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ДОСЛІДЖЕННЯ РОБОЧОГО ПРОЦЕСУ ВІЛЬНОВИХРОВОГО НАСОСА З НЕРІВНОМІРНИМ РОЗТАШУВАННЯМ ЛОПАТЕВОЇ СИСТЕМИ РОБОЧОГО КОЛЕСА

З огляду на постійно зростаючу вартість енергоресурсів у світі, на перший план виходить питання ефективності використання енергетичного обладнання. При цьому, саме насосне обладнання є одним з основних споживачів електроенергії у світі. Середній показник споживання електроенергії насосним обладнанням за галузями економіки становить близько 20%, у тому числі до 50% в окремих галузях господарства. Таким чином, зниження енергоспоживання насосного обладнання шляхом підвищення його енергоефективності є одним з важливих питань щодо досягнення Цілей сталого розвитку ООН (зокрема, ЦСР 6 "Чиста вода та належні санітарні умови", ЦСР 7 "Доступна та чиста енергія", ЦСР 9 "Промисловість, інновації та інфраструктура") Основними перевагами використання вільновихрових насосів є їх простота конструкції, підвищений ресурс служби та менша ймовірність забруднення у порівнянні з відцентровими аналогами. Однак, використання насосів цього типу пов'язане із трансопртування рідин з різними типами включень. Це може призводити до негативних наслідків у вигляді засмічення прохідних каналів, зниження продуктивності, енергетичної ефективності вільновихрових насосів. Стаття присвячена розробці дієвого механізму запобігання засмічення насосів даного типу, що дозволить суттєво підвищити енергоефективність насосного обладнання та підвищити ресурс його служби.

Ключові слова: *цілі сталого розвитку ООН, чиста вода, доступна та чиста енергія, промисловість, інновації та інфраструктура, вільновихрові насоси, енергоефективність.*

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THE RESEARCH OF THE TORQUE-FLOW PUMP OPERATING PROCESS WITH AN UNEVEN ARRANGEMENT OF THE IMPELLER BLADE SYSTEM

Given the ever-increasing cost of energy resources in the world, the issue of efficiency in the use of energy equipment comes to the fore. At the same time, the pumping equipment itself is one of the main consumers of electricity in the world. The average rate of electricity consumption by pumping equipment by economic sector is about 20%, including up to 50% in certain sectors of the economy. Thus, reducing the energy consumption of pumping equipment by increasing its energy efficiency is one of the important issues regarding the achievement of the UN Sustainable Development Goals (in particular, SDG 6 "Clean water and sanitation", SDG 7 "Affordable and clean energy", SDG 9 "Industry, innovation, infrastructure") The main advantages of torque-flow pumps using are their simplicity of design, increased service life and lower probability of contamination compared to centrifugal analogues. However, the use of pumps of this type is associated with the transportation of liquids with various types of inclusions. This can lead to negative consequences in the form of clogging of passage channels, reduction of productivity, energy efficiency of torque-flow pumps. The article is devoted to the development of an effective mechanism for preventing the clogging of pumps of this type, which will significantly increase the energy efficiency of the pumping equipment and increase its service life.

Key words: *UN sustainable development goals, clean water, affordable and clean energy, industry, innovation and infrastructure, torque-flow pumps, energy efficiency.*

1. Introduction.

Today, free-vortex pumps are widely used in various spheres of Ukrainian and foreign industry and national economy [1]. This type of pump is designed to move contaminated liquids, liquids with solid and fibrous impurities, as well as liquids with gaseous components.

The efficiency of using these machines for similar tasks is determined by the design and operational characteristics [2]:

- simplicity of design (for example, lack of front seals, simple shape of the flow part);
- the features of the location of the impeller and the presence of a free chamber together with the features of the working process of free-vortex pumps ensure the passage of a significant part of the liquid without contact with the impeller;
- low probability of clogging of the pump, clogging of its flow part.

The total value of these factors provides great wear resistance and reliability. Together with the possibility of quick maintenance and repair, this ensures efficient use in a variety of industries. It is important to note that this significantly compensates for economic disadvantages.

However, the main disadvantages of torque-flow pumps [3] are low efficiency (up to 58%) and limited heads (up to 100 m).

Torque-flow pumps are currently widely used in various industries, in particular in the food and chemical industries. They are also used in municipal and agricultural industries for pumping fecal, soil and sewage liquids, as well as sludge. In the field of transport, torque-flow pumps are used to move fruits, fish, juices, suspensions, syrups and other various substances, such as wood pulp, waste paper, polymers, gaseous liquids and others. Their use is also promising in energy (thermal energy), metallurgy, mining, oil and coal industries.

2. Literature review and formulation of the research problem.

Torque-flow pumps are a relatively new type of pumping equipment, which is characterized by an easy-to-use design and provides high reliability, durability and economic efficiency while operating with hydraulic mixtures. In addition, they effectively cope with the transportation of various solid substances and products [4].

Analysis of the components of the life cycle of pumping equipment and the main trends in the development of the pump market indicate the advantages of torque-flow pumps [1] when pumping liquids with a high content of abrasive particles, suspensions with a significant content of solids and fibrous impurities, liquids with increased density, liquids with a high air content or gas [5], liquids sensitive to shear, as well as liquids with fragile substances, while ensuring unhindered and continuous transport of fibrous suspensions [6].

Despite these advantages, torque-flow pumps have their disadvantages, the main of which is low efficiency (the pump efficiency is η=0.38-0.58). However, even with this, the use of torque-flow pumps leads to a significant economic effect. At the same time, a significant decrease in the energy efficiency of pumps of this type is associated with clogging of the passage channels (in particular, the impeller) when pumping liquids with inclusions (for example, sewage) [7].

3. The aim and objectives of the research.

The aim of the research is to develop an effective mechanism for preventing clogging of the passage channels (in particular, the impeller) of torque-flow pumps while pumping liquids with inclusions.

To achieve this aim, the following tasks are set:

- development of structures of elements of passage channels of the flow part of free-vortex pumps with a mechanism to prevent their clogging;
- determination of the methodology of experimental research;
- conducting an experimental research;
- analysis of the obtained results;
- establishing the degree of influence of the developed pump design on its integral characteristics and flow parameters in it in comparison with the basic version of the pump.

4. Methodology for designing the structure of the profiled impeller of the torque-flow pump.

- The design of the impeller, in particular its passage channels (Fig. 1), was carried out in accordance with the recommendations given in the work [5]. In particular, the blade skeleton was designed for this, namely:

- The differential equation for the blade skeleton in plan:

$$d\theta = \frac{dr}{rtg\beta}; \tag{1}$$

- the angle of coverage of the blade in the plan, expressed in degrees:

$$\theta_{Л} = \frac{180}{\pi}\int_{r_1}^{r_2} \frac{dr}{rtg\beta}; \tag{2}$$

- angle of inclination of the blade at any radius:

$$\sin\beta = \frac{S}{l} + \frac{V_m`}{W} \tag{3}$$

5. Methods of experimental research conducting.

The torque-flow pump SVN 125-50, which is widely used in production processes for transporting liquids with inclusions [1, 3], was chosen as the research object. The object of analysis is the operating process [6] in the flowing part of the SVN 125-50 pump equipped with a standard impeller and an impeller with two missing blades. The main parameters of the pump is: flow rate - 125 m3/h and head - 50 m.

To solve this problem, an impeller design with two missing blades was used. Compared to the basic version, the proposed configuration of the impeller has 2 blades less (6 instead of 8). The **basic hypothesis** is that due to the different angle of coverage of standard and extended inter-blade channels, pulsation processes will be formed. This pressure pulsation will prevent clogging of the passage channels of the pump.

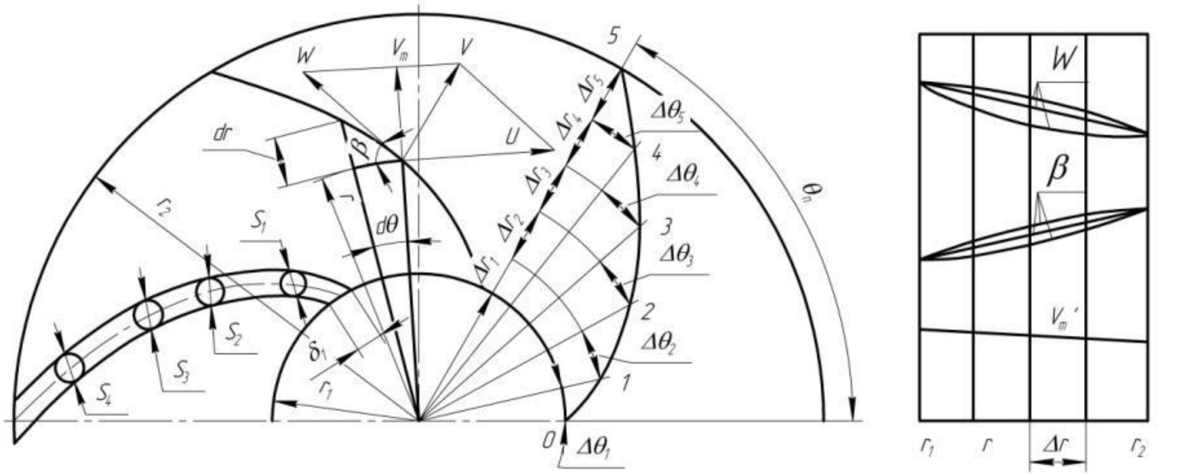


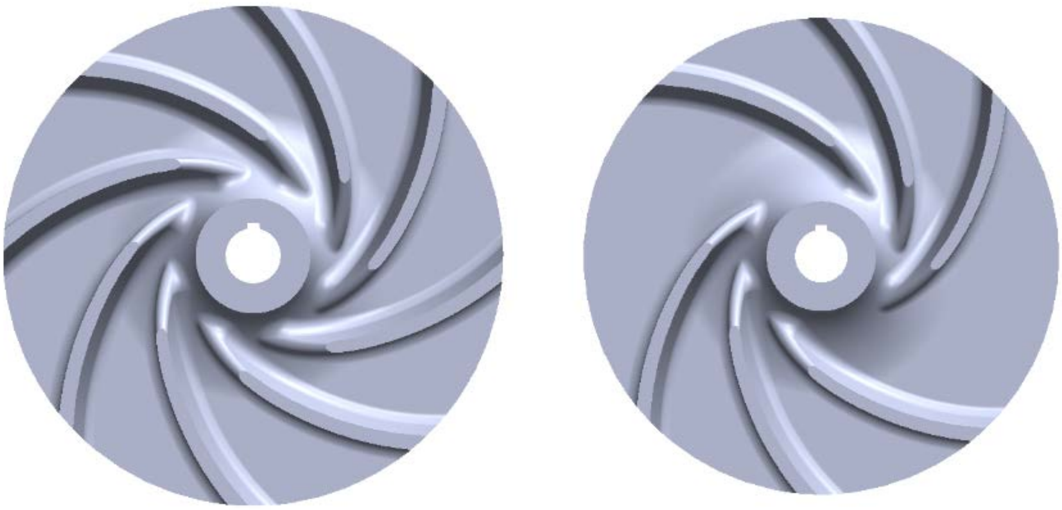
Fig . 1. **Designing of the impeller blade**

The calculation was performed both using the standard version of the impeller (Fig. 2 a) and the version using the proposed impeller with missing blades (Fig. 2 b).

The Ansys CFX software [8] was used to conduct the experimental study, which has proven itself well in solving similar problems [9-11].

The solid-state model [12] of the fluid in the flowing part of the stator pump housing element (Fig. 3) remains the same for both versions of the impellers and was created using the Solidworks software product.

The solid-state model of the fluid in the inter-blade channels of the impeller is presented for the standard impeller (Fig. 4 a) and for the proposed variant (Fig. 4 b).



a b

Fig. 2. **Construction of the impeller of the SVN 125-50 pump: a - basic version; b - the proposed version**

To carry out a numerical research, a calculation grid was built [13] using the ICEM CFD software package. The calculation area [15] includes two main elements: the stator element of the pump housing (Fig. 5), and the rotor element - the impeller (Fig. 6). An unstructured calculation grid was created for both elements of the workspace. For effective modeling of the flow in the boundary layer near solid walls, a layer consisting of prismatic cells was used. A tetrahedron mesh was used in the flow core for the free chamber and the impeller. The total number of elements of the calculation grid is 1 million 550 thousand cells. The flow simulation was carried out in a stationary setting.

The computational model [16] was created in the Ansys CFX environment. Water at a temperature of 25°C was used as the operating medium. The operating mode was defined as turbulent. The standard k-ε turbulence model was used to solve the Reynolds equations. This model makes it possible to describe the turbulent movement of the liquid in the flowing part of the SVN 125-50 torque-flow with sufficient accuracy [17].

As a boundary condition at the entrance to the calculation area, the mass flow rate through the channel of the impeller was set, which was determined using the corresponding dependence:

$$G_{кан} = Q \cdot \rho; \quad (4)$$

where ρ is water density; Q is the volume flow rate of liquid passing through the flowing part of the pump.

The boundary condition at the exit from the calculation area was set by static pressure. In this case, the pressure value was fixed at 1 MPa, since all subsequent studies and comparisons were made for relative values.

Taking into account the possibility of reverse currents [18] at the exit from the calculation area, the boundary condition type was set as "opening".

The convergence criterion [19] was to achieve an accuracy of 10-4, which is sufficient for scientific calculations.

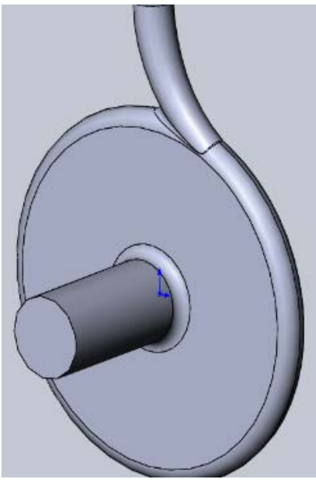


Fig. 3. **The solid-state model of the fluid in the flowing part of the pump casing**

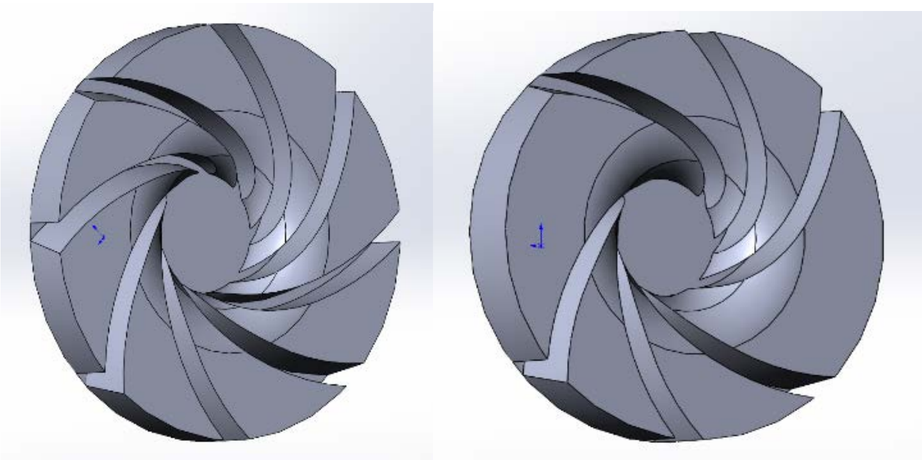


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Fig. 4. **The solid-state model of the fluid in the impeller: a - basic version; b - the proposed option**

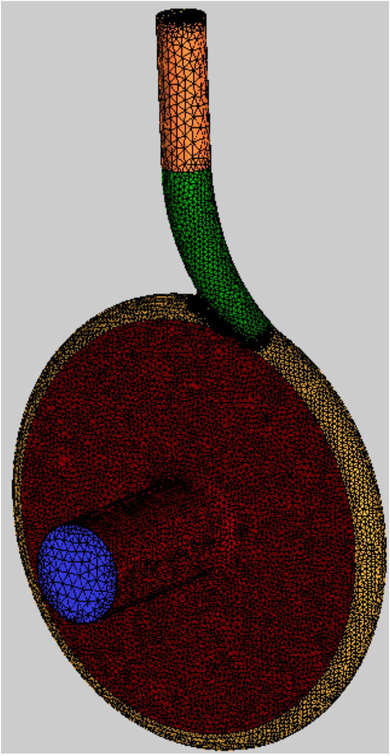

Fig. 5. **Calculation grid for the flowing part of the pump casing**

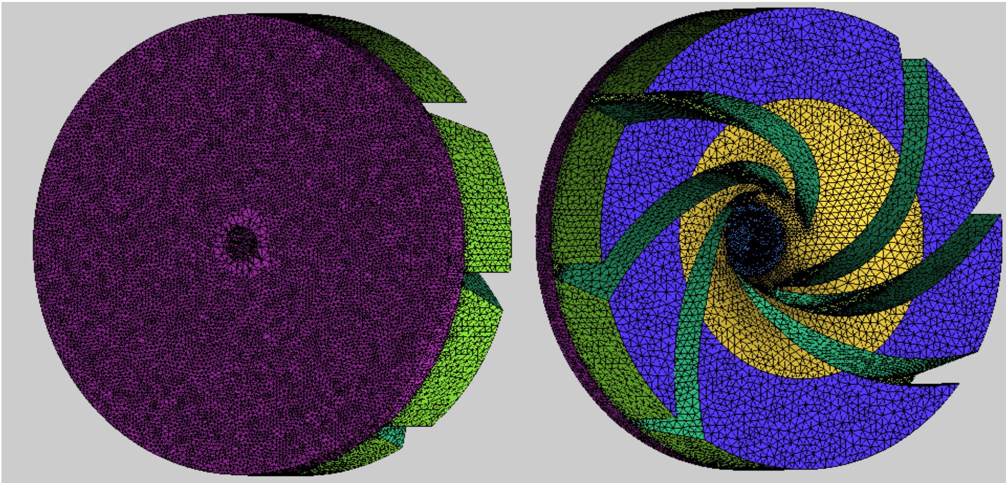

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Fig. 6. **Calculation grid for the impeller: a – basic version; b - of the proposed version**

6. Research results.

As a result of the conducted experimental research, the integral characteristics and main operating parameters of the pump were obtained [20-21] in the range of supply from 6.25 m3/h to 150 m3/h (0.05Qopt - 1.2Qopt) for the impeller of a conventional design and the impeller with two missing blades (Fig. 7).

The standard permissible ranges of flow rates modes for different operating types are defined as follows: for short-term operating: from 70% to 120% of the optimal flow rate; for long-term operation: from 90% to 110% of the optimal flow rate.

Based on the results of the study, the following patterns were found for the calculation mode.

An impeller with missing blades has a 2.3% lower head than a conventional impeller (59.44 m and 60.83 m, respectively). The pump with an impeller with missing blades has a slightly lower (up to 0.7%) energy efficiency value compared to the impeller of the basic design (39.8% and 40.5%, respectively). For the working zone of the supply range, an approximately similar picture of the ratio of pressures and energy efficiency is observed.

Further studies provided comparative visual representations of flow in a pump with an impeller of conventional design and an impeller with missing vanes.

The distribution of total pressure in the inter-blade channels of the impeller near the edge, in the center of the channels, and near the disc is shown in Figures 8–10.

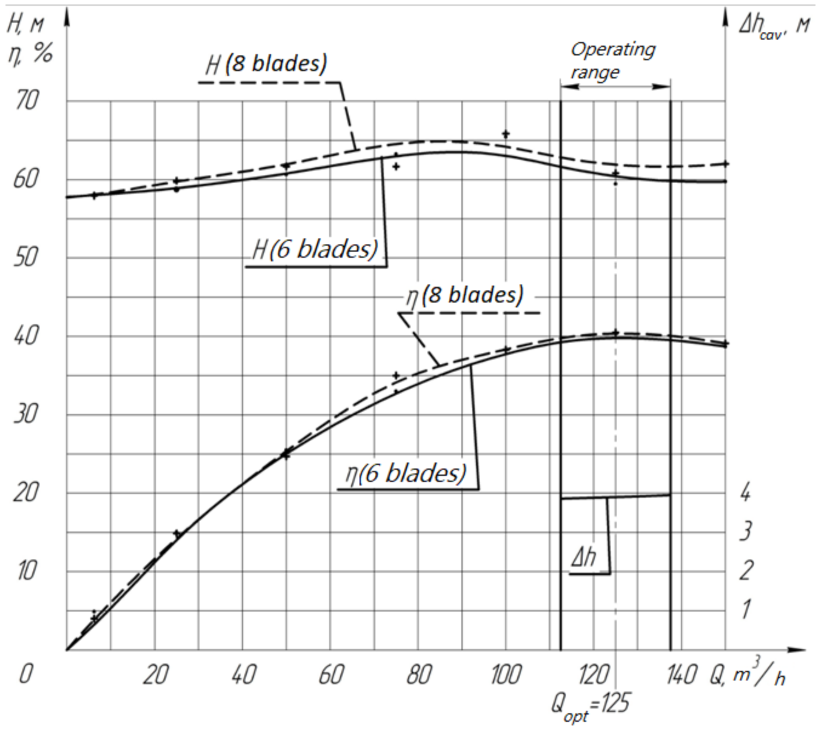

Fig. 7. **Integral characteristics of the SVN 125-50 torque-flow pump with an impeller of a conventional design and an impeller with missing blades**

The following pattern is observed: on a normal impeller, the same distribution of pressure in the inter-blade channels is found, while on a wheel with missing blades, a decrease in pressure in the expanded channels can be observed, parallel to an increase in pressure near the working side of the blade. This indicates the presence of the phenomenon of pressure and head pulsation in the structure of the impeller with missing blades.

The distribution of relative velocities in the inter-blade channels of the impeller near the edge, in the center of the channels, and near the disc is shown in Figures 11–13.

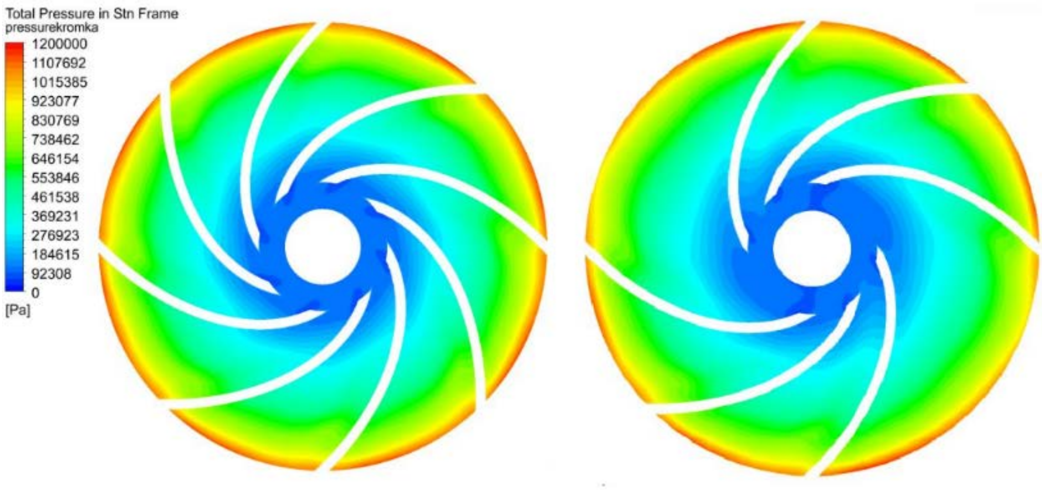

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Fig. 8. **Distribution of total pressure near the edge for: a – a conventional impeller; b - impeller with two missing blades**

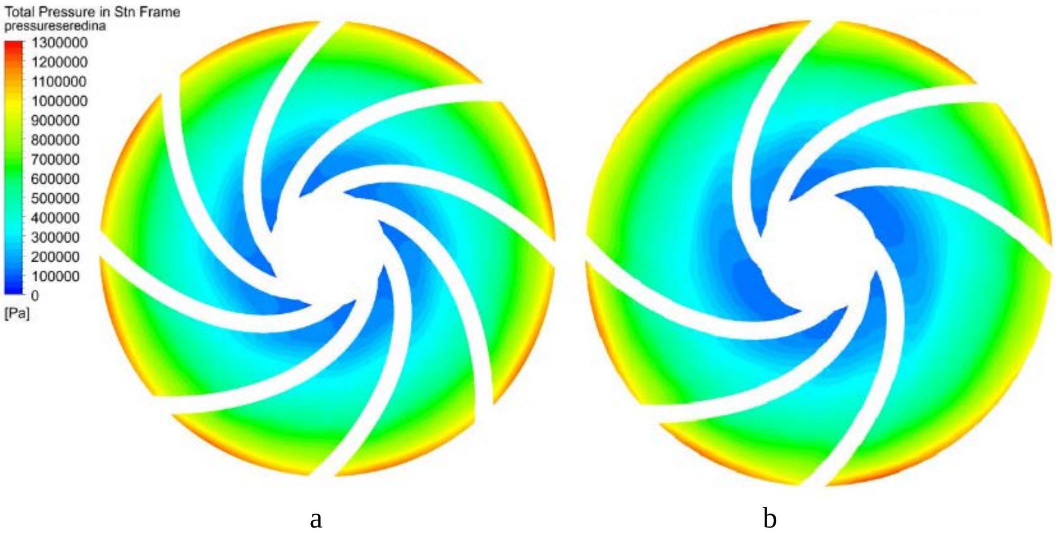

Fig. 9. **Distribution of total pressure in the center of the inter-blade channels for: a – a conventional impeller; b - impeller with two missing blades**

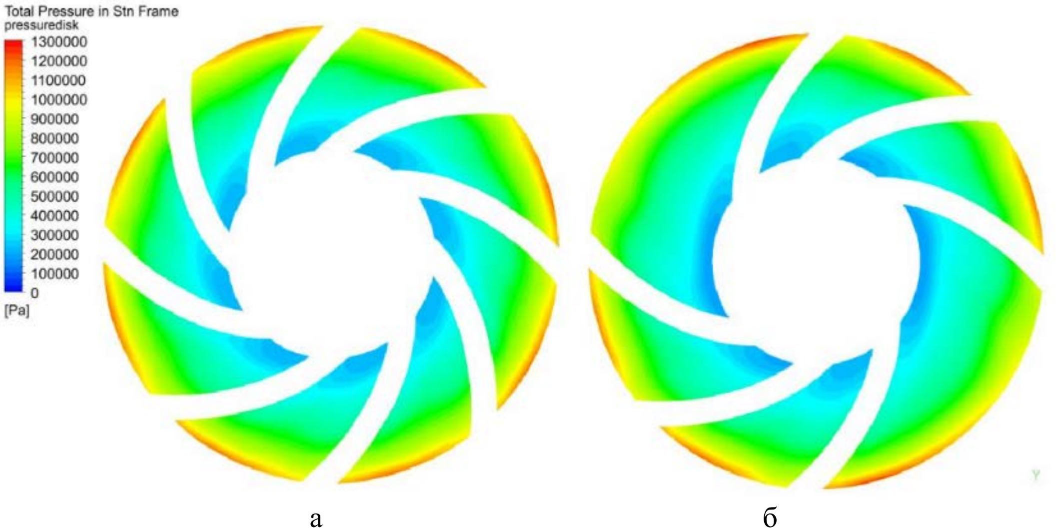

Fig. 10. **Distribution of total pressure near the disc for: a - a conventional impeller; b - impeller with two missing blades**

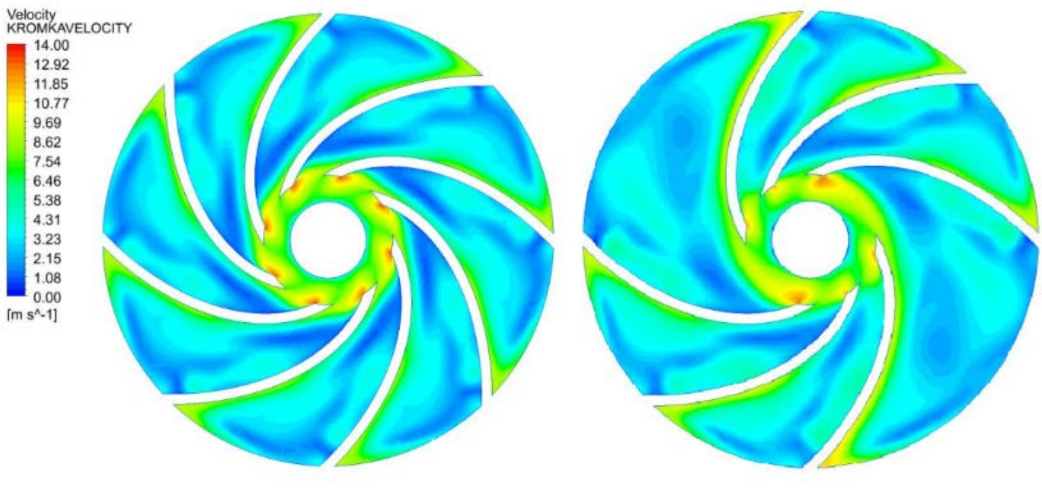

Fig. 11. **Distribution of the relative velocity near the edge for: a - a conventional impeller; b - impeller with two missing blades**

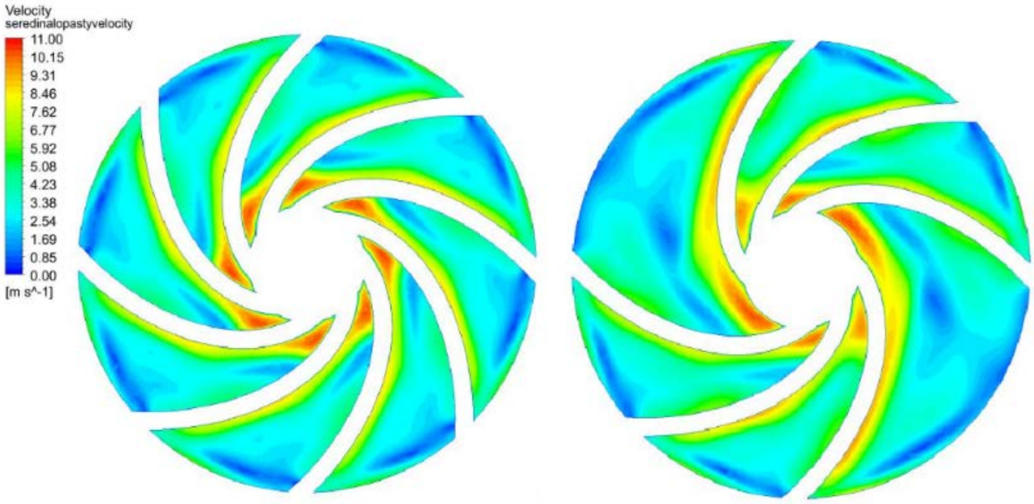

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Fig. 12. **Distribution of the relative velocity in the center of the interblade channels for: a - a conventional impeller; b - impeller with two missing blades**

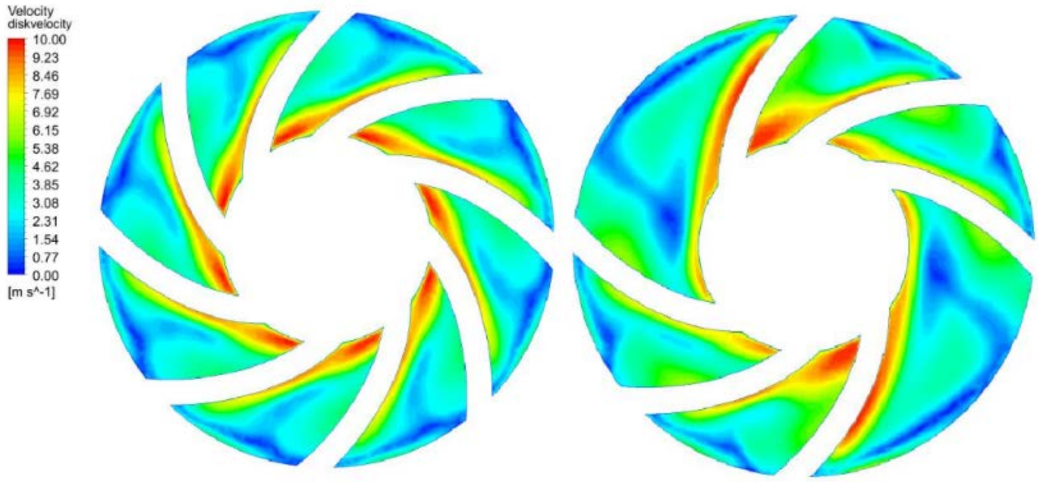

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Fig. 13. **Distribution of the relative velocity near the disk for: a - a conventional impeller; b - impeller with two missing blades**

When analyzing the patterns of the distribution of relative velocity, the following can be noted: on a conventional impeller, a uniform distribution of relative velocity is observed in all inter-blade channels, while on an impeller with missing blades, an increase in velocity near the operating side of the blade in the extended channel is noted. There is also an uneven distribution of velocity at the inlet to the impeller, along with the appearance of a flow separation zone in the inter-blade channels. This leads to an increase in losses, a decrease in pressure and, accordingly, a decrease in energy efficiency. In general, there is a decrease in the relative velocity from the edges to the disk.

For the calculation mode, pressure distribution plots near the edge, in the center of the inter-blade channels, near the disk for both types of impellers were constructed and compared.

It can be seen from Figures 8–10 that a similar pressure distribution is observed on all inter-blade channels of a wheel of a standard design. At the same time, in the wheel with missing blades in the expanded inter-blade channels, compared to normal ones, the pressure is a little lower (in the intervals between points 19...1 and 7...13), and the pressure near the operating side of the blade for the expanded channel (points 1 and 13) higher. This is explained by the presence of an expanded channel and, as a result, more liquid interacting with the operating side of the blade. The above-mentioned picture indicates the presence of certain pressure pulsations in the impeller with missing blades, which allows to almost completely avoid sticking of the viscous product on the impeller blade.

7. Conclusions.

While analyzing the results of the research, the following features were noted when comparing the impeller of the basic design and the proposed impeller:

1. On an impeller with missing blades, there is a decrease in absolute (total) pressure in the expanded channels and an increase in absolute (total) pressure near the operating side of the impeller blade. This indicates the presence of certain pressure pulsations in the impeller.

2. The relative velocity distribution on an impeller with missing blades reveals an increase in velocity near the operating side of the blade in the extended channel and a non-uniform velocity distribution at the inlet to the impeller. This also confirms the presence of such pulsation processes.

3. The indicated pulsation effects create prerequisites for almost complete avoidance of sticking of the viscous product on the impeller blades.

Comparing the results of the physical and numerical research of the flowing part using the basic model of the impeller, it was found that they differ only within the margin of error. This confirms the adequacy of the choice of initial and boundary conditions, the fluid model, as well as the physical properties of the fluid.

Based on the results of the research, the following was found for the calculation mode:

1. An impeller with missing blades has a lower pressure (59.44 m) compared to an impeller of conventional design (60.83 m).

2. The impeller with missing blades turned out to have a lower efficiency compared to the impeller of conventional design (39.8% and 40.5%, respectively).

3. In the operating zone of the flow rate range, an approximately similar picture of the ratio of pressures and energy efficiency is observed.

List of used sources:

1. Kotenko, A., Herman, V., Kotenko, A. (2014). Rationalization of Ukrainian industrial enterprises in a context of using torque flow pumps on the basis of valuation of the life cycle of pumping equipment. *Nauka i Studia*, Vol. 16 (126), pp. 83–91. http://essuir.sumdu.edu.ua/bitstream/123456789/38769/3/kotenko_poland1.PDF

2. Antonenko, S., Sapozhnikov, S., Kondus, V., Chernobrova, A., Mandryka, A. (2021). Creation a universal technique of predicting performance curves for small-sized centrifugal stages of well oil pump units. *Journal of Physics: Conference series*, Vol. 1741 012011. https://doi.org/10.1088/1742-6596/1741/1/012011

3. Gusak, O., Krishtop, I., German, V., Baga, V. (2017). Increase of economy of torque flow pump with high specific speed. *IOP Conf. Ser.: Mater. Sci. Eng.*, 233 012004. Retrieved from https://doi.org/10.1088/1757-899X/233/1/012004

4. Krishtop, I. (2015). Creating the flowing part of the high energy-efficiency torque flow pump. *Eastern-European Journal of Enterprise Technologies*, 2 (74), 31–37. Retrieved from https://doi.org/10.15587/1729-4061.2015.39934

5. Kondus, V., Kalinichenko, P., Gusak, O. (2018). A method of designing of torque-flow pump impeller with curvilinear blade profile. *Eastern-European Journal of Enterprise Technologies*, 3/8 (93), 29–35. Retrieved from https://doi.org/10.15587/1729-4061.2018.131159

6. Panchenko, V., German, V., Ivchenko, O., Ryasnaya, O. (2021). Combined operating process of torque flow pump. *Journal of Physics: Conference series*, Vol. 1741 012011. Retrieved from https://doi.org/10.1088/1742-6596/1741/1/012022

7. Gao, X., Shi, W., Zhang, D., Zhang, Q. & Fang, B. (2014). Optimization design and test of vortex pump based on CFD orthogonal test. *Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery*, 45 (5), 101–106. Retrieved from http://dx.doi.org/10.6041/j.issn.1000-1298.2014.05.016

8. Kumar, J., Gopi, S., Amirthagadeswaran, K. (2023). Redesigning and numerical simulation of gating system to reduce cold shut defect in submersible pump part castings. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, Vol. 237 (3), pp. 971-981. https://doi.org/10.1177/09544089221142185

9. Quan, H., Chai, Y., Li, R., Guo, J. (2019). Numerical simulation and experiment for study on internal flow pattern of vortex pump. *Engineering Computations*, 36, 1579–1596. Retrieved from https://doi.org/10.1108/EC-09-2018-0420

10. Rogovyi, A., Korohodskyi, V., Neskorozhenyi, A., Hrechka, I., Khovanskyi, S., Reduction of Granular Material Losses in a Vortex Chamber Supercharger Drainage Channel. *Advances in Design, Simulation and Manufacturing V. DSMIE 2022. Lecture Notes in Mechanical Engineering*, pp. 218–226. Retrieved from https://doi.org/10.1007/978-3-031-06044-1_21

11. Krishtop, I., German, V., Gusak, A., Lugova, S., & Kochevsky, A. (2014). Numerical Approach for Simulation of Fluid Flow in Torque Flow Pumps. In Applied Mechanics and Materials. *Trans Tech Publications, Ltd*., 630, 43–51. Retrieved from https://doi.org/10.4028/www.scientific.net/amm.630.43

12. Dehnavi, E., Danlos, A., Solis, M., Kebdani, M., Bakir, F. (2024). Study on the pump cavitation characteristic through novel independent rotation of inducer and centrifugal impeller in co-rotation and counter-rotation modes. *Physics of Fluids*, Vol. 36(1), pp. 015120. Retrieved from http://dx.doi.org/10.1063/5.0182731

13. Dehghan, A., Shojaeefard, M., Roshanaei, M. (2024) Exploring a new criterion to determine the onset of cavitation in centrifugal pumps from energy-saving standpoint; experimental and numerical investigation. *Energies*, Vol. 293, 130681. Retrieved from http://dx.doi.org/10.1016/j.energy.2024.130681

14. Dehnavi, E., Solis, M., Danlos, A., Kebdani, M., Bakir, F. (2023). Improving the Performance of an Innovative Centrifugal Pump through the Independent Rotation of an Inducer and Centrifugal Impeller Speeds. *Energies*, 16(17), 6321. Retrieved from https://doi.org/10.3390/en16176321

15. Jung, D.-W., Seo, C.-W., Lim, Y.-C., ... Lee, S.-Y., Suh, H.-K. (2023). Analysis of Flow Characteristics of a Debris Filter in a Condenser Tube Cleaning System. *Energies*, 2023, 16(11), 4472 Retrieved from https://doi.org/10.3390/en16114472

16. Dehnavi, E., Bakir, F., Danlos, A., Kebdani, M. (2023). Numerical Analysis of Distance Effect between Inducer and Centrifugal Impeller in Independent Rotational Turbopump in Co-rotating and Counter-rotating Mode. *European Conference on Turbomachinery Fluid Dynamics and Thermodynamics, ETC*, 2023. Retrieved from http://dx.doi.org/10.29008/ETC2023-203

17. Kondus, V., Puzik, R., German, V., Panchenko, V., Yakhnenko, S. (2021). Improving the efficiency of the operating process of high specific speed torque-flow pumps by upgrading the flowing part design. *Journal of Process Mechanical Engineering*, Vol. 237, pp. 1741 012023 https://doi.org/10.1088/1742-6596/1741/1/012023

18. Gerlach, A., Thamsen, P. & Lykholt-Ustrup, F. (2016). Experimental Investigation on the Performance of a Vortex Pump using Winglets. *ISROMAC 2016. International Symposium on Transport Phenomena and Dynamics of Rotating Machinery*. Retrieved from http://isromac-isimet.univ-lille1.fr/upload_dir/finalpaper/181.finalpaper.pdf

19. Kondus, V.; Kotenko A. (2017). Investigation of the impact of the geometric dimensions of the impeller on the torque flow pump characteristics. *Eastern-European Journal of Enterprise Technologies*, Vol. 1/4 (88), pp. 25–31. Retrieved from https://doi.org/10.15587/1729-4061.2017.107112

20. Zhang, H., Deng, C., Chang, C., You, H. Novel dual synergistic sealing ring design for a high-pressure pump – Part I. Retrieved from http://dx.doi.org/10.12968/s1350-4789(22)70085-2

21. Zhang, H., Deng, C., Chang, C., You, H. Novel dual synergistic sealing ring design for a high-pressure pump – Part II. Retrieved from https://doi.org/10.12968/S1350-4789(22)70086-4

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