstan

e-mail: mnikolay84@mail.ru

Abstract

Introduction. *Basic performance requirements for the main mine drainage pumps arise from modern technologies of mining that take into account technical and economic capabilities of mining operations and geological features of the most accessible proved and producing fields. To carry out short-term prediction of the required equipment characteristics in order to organize rational mine dewatering, it is necessary to establish historical relationships between the true mining depths growth and the dynamics of centrifugal pumps technological development.*

Methods of research *include collecting and analyzing data from literary sources, using the chronological order and mathematical statistics of the hydrodynamic characteristics of the main drainage centrifugal pumps and the producing mine depths, and analyzing historical data and patterns of centrifugal pump hydromechanical characteristics improvement as a function of time.*

Results. *Correlation dependences are obtained between centrifugal pump hydromechanical parameters and mine depth growth dynamics as a function of time.*

Conclusions. *The level of centrifugal pump performance indicators is maintained for a sufficiently long period of time. The existing methods of centrifugal pump calculation and design have therefore practically exhausted their potential for modernization. Modern trends in natural resource consumption require maintaining the pace of mining development. It is predicted that in the short term, the main mine drainage is going to express a need for centrifugal pumps with increased hydrodynamic load and energy efficiency. The methods of vortex flow control in the wet and hydraulic ends of pump have the potential to improve these indicators.*

Keywords: *centrifugal pumps; head; efficiency; hydrodynamic load; energy efficiency; mine drainage.*

Introduction. To increase the accuracy of calculations during strategic planning of mineral deposits integrated development for 10–30 years or more [1], it is essential to assess the dynamics of process equipment, auxiliary equipment, and main mine drainage performance characteristics improvement. Design parameters of the main drainage operating modes depend on the field water content and inflow, determined by hydrogeological factors as well as the characteristics of mineral body occurrence and planned development stages depth. Therefore, the timeliness of requirements for main drainage equipment characteristics depends on the average indicators of the current stages and conditions of producing solid mineral deposits, determined by the demand for raw materials under the current capacity of field to produce.

Historically, mining was prefaced by easy-to-develop deposits with low production costs. Field depletion in the course of mining creates a tendency towards greater depths and technical sophistication of the mining process. When the feasibility limit is reached or minerals are fully developed, it is possible to consider the transition to new deposits with more complex development conditions and lower content of useful components. The factor of mining depth growth, as a rule, is also present [1].

Trends towards deeper and more complex mining increase the cost of mining. To maintain the competitive advantage, mining enterprises should improve the efficiency and the technological level of flow processes, including mine drainage. Thus, it seems relevant to compare the dynamics of mineral deposits mining and the dynamics of the of mine centrifugal pumps characteristics improvement.

The relationship between mine depths, efficiency, and coefficients of centrifugal pump head. Figure 1 shows a sample of the depths of mines operating on the territory of the USSR, and later on the territory of the former Soviet Union. Two dependencies as a function of time were selected from the given data sample by statistics: the average digging depth and the maximum digging depth. The indicators of the average and maximum digging depth as a function of time can be described by empirical regression equations:

$$H_{\text{average}} = 6{,}7 \cdot 10^{-49} T^{15{,}456}; \quad (1)$$

$$H_{\max} = 5{,}83 \cdot 10^{-69} T^{21{,}631}, \quad (2)$$

where T – time, year; in this case, the root-mean-square deviation is $R^2 = 0.70$ and $R^2 = 0.87$, respectively.

In this study, to assess the technical development of centrifugal pumps for the main mine drainage, the following criteria have been taken: the efficiency, as soon as it characterizes the indicators of equipment energy efficiency and cost-effectiveness, and the head coefficient ψ, which is an indicator for the hydrodynamic load level assessment of a centrifugal pump impeller:

$$\psi = \frac{2gH}{u_2^2},$$

where g is the gravitational acceleration; H is the head; u_2 is peripheral speed at the exit from the impeller.

Figures 2 and 3 show head and efficiency coefficients of centrifugal segmental pumps for the main mine drainage, designed and widely used at different times. The dependences of head coefficients and efficiency as a function of time can also be described by empirical regression equations:

$$\psi = -5{,}6412 \cdot 10^{-5} T^2 + 0{,}2295T - 232{,}28;$$
$$\eta = -2{,}804 \cdot 10^{-5} T^2 + 0{,}1139T - 114{,}91,$$

in this case, the root-mean-square deviation is $R^2 = 0.82$ and $R^2 = 0.90$, respectively.

Models of centrifugal segmental pumps. In the history of the technical development of centrifugal segmental pumps for the main mine drainage, several basic models are distinguished (Figures 2 and 3). Segmental pumps of the КСМ type [2] used until the 1940s were the first. КСМ centrifugal segmental pumps were in batch production. They were designed based on duplicate parts and characterized by low energy efficiency explained, firstly, by the increased energy losses in the vaned casings and transfer channels to the next segment of the pump, and secondly, by the additional losses in the hydraulic unloading device which compensates for the axial force. Rapid growth in the national economy's consumption of natural resources

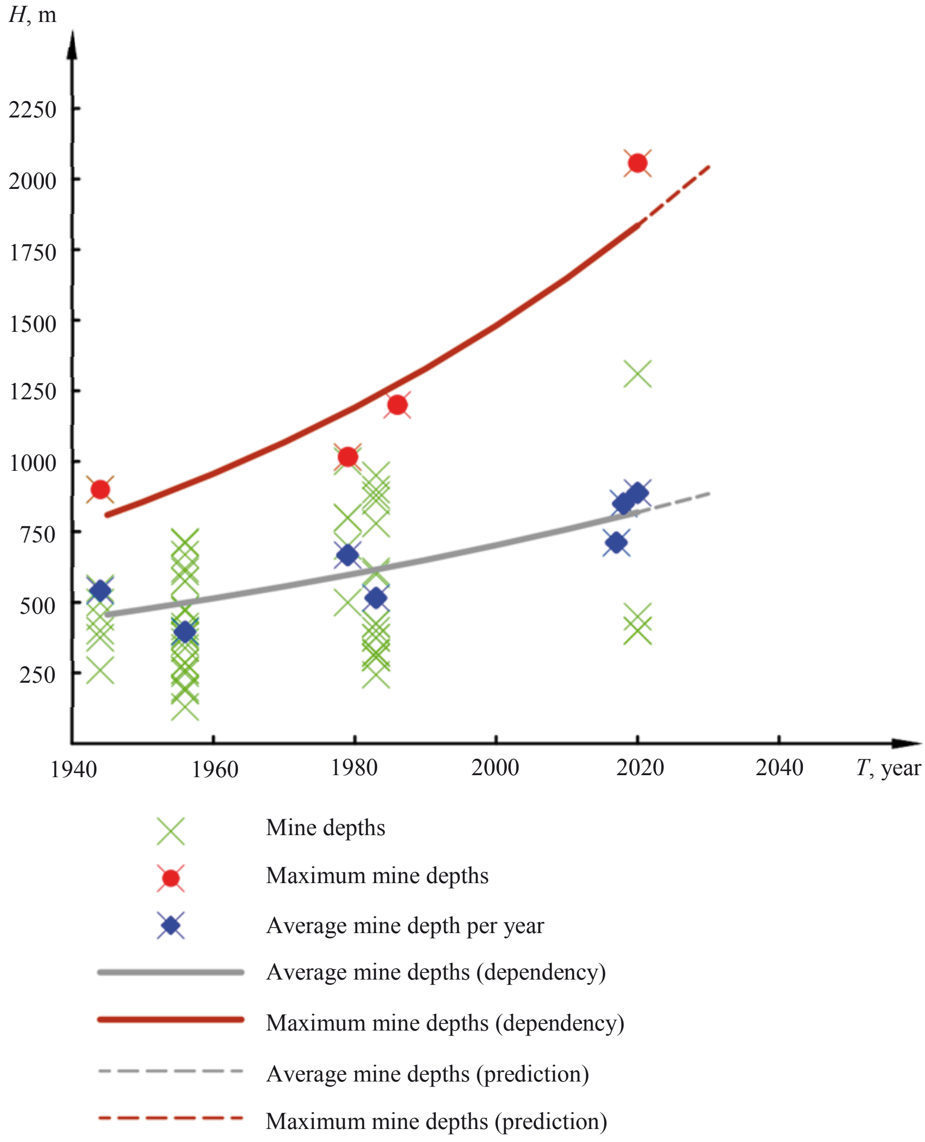

Figure 1. Mine depths on the territories of the USSR and former Soviet Union
Рисунок 1. Глубины шахт на территории СССР и постсоветского пространства

conditioned a significant development of mining technologies and production capacities from the 1940s to the 1970s. Centrifugal segmental pumps for the main mine drainage were reworked and adapted to the increasing needs and variety of mine drainage conditions; outdated КСМ and АЯП were replaced by МС and ЦНС.

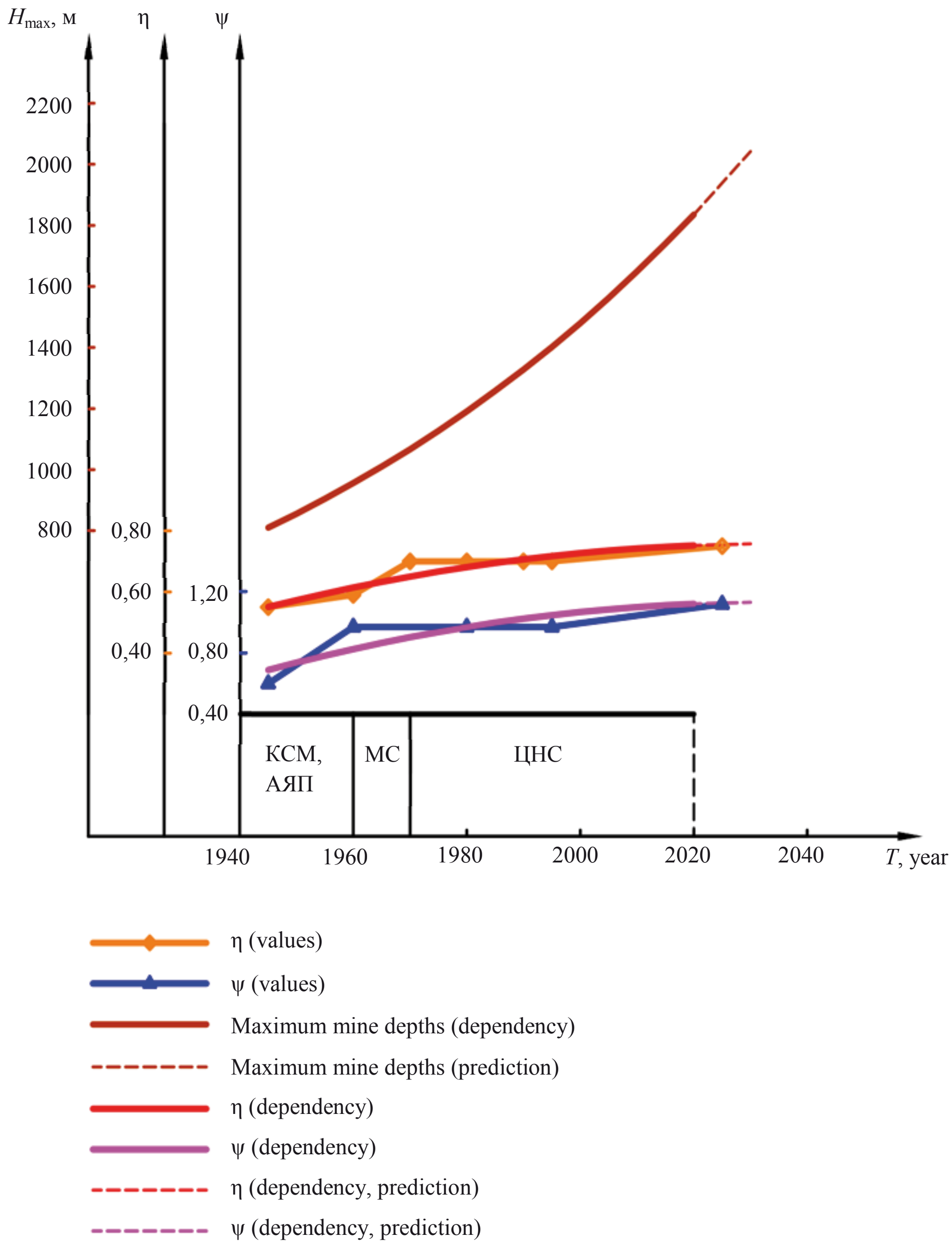

Figure 2. Dependencies between the efficiency and the head coefficient of the centrifugal segmental pumps and maximum mine depths on the territories of the USSR and former Soviet Union: КСМ – inclined rotor monoblock pump; АЯП – pump designed by A. Ia. Podoprigora; МС – multistage segmental pump; ЦНС – centrifugal segmental pump

Рисунок 2. Зависимости КПД и коэффициента напора применяемых центробежных секционных насосов и максимальных глубин шахт на территории СССР и постсоветского пространства: КСМ – центробежно-вихревой моноблочный насос; АЯП – насос конструктора А. Я. Подопригора; МС – многоступенчатый секционный насос; ЦНС – центробежный секционный насос

Based on standardized parts, a universal range of models was formed with sufficient coverage of the fields of mine drainage regimes. The efficiency was increased due to design optimization. GOST 10407-70 state standard for centrifugal segmental pumps was introduced.

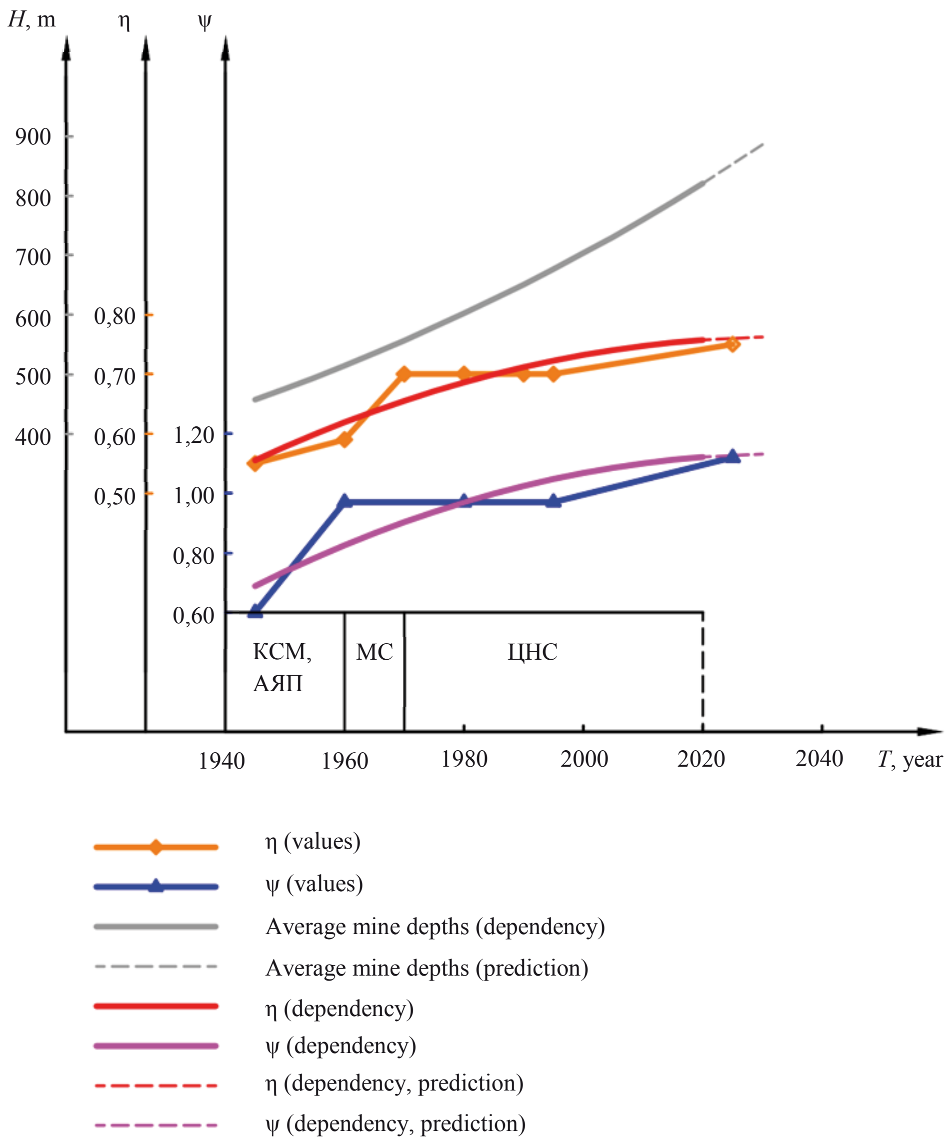

Figure 3. Dependencies between the efficiency and the head coefficient of the centrifugal segmental pumps and average mine depths on the territories of the USSR and former Soviet Union
Рисунок 3. Зависимости КПД и коэффициента напора применяемых центробежных секционных насосов и средних глубин шахт на территории СССР и постсоветского пространства

Centrifugal pumps, widely used in the main mine drainage [3], are mainly designed with low-speed and normal impellers with a specific speed number n_s = 70–100, since it is important to create a significant head per pump stage, because, as a rule, the maximum number of the stages is limited to ten. Increased head on one impeller is achieved through relatively longer blades and a longer inter-blade channel of the impeller. However, the indicated technical solutions have disadvantages in the form of reduced efficiency due to considerable friction of the pumped liquid against the impeller surface, and the increased dynamic head is accompanied by losses in the process of converting it into the static one [4]. Low-speed impellers have low adaptability, since flow stability at the exit edges of blades is impaired at a relatively early stage of the operating mode deviation from the nominal one, leading to additional energy losses due to vortex formation, which is confirmed by foreign studies [4]. In real operating conditions, in most cases, pumps do not operate in the nominal mode, but in the permissible operating range, i.e., with impaired stability of the flow in the wet and hydraulic end, which leads to lower energy efficiency of centrifugal pumps [5]. Operation with reduced productivity at increased head is a particularly detrimental mode for a centrifugal pump; in this case, stagnant areas appear, which turn into single vortices with the possibility of further transition to separation vortices. Such hydrodynamic processes have an adverse effect on the efficiency of energy transfer to the fluid flow from the centrifugal pump impeller rotation [6–8]. Such pump operating modes are accompanied by increased head discontinuity and pulsations from the hydrodynamic interaction of the exit edges of blades with the edges of the vaned casing in the discharge pipe [9–11]. These phenomena cause increased vibration on pump parts [12].

The most promising direction for turbomachines hydrodynamic load and efficiency improvement are vortex methods for flow control the in the flow end of pump [13, 14]. Currently, active study is underway on the use of centrifugal vortex pumps for mine drainage [15].

Table 1. Theoretical dependencies between the hydrodynamic parameters centrifugal pumps and mine depth dynamics

Таблица 1. Теоретические зависимости гидромеханических параметров центробежных насосов и динамики углубления шахт

Year	Average mine depth, m	Maximum mine depth, m	Pump efficiency	Head coefficient ψ
1945	457	810	0.55	0.60
1960	514	956	0.59	0.97
1970	556	1067	0.70	–
1980	602	1191	0.70	0.97
1995	676	1402	0.70	0.97
2025	851	1936	0.75	1.12

Results. Based on the obtained dependences of $H_{average}$ and H_{max}, average series of values of mine depths as a function of time (1), (2) are specified. The data are given in Table 1 with the corresponding values of the efficiency and head coefficient parameters of centrifugal segmental pumps used in different years at the main mine drainage.

Correlation dependences of parameters $H_{average}$ and efficiency; H_{max} and efficiency; $H_{average}$ and ψ; H_{max} and ψ:

$H_{average}$ and efficiency 0,84
$H_{average}$ and ψ 0,80
H_{max} and efficiency 0,82
H_{max} and ψ 0,78

The obtained correlation dependencies show the historical interconnection between the characteristics of the operating centrifugal segmental pumps and the depths of mines, which are determined by the needs of underground mining.

Conclusions. Correlation dependencies were obtained between the head coefficient, the efficiency of centrifugal segmental pumps and the required lifting height of mine drainage water.

It follows from the analysis of the centrifugal segmental pump impeller designs developed according to the theory of L. Euler, that the stage head coefficient increase by classical methods has reached its limit and its further increase is possible only through the improved hydrodynamic processes using vortex methods of flow control in the wet and hydraulic ends of pump.

By means of correlation equations, the predicted values of the head coefficient and efficiency have been presented. The predicted values have been obtained from the analysis of the operating centrifugal segmental pump required parameters, determined by mine construction development dynamics.

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Iakovlev V. L. Solid mineral deposits integrated development methodology for Russian mineral resource base development strategy. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal.* 2020; 7: 5–20. (In Russ.) Available from: doi: 10.21440/0536-1028-2020-7-5-20

2. Veselov A. I. Mine drainage. Sverdlovsk: Metallurgizdat Publishing; 1956. 532 p. (In Russ.)

3. Palamarchuk N. V., Timokhin Iu. V., Potiugov S. I. Composite indices of mine drainage. In: *Progressive equipment of mine stationary equipment: collection of scientific papers.* Donetsk: VNIIGIM Publishing; 1989. (In Russ.)

4. Shivani Kaustubh Chitale, Pranjal Nitin Jadhav, Snehal Suresh Dhoble, Dr. Mr. Satyajeet Deshmukh. Parameters affecting efficiency of centrifugal pump a review. *International Journal of Scientific Research in Science and Technology.* 2021; 8(6): 49–58. Available from: doi: https://doi.org/10.32628/IJSRST218573

5. Bai Y., Appiah D., Tao Y. Computational turbulent flow characteristics in a centrifugal pump. In: *AIP Advances.* 2022; 12(7): Art. 075025. Available from: doi: 10.1063/5.0100915

6. Bellary S. A. I., Husain A., Samad A., Kanai R. A. Performance optimization of centrifugal pump for crude oil delivery. *The Journal of Engineering Research (TJER).* 2018; 15(1): 88–101. Available from: doi: 10.24200/tjer.vol15iss1pp88-101

7. Zhang N., Gao B., Li Z., Li Zh., Ni D. Unsteady flow structure and its evolution in a low specific speed centrifugal pump measured by PIV. In: *Experimental Thermal and Fluid Science.* 2018; 97(6): 133–144. Available from: doi: 10.1016/j.expthermflusci.2018.04.013

8. Zhou S., Lin P., Zhang W., Zhu Z. Evolution characteristics of separated vortices and near-wall flow in a centrifugal impeller in an off-designed condition. *Applied Sciences.* 2020; 10(22): 1–17. Available from: doi: 10.3390/app10228209

9. Zeng Y., Yao Z., Wang F., Xiao R., He C. Experimental investigation on pressure fluctuation reduction in a double suction centrifugal pump: influence of impeller stagger and blade geometry. *Journal of Fluids Engineering.* 2020; 142: 041202-1–041202-12. Available from: doi: 10.1115/1.4045208

10. Shamsuddeen M. M., Ma S., Kim S., Yoon J., Lee K., Jung C., Kim J. flow field analysis and feasibility study of a multistage centrifugal pump designed for low-viscous fluids. *Applied Sciences.* 2021; 11(3): Art. 1314. Available from: doi: 10.3390/app11031314

11. Huang S., Qiu G., Su X., Chen J., Zou W. Performance prediction of a centrifugal pump as turbine using rotor-volute matching principle. *Renewable Energy.* 2017; 108: 64–71.

12. Zeng Y., Yao Z., Tao R., Liu W., Xiao R. Effects of lean mode of blade trailing edge on pressure fluctuation characteristics of a vertical centrifugal pump with vaned diffuser. *Journal of Fluids Engineering.* 2021; 143: 111201-1–111201-13. Available from: doi: 10.1115/1.4051386

13. Makarov V. N., Makarov N. V., Vakulin V. E., Soldatenko A. A. Modification of the hydrodynamic theory of circular grids of mine turbomashes. In: *Processing facilities for mining and oil and gas industry: Collection of articles of the XV International scient. and techn. conf. Readings in memory of V. R. Kubachek.* Ekaterinburg: UrSMU Publishing; 2018. P. 251–254. (In Russ.)

14. Makarov N. V., Makarov V. N., Lifanov A. V., Tauger V. M., Ugolnikov A. V. Modification of vortex theory for engineering aerodynamically stable circular gratings for turbo machines. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal).* 2019; 9: 184–194. (In Russ.) Available from: doi: 10.25018/0236-1493-2019-09-0-184-194

15. Makarov V. N., Potapov V. Ia., Churakov E. O., Makarov N. V. Improvong the energy efficiency of mine centrifugal pumps. *Vestnik Zabaikalskogo gosudarstvennogo universiteta = Transbaikal State University Journal (Bulletin of ZabGU).* 2021; 27(5): 26–35. (In Russ.)

Received 3 May 2023

Information about the authors:

Evgenii O. Churakov – mechanical engineer, OOO SMNP Ekspertnaladka. E-mail: tschurakov.102.evgeniy@mail.ru
Vladimir N. Makarov – DSc (Engineering), Professor, Professor of the Mining Mechanics Department, Ural State Mining University. E-mail: uk.intelnedra@gmail.com; https://orcid.org/0000-0002-3785-5569
Nikolai V. Makarov – PhD (Engineering), Associate Professor, Head of the Mining Mechanics Department, Ural State Mining University. E-mail: mnikolay84@mail.ru; https://orcid.org/0000-0001-7039-6272
Rustam G. Akhmetov – chief engineer, JSC Kostanay Minerals. E-mail: akhmetov@km.kz

УДК 62-137 DOI: 10.21440/0536-1028-2023-6-9-17

Динамика технического развития центробежных насосов шахтного водоотлива

Чураков Е. О.[1], Макаров В. Н.[2], Макаров Н. В.[2], Ахметов Р. Г.[3]
[1] ООО СМНП «Экспертналадка», Екатеринбург, Россия.
[2] Уральский государственный горный университет, Екатеринбург, Россия.
[3] АО «Костанайские минералы», Житикара, Республика Казахстан.

Реферат

Введение. *Современные технологии по добыче полезных ископаемых в условиях технических и экономических возможностей производства горных работ с учетом геологических особенностей наиболее доступных разведанных и принятых к разработке месторождений диктуют основные требования к характеристикам насосов для главного водоотлива шахт. Для прогнозирования в ближайшей перспективе актуальных требуемых характеристик оборудования для рациональной организации водоотлива горных предприятий нужно установление исторических взаимосвязей тенденции увеличения фактических глубин производства горных работ в шахтах и динамики показателей уровня технического развития применяемых центробежных насосов.*

Методология. *Сбор и анализ данных из литературных источников с применением хронологического порядка и математической статистики гидродинамических характеристик используемых для главного водоотлива центробежных насосов и глубин эксплуатируемых шахт, обусловленных потребностью в проведении горных работ по добыче полезных ископаемых. Исследование исторических данных и закономерностей повышения гидромеханических характеристик центробежных насосов в функции времени.*

Результаты. *Получены корреляционные зависимости гидромеханических параметров центробежных насосов и динамики углубления шахт в функции времени.*

Выводы. *Уровень показателей характеристик центробежных насосов сохраняется на достаточно длительном промежутке времени, следовательно, существующие применяемые методы расчета и проектирования центробежных насосов практически исчерпали свой потенциал к модернизации. Современные тенденции потребления природных ресурсов требуют сохранения темпов развития горнодобывающего производства, и в ближайшей перспективе для главного водоотлива шахт прогнозируется потребность в центробежных насосах увеличенной гидродинамической нагруженности и энергоэффективности. Для улучшения данных показателей перспективно применение методов вихревого управления течением в проточно-гидравлической части насоса.*

Ключевые слова: *центробежные насосы; напор; КПД; гидродинамическая нагруженность; энергоэффективность; шахтный водоотлив.*

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Яковлев В. Л. О методологии комплексного освоения запасов месторождений твердых полезных ископаемых для разработки стратегии развития минерально-сырьевой базы России // Известия вузов. Горный журнал. 2020. № 7. С. 5–20. DOI: 10.21440/0536-1028-2020-7-5-20
2. Веселов А. И. Рудничный водоотлив. Свердловск: Металлургиздат, 1956. 532 с.

3. Паламарчук Н. В., Тимохин Ю. В., Потюгов С. И. Обобщенные показатели шахтного водоотлива // Прогрессивное оборудование шахтных стационарных установок: сб. науч. тр. Донецк: ВНИИГМ, 1989. С. 111–115.

4. Shivani Kaustubh Chitale, Pranjal Nitin Jadhav, Snehal Suresh Dhoble, Dr. Mr. Satyajeet Deshmukh. Parameters affecting efficiency of centrifugal pump a review // International Journal of Scientific Research in Science and Technology. 2021. Vol. 8. Issue 6. P. 49–58. DOI: https://doi.org/10.32628/IJSRST218573

5. Bai Y., Appiah D., Tao Y. Computational turbulent flow characteristics in a centrifugal pump // AIP Advances. 2022. Vol. 12. Issue 7. Art. 075025. DOI: 10.1063/5.0100915

6. Bellary S. A. I., Husain A., Samad A., Kanai R. A. Performance optimization of centrifugal pump for crude oil delivery // The Journal of Engineering Research (TJER). 2018. Vol. 15. No. 1. P. 88–101. DOI: 10.24200/tjer.vol15iss1pp88-101

7. Zhang N., Gao B., Li Z., Li Zh., Ni D. Unsteady flow structure and its evolution in a low specific speed centrifugal pump measured by PIV // Experimental Thermal and Fluid Science. 2018. Vol. 97(6). P. 133–144. DOI: 10.1016/j.expthermflusci.2018.04.013

8. Zhou S., Lin P., Zhang W., Zhu Z. Evolution characteristics of separated vortices and near-wall flow in a centrifugal impeller in an off-designed condition // Applied Sciences. 2020. Vol. 10. Issue 22. P. 1–17. DOI: 10.3390/app10228209

9. Zeng Y., Yao Z., Wang F., Xiao R., He C. Experimental investigation on pressure fluctuation reduction in a double suction centrifugal pump: influence of impeller stagger and blade geometry // Journal of Fluids Engineering. 2020. Vol. 142. P. 041202-1–041202-12. DOI: 10.1115/1.4045208

10. Shamsuddeen M. M., Ma S., Kim S., Yoon J., Lee K., Jung C., Kim J. flow field analysis and feasibility study of a multistage centrifugal pump designed for low-viscous fluids // Applied Sciences. 2021. Vol. 11. Issue 3. Art. 1314. DOI: 10.3390/app11031314

11. Huang S., Qiu G., Su X., Chen J., Zou W. Performance prediction of a centrifugal pump as turbine using rotor-volute matching principle // Renewable Energy. 2017. Vol. 108. P. 64–71.

12. Zeng Y., Yao Z., Tao R., Liu W., Xiao R. Effects of lean mode of blade trailing edge on pressure fluctuation characteristics of a vertical centrifugal pump with vaned diffuser // Journal of Fluids Engineering. 2021. Vol. 143. P. 111201-1–111201-13. DOI: 10.1115/1.4051386

13. Макаров В. Н., Макаров Н. В., Вакулин В. Е., Солдатенко А. А. Модификация гидродинамической теории круговых решеток шахтных турбомашин // Технологическое оборудование для горной и нефтегазовой промышленности: сб. тр. XIV Междунар. науч.-техн. конф. Чтения памяти В. Р. Кубачека. Екатеринбург: УГГУ, 2018. С. 251–254.

14. Макаров Н. В., Макаров В. Н., Лифанов А. В., Таугер В. М., Угольников А. В. Модификация вихревой теории для создания аэродинамически устойчивых круговых решеток турбомашин // ГИАБ. 2019. № 9. С. 184–194. DOI: 10.25018/0236-1493-2019-09-0-184-194

15. Макаров В. Н., Потапов В. Я., Чураков Е. О., Макаров Н. В. Пути повышения энергоэффективности шахтных центробежных насосов // Вестник Забайкальского государственного университета. 2021. Т. 27. № 5. С. 26–35.

Поступила в редакцию 3 мая 2023 года

Сведения об авторах:

Чураков Евгений Олегович – инженер механик ООО СМНП «Экспертналадка». E-mail: tschurakov.102.evgeniy@mail.ru
Макаров Владимир Николаевич – доктор технических наук, профессор, профессор кафедры горной механики Уральского государственного горного университета. E-mail: uk.intelnedra@gmail.com; https://orcid.org/0000-0002-3785-5569
Макаров Николай Владимирович – кандидат технических наук, доцент, заведующий кафедрой горной механики Уральского государственного горного университета. E-mail: mnikolay84@mail.ru; https://orcid.org/0000-0001-7039-6272
Ахметов Рустам Гумарович – главный механик АО «Костанайские минералы». E-mail: akhmetov@km.kz

Для цитирования: Чураков Е. О., Макаров В. Н., Макаров Н. В., Ахметов Р. Г. Динамика технического развития центробежных насосов шахтного водоотлива // Известия вузов. Горный журнал. 2023. № 6. С. 9–17 (In Eng.). DOI: 10.21440/0536-1028-2023-6-9-17
For citation: Churakov E. O., Makarov V. N., Makarov N. V., Akhmetov R. G. Dynamics of mine drainage centrifugal pumps technological development. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering*. 2023; 6: 9–17. DOI: 10.21440/0536-1028-2023-6-9-17