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PETCO ANDREI

INCREASING THE ENERGY EFFICIENCY OF CENTRIFUGAL PUMPS THROUGH FLUID FLOW MATHEMATICAL MODELING AND NUMERICAL CALCULATION

242.01 - THEORY OF MACHINES, MECHATRONICS

Abstract of the doctoral thesis in engineering sciences

CHIȘINĂU, 2024

The thesis was elaborated within the **Doctoral School of the Technical University of Moldova**

Scientific adviser:

BOSTAN Viorel, prof. univ., dr. hab.

Composition of the PhD Committee:

DULGHERU Valeriu, prof. univ., dr. hab.	President of the PhD Committee;
BODNARIUC Ion, conf. univ., dr.	Scientific Secretary of the PhD Committee;
BOSTAN Viorel, prof. univ., dr. hab.	Member of the PhD Committee;
CIUPERCĂ Rodion, conf. univ., dr.	Member of the PhD Committee;
CIOBANU Bogdan, prof. univ., dr.ing	Official Reviewer
TOCA Alexei, prof., dr.	Official Reviewer
MĂLĂEL Ion, conf. univ., dr.ing	Official Reviewer

The presentation will take place on March 6'th 2024, 14:00, in the meeting of the PhD Committee at the Technical University of Moldova, MD 2045, Republic of Moldova, Chisinau, str. Studenților 9/8, bl. 6, aud. 415.

The PhD thesis and the abstract can be consulted at the library of the Technical University of Moldova and on the CNAA website (www.cnaa.md).

The abstract has been sent on February 1'st 2024.

Scientific adviser,
BOSTAN Viorel, prof. univ., dr. hab. *signature*

Autor
PETCO Andrei *signature*

SUMMARY

CONCEPTUAL RESEARCH MILESTONES

Topicality of the theme: The current state of the pump manufacturing industry shows a clear trend of decreasing production volume. This fact requires pump producers in the Republic of Moldova to orient their efforts from east to west, primarily on the European Union (EU) market, which is of increased interest to Moldovan producers.

It should be noted that pumping systems are a significant consumer of electricity, consuming between 25 and 50% of energy consumption in some industries (Moisă, Susan-Resiga, and Muntean 2013). At the same time, consumers in the EU are paying increasing attention to energy efficiency; the current EU 2030 energy targets plan to increase energy efficiency by at least 32.5% by 2030. (Ciucci 2023) to go beyond the EU's commitments under the Paris Agreement on climate change ('Keflection paper. Towards a sustainable europe by 2030' 2019). We can also note that the new Energy Strategy 2050 of the Republic of Moldova also mentions as an objective the increase and promotion of energy efficiency (' Energy Strategy of the Republic of Moldova 2050 (SEM 2050)' 2022).

Nowadays most of the pump types manufactured in the Republic of Moldova are products of a constructive-technological evolution of Soviet pump models. In order to expand the sales market to the West, the modernization of pumps produced in the Republic of Moldova must take into account the need to increase energy efficiency: increase efficiency, reduce the NPSHr, increase the working range, etc. (Petco 2019). Therefore, we can attest a pressing need for constructive-functional modernization of pumps produced in the Republic of Moldova, with the aim of obtaining energy efficiency characteristics comparable to their analogues in the EU, USA, Japan.

The present thesis, developed within the Doctoral School of the Technical University of Moldova, represents a new approach to the optimization of the working parts of centrifugal pumps produced by the Moldovan machine-building industry. The presented methodology, based on CFD simulations and optimization algorithms, was applied to the optimization of working parts of pumps produced by the company CRIS Hermetic Pumps from the Republic of Moldova. Based on the described considerations the aim and objectives of the research were formulated.

Purpose of the thesis. To increase the energy efficiency of centrifugal pumps, i.e., to increase the pump efficiency and decrease the NPSHr by applying CFD simulations of fluid flow coupled with optimization algorithms.

Basic objectives of the thesis. In order to achieve the formulated aim, the following problems need to be solved:

- Establishing the current state of the centrifugal pump manufacturing industry and determining the directions of modernization of centrifugal pumps produced in the RM.
- Establishment of methods for obtaining geometrical models of the working parts of centrifugal pumps.
- Study of theoretical considerations of fluid flow in pump working parts and investigation of empirical models to obtain them.
- Selection of the parameterization model for centrifugal pumps working parts geometry.
- Selection of geometric model discretization methods.
- Establishing the mathematical model of fluid flow in the working parts of the centrifugal pump.

— Selection of the fluid flow turbulence model.
— Selection of the cavitation model.
— Argumentation of the application of numerical methods for calculating the working parts of centrifugal pumps.
— Defining the methodology for optimizing the centrifugal pumps working parts.
— Results validation of the methodology application through CFD simulations and experimental tests.

The novelty and scientific originality of the obtained results. Centrifugal pump impellers with improved energy efficiency characteristics were obtained by applying CFD simulations coupled with optimization algorithms, namely, optimization of impellers of the centrifugal pump model CH 6.3/20 1.1-2 and wastewater centrifugal pump impeller with increased efficiency, including the creation of an inducer for CMP type pumps with reduced NPSHr.

The technical solution developed for the centrifugal pump impeller model CH 6.3/20 1.1-2 is currently under examination for a patent (application is in further examination phase).

Practical value of the thesis. The technical solutions developed have been implemented:

- When optimizing the design of the centrifugal pump model CH 6.3/20 1,1-2 impeller;
- When obtaining the centrifugal pump's impeller for waste water, approved by the enterprise "CRIS" SRL on the production of series "0";
- When creating an impeller for CMP pumps, series "0" (10 units), which have already been manufactured, tested and delivered to consumers.
- At the same time, the results of the thesis were used in the undergraduate studies for laboratory work with the subject "Computer Aided Design".

The main scientific results for submitting thesis. The methodology for the optimization of pump's working parts has been developed and approved. The methodology is based on the application of CFD simulations, the results of which are processed with the use of optimization algorithms in order to obtain a geometry with optimal characteristics. The methodology has been validated both numerically and experimentally on physical models, and the results of the application of the optimization methodology are applied within enterprise "CRIS" SRL, Republic of Moldova (implementation papers are attached).

Getting the thesis results. The work was carried out in the framework of the PhD grant on "Increasing the energy efficiency of centrifugal pumps by mathematical modelling and numerical computation of fluid flow".

Thesis approval. The main results, presented in the thesis, were presented and discussed within scientific seminars of the Faculty of Mechanical, Industrial and Transport Engineering of the Technical University of Moldova; at scientific conferences: The *Technical-scientific conference of students, master's and PhD. students of 27-29 March 2019 and 23-25 March 2021,* within the *Days of the Romanian Academy of Technical Sciences 2019, XIV edition, 17-18 October 2019, Chisinau* and at the international conference *Innovative Manufacturing Engineering & Energy 2023, 27th edition, 12 -14 October 2023,* as well as *on the pages of the Journal of Engineering Science,* Chisinau: TUM, no. 2 and 4, 2023. The thesis results were also presented at exhibitions: *the UGAL INVENT 2023 Innovation and Research Salon, Galati, 9-10 November 2023 and the International Specialized Exhibition INFOINVENT 2023 18th edition, Chisinau 22-24 November 2023.*

The presented works were appreciated with: Diploma of Excellence, for the plenary report with the theme: *Increasing energy efficiency - an essential condition for the expansion of the domestic centrifugal pump markets,* at the Technical-Scientific Conference of PhD, collaborators and students 2019, and the First-Degree Award, at the Technical-Scientific Conference of UTM students, masters and PhD students, Chisinau, 23-25 March 2021. At the same time, one gold medal was obtained at the UGAL INVENT 2023 Innovation and Research Salon.

It should also be mentioned that the author of the thesis was awarded the Government Excellence Scholarship for PhD students for the 2019-2020 academic year. The author was awarded with two silver medals for another research areas (ICE-USV - IIIrd Edition, Suceava 2019 and INFOINVENT 2021, Chisinau) with the work on other scientific direction.

Publications on the thesis topic. The main content of the thesis is reflected in 5 scientific papers, 2 of which are single-authored and 1 patent application with a priority from 23.03.2023.

Structure and volume of the PhD thesis. The work consists of an introduction, four chapters, general conclusions, recommendations and it contains 136 pages of text, 14 tables, 115 figures, 6 appendices and 113 bibliographical sources used**.**

Keywords: centrifugal pumps, centrifugal pump impeller, fluid flow modeling, turbulence models, cavitation process, CFD simulations, optimization algorithms, centrifugal pump testing.

THESIS CONTENT

1. THE STATE OF THE ART IN CENTRIFUGAL PUMP DESIGN AND PRODUCTION

The first chapter analyses and describes the current state of the centrifugal pump manufacturing industry. At present, there are 8 enterprises on the territory of the Republic of Moldova (RM) which have centrifugal pumps in their production nomenclature. The pumps produced by Moldovan enterprises have about 150 models and are exported to more than 60 countries.

The current state of the industry, with a clear trend towards a reduction in production volume (fig.1), requires producers to rapidly change their market, orienting their efforts from east to west. The European Union (EU) market is of increased interest to domestic producers. This situation can be remedied by upgrading the construction and operation of pumps produced in the Republic of Moldova.

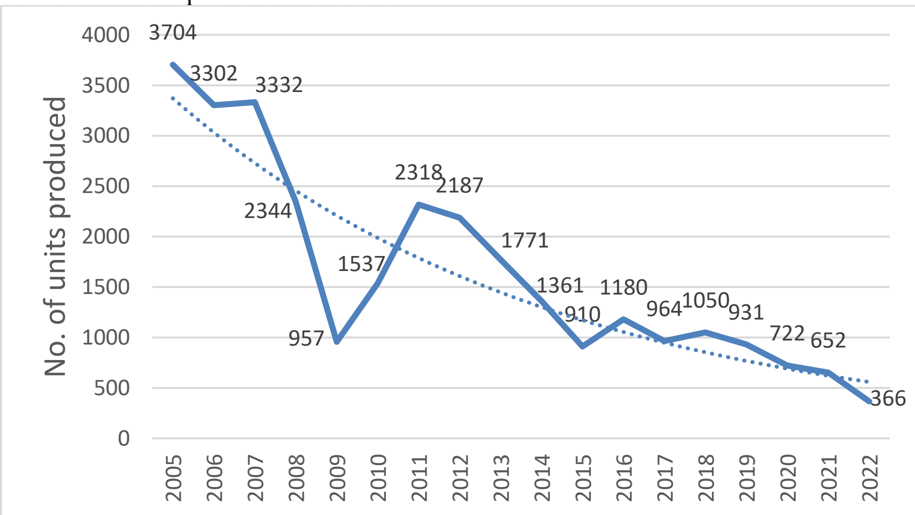


Fig. 1. Production of centrifugal pumps, liquid pumps or liquid elevators in the Republic of Moldova in the period 2005-2022,units ('Production of Main Products Industrial by Types, Product and Years. ISM', 2023)

Nowadays most of the pump types manufactured in the RM are products of a constructive-technological evolution of the Soviet pump models. Therefore, in order to expand the sales market to the West, the following energy efficiency objectives should be taken into account in the process of pumps' modernization produced in Moldova (Petco 2019):

— increasing the energy efficiency of the pumps, including increasing their efficiency both at nominal flow rate Q_{nom} and within the working interval;
— the reduction of the Net Positive Suction Head Required (NPSHr);
— range extension between minimum flow rate Q_{min} and maximum flow rate Q_{max} etc.

At the same time the construction of the pumps is studied, the characteristic features of the centrifugal pumps produced in Moldova are described and the principle of operation of the centrifugal pump is described.

The study presented in the given thesis was carried out based on CH and CMP hermetic centrifugal pumps with canned motor. Their field of application are hazardous production enterprises of petrochemical, chemical, atomic or other industrial sectors with hydraulic systems operating with aggressive liquids. According to ISO 17769-1 classification, pumps of type CH and CMP (International Organization for Standardization, 2012), are hermetic centrifugal pumps with asynchronous three-phase canned motor, with short-circuit explosion-proof rotor, explosion-proof construction corresponding to Ex ds IIB or Ex ds IIC classes.

Chapter 1 also describes the evolution of methods for obtaining the geometry of the centrifugal pumps' working parts from analytical computational methods, based on empirical data, to two-dimensional and quasi-three-dimensional computational methods, to computational software environments and methods based on Computational Fluid Dynamics (CFD) simulations and optimizations.

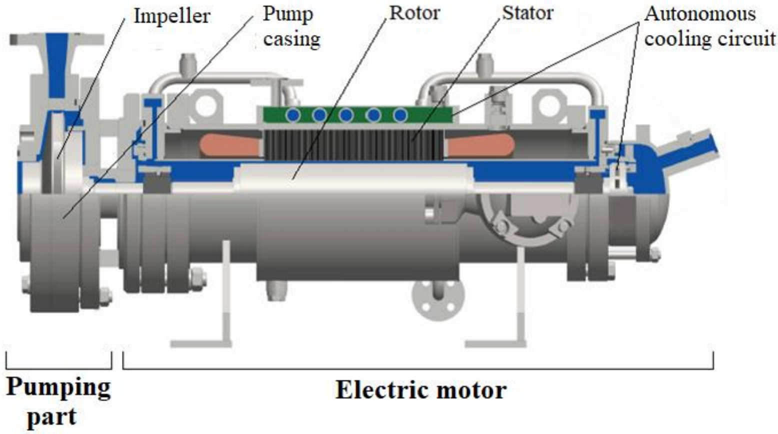


Fig. 2. The main components of the CMP pump

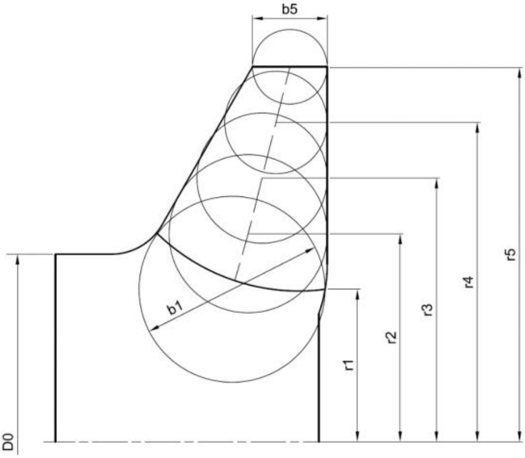
At the same time, direct and stochastic optimization algorithms are described and compared, and models used in optimization processes of pump working parts in existing industrial applications are presented. The optimization models applied in industrial solutions are presented.

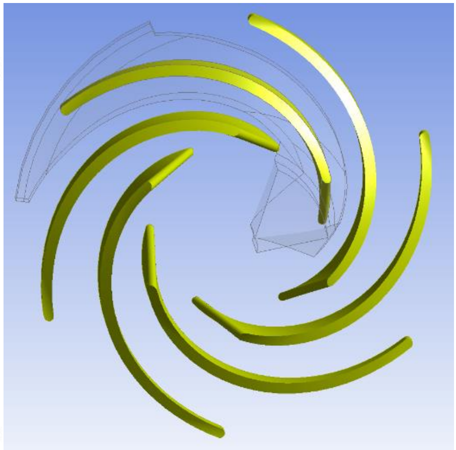
2. THE ANALYTICAL METHODS PRESENTATION FOR CALCULATING THE CENTRIFUGAL PUMPS' WORKING PARTS

The second chapter presents theoretical considerations of centrifugal pump theory and classification of the centrifugal pumps by impeller geometry. Based on the fundamental equation of dynamic pumps (Euler), the kinematics of fluid flow in the centrifugal pump impeller are described and the relationships linking the main geometrical parameters of the centrifugal pump impeller with the parameters of fluid flow in the pump (pumping head, volume flow, etc.) are given. The proportionality and similarity relationships of pump impellers, the concept of rapidity, the influence of rapidity on pump impeller geometry and the classification of centrifugal pumps according to the rapidity parameter are also presented.

The second chapter presents methods for determining the main parameters of the centrifugal pump: pump flowrate, pumping head, pump speed, power output, efficiency and NPSHr.

Also, in the second chapter, methods for calculating the geometrical parameters of the pump impeller and profiling the impeller blade were presented. At the end of the chapter the calculation based on the presented model (fig.3(a)) of the pump impeller parameters was performed. In MathCad environment, the analytical calculation of the impeller geometrical parameters for pump model CH 6.3/20-1.1-2 with the following geometrical parameters was performed (fig.3(b)).





(a) **(b)**

Fig. 3. (a) Meridian section modelling of the pump impeller.
(b) Pump impeller blade geometry (model CH 6,3/20 1,1-2*)* obtained in ANSYS DM

3. ARGUMENTATION OF THE NUMERICAL METHODS FOR CALCULATING THE WORKING PARTS OF CENTRIFUGAL PUMPS

In third chapter, the numerical methods for calculating working parts of centrifugal pumps were argued. The software environments for performing the optimization process were compared. The computational ANSYS software environment was chosen.

The models for geometry parameterization of the centrifugal pump working parts were compared and the ANSYS DesignModeler module used for parameterization and geometric model generation was chosen.

The discretization methods for geometric model were investigated. The application of structured and unstructured discretization networks was compared. A study was carried out to determine the optimal parameters of the discretization networks (convergence study) necessary to increase the accuracy of the computation. During this study, 128 simulations were performed on different discretization grids, with a finite volume size of 1÷2.5 mm and 5÷20 swelling layers, at different flow regimes: minimum flowrate (Q_{min} = 2 m3/h), nominal flowrate (BEP) (Q_{nom} = 6.3 m3/h) and at maximum flowrate (Q_{max} = 9.5 m3/h) (fig.4),

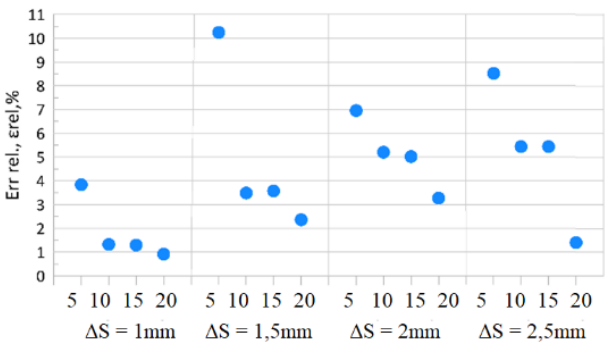


Fig. 4 Simulation results (relative error, pump:CH 6.3/32; Q_{nom} = 6.3 m3/h, Frozen rotor, SST model
(Bostan and Petco 2023-a)

also k-ε and SST turbulence models at nominal flow were compared (fig.5). (Bostan and Petco 2023). At the same time, a series of simulations at a different finite volume size (S = 1÷2.5mm), at a different number of inflation layers (5÷20 layers) for CH 6,3/20-1,1-2 pump was also performed. ANSYS discretization modules, ANSYS Mesher for unstructured grid and ANSYS TurboGrid for structured grid were also compared and selected.

Turbulence models based on the Navier-Stokes equation used in the numerical calculation of fluid flow were also compared. Quasi-dynamic and transient computational approaches were compared. A set of optimal settings of the computational flow process in pump working parts was established. Also, a study of the influence of turbulence models at different dimensions of the finite volume of the unstructured discretization network was carried out with the aim of increasing the accuracy of the simulations. Menter's SST model was selected as the turbulence model:

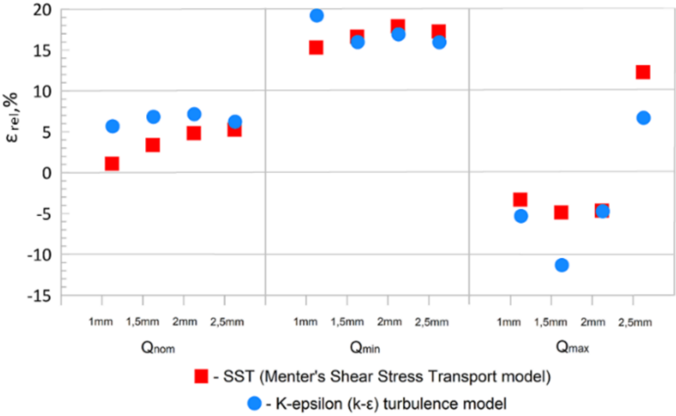


Fig.5. Comparison of head calculation accuracy of the CH 6.3/32-2.2-2 pump using k-ε and SST turbulence models

(Bostan and Petco 2023)

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=P-\beta^*\rho\omega k+\frac{\partial(\rho k)}{\partial x_j}\left[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right], \qquad (1)$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial(\rho u_j\omega)}{\partial x_j}==\frac{\gamma}{v_t}P-\beta\rho\omega^2+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_\omega\mu_t)\frac{\partial\omega}{\partial x_j}\right]+2(1-F_1)\frac{\rho\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial\omega}{\partial x_j}. \qquad (2)$$

Flow characteristics with pronounced cavitation effect were determined. The classification of typical cavity shapes that can occur in the working parts of centrifugal pumps has been described. The conditions of development, the reasons of occurrence and the consequences of the cavitating process in the working parts of the centrifugal pump were also described. Models of cavitation based on the Rayleigh-Plesset equation have been presented and the parameters at which cavitation modelling will be carried out have been indicated. The cavitation model used in the study is the Zwart, Gerber, and Belamri model are described in the thesis *(Ansys CFX Solver Theory Guide. Release 2021 R2 2021):*

$$\dot{S}_{lv}=\begin{cases} Fvap\dfrac{3r_{nuc}(1-r_v)\rho_v}{R_B}\sqrt{\dfrac{2}{3}\dfrac{P_v-P}{\rho_l}}, & P<P_v \\ Fcond\dfrac{3r_v\rho_v}{R_B}\sqrt{\dfrac{2}{3}\dfrac{P-P_v}{\rho_l}}, & P>P_v \end{cases}$$

The model is based on the calculation of the multiphase mass transfer rate per unit volume $\dot{S}_{lv}$where r_{nuc} is the nucleation volume fraction (Zwart, Gerber, and Belamri 2004). The radius of the chosen nucleation bubble is R_B = 1-10^{-6} m, and the vapor saturation pressure $\mathrm{P_v} = 3170$ Pa.

At the same time, ANSYS modules for performing the optimization process were compared and the optimization algorithm was chosen.

4. CONSTRUCTIVE-FUNCTIONAL OPTIMIZATION OF THE CENTRIFUGAL PUMP'S WORKING PARTS

Chapter four is devoted to the application of the optimization methodology formed using the recommendations presented in Chapter 3.

4.1. Optimization of the impeller of the centrifugal pump model CH 6.3/20-1.1-2

Today, CH-type centrifugal pumps, used in various branches of industry, are some of the most common types of autochthon pumps. As optimization parameters, in the given optimization process, parameters that determine the shape of the impeller blades and the number of blades were chosen. As optimization criteria, it was chosen to minimize the impeller torque while maintaining the impeller head.

Parameterization and geometric model creation. The ANSYS DesignModeler module was used to obtain the geometric model. The initial geometry represents the geometric model of the impeller of the CH 6.3/20-1.1-2 canned motor centrifugal pump. Only the geometry of blade 1 was subjected to parameterization (Fig. 6), the surfaces of hub 2 (disc with shaft driven driving hub 4) and shroud 3 remained unchanged. ANSYS BladeEditor tools were applied to obtain the parameterized geometric model. The parameterization scheme is shown in Figure 7.

The blade geometry was parameterized by varying the angle β of the blade at 5 points, keeping the blade thickness distribution constant along the length of the blade, identical to that of the original impeller.

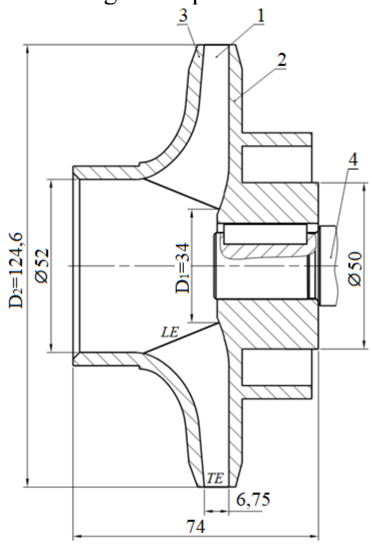


Fig. 6. Diagram with gauge dimensions of centrifugal pump impeller model of pump impeller blades CH 6,3/20-1,1-2 in axial section
(Bostan and Petco, 2023-c)

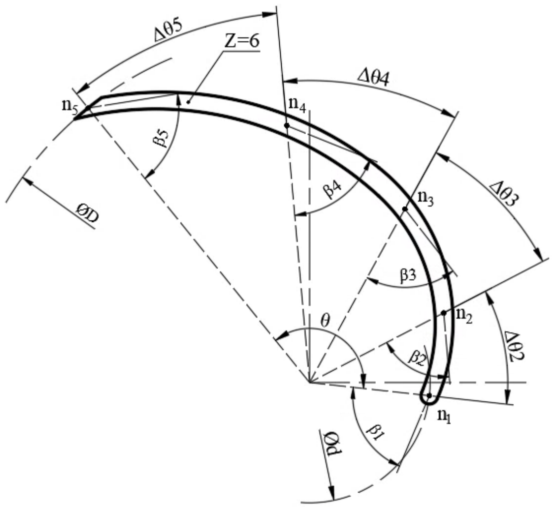


Fig. 7. Geometrical parameterization scheme
(Bostan and Petco, 2023-c)

The geometric ***model discretization*** was performed in ANSYS TurboGrid, a powerful discretization grid generation tool specifically designed for turbomachinery tasks (turbines, pumps and compressors). ANSYS TurboGrid was chosen because it offers automated discretization algorithms that can generate discretization grids for complex geometries of blades, impellers, inducers, etc. without the intervention of an engineer. Autonomous grid generation is one of the key factors in creating a multi-iteration optimization process.

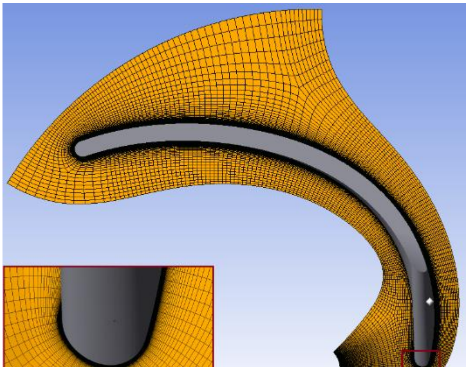


Fig. 8. Application of initial and boundary conditions in ANSYS CFX pre
(Bostan and Petco, 2023-b)

Figure 8 shows a grid created in ANSYS TurboGrid. The discretization grid was created according to the desired parameter y^+, equal to 1, at the accepted Reynolds number of fluid flow in the pump impeller equal to $5{\cdot}10^5$, with ca. $1.5\text{-}2{\cdot}10^6$ finite elements per grid.

Setting initial and boundary conditions. At the entrance to the flow zone (***Inlet***) (fig.9), the total (steady) pressure, $P_{inlet} = 10^6$ Pa is indicated. At the ***outlet***, the flow rate is indicated for the nominal flow rate Q_{outlet} = 1,75 (kg/s)/n, where n is the number of impeller blades. At the outlet, flow characteristics associated with turbulence and cavitation are calculated by the solver (Zero Gradient). The impeller domain is rotated at 2950 min^{-1}, at zero reference pressure (Pref = 0 atm).

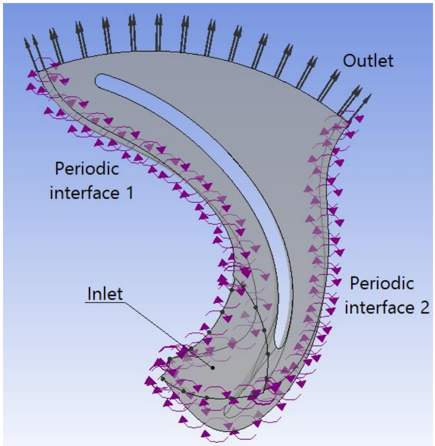


Fig. 9. Application of initial conditions and borderline in ANSYS CFX pre
(Bostan and Petco, 2023-b)

The simulation is based on a two-phase continuous fluid model composed of water in liquid form and water vapour at 25°C. The Periodic Interface (Fig. 4.6.) was applied to the edge surfaces of the computational domain.

Since the main motion studied is the rotational motion of the impeller at a constant speed, the optimal time step was chosen equal to $1/\omega$ = 0.0032 s, in accordance with the recommendations in the paper (Bostan and Petco 2023), and the Frozen impeller was chosen as the interface between domains (Interface model) at the validation phase of the results.

Simulating the turbulence process is one of the biggest difficulties that arise when calculating the flow parameters in a pump impeller. Turbulence occurs when inertial forces in the fluid become significant compared to viscous forces and is characterized by a Reynolds number reaching the order of $10^{\,6}$(Gülich 2020). Taking into account that the steady-state was used in the study, the Menter's Shear Stress Transport (SST) turbulence model is used in this research. (Menter, 1994).

The mass transfer model is the cavitation model, based on the Rayleigh-Plesset equation, which governs the dynamics of a spherical bubble in an incompressible fluid. The cavitation model used is the Zwart, Gerber and Belamri model (Zwart, Gerber, and Belamri

2004). The following parameters were chosen: the radius of the nucleation site was chosen R_B equal to $1\cdot10^{-6}$ m, and the saturation vapor pressure P_v = 3170 Pa.

Processing and post-processing stage. The minimum requirements have been chosen to optimize computational resources, ensuring numerical convergence with minimum execution time (Bostan and Petco, 2023-c; 2023-b). A finite number of computational iterations of 200 was chosen, and the computation is also completed when the tolerance for the root mean square residual error of 10^{-5} is reached. In order to control convergence, the following indicators were chosen: domain unbalance, static pressure at inlet and outlet, and torque at the rotation axis applied to the pump impeller (Bostan and Petco, 2023-b). After performing the calculation (fig.10), the system displays the pressure at the impeller outlet and the impeller torque with respect to the rotation axis Z as an indicator of the optimization criterion.

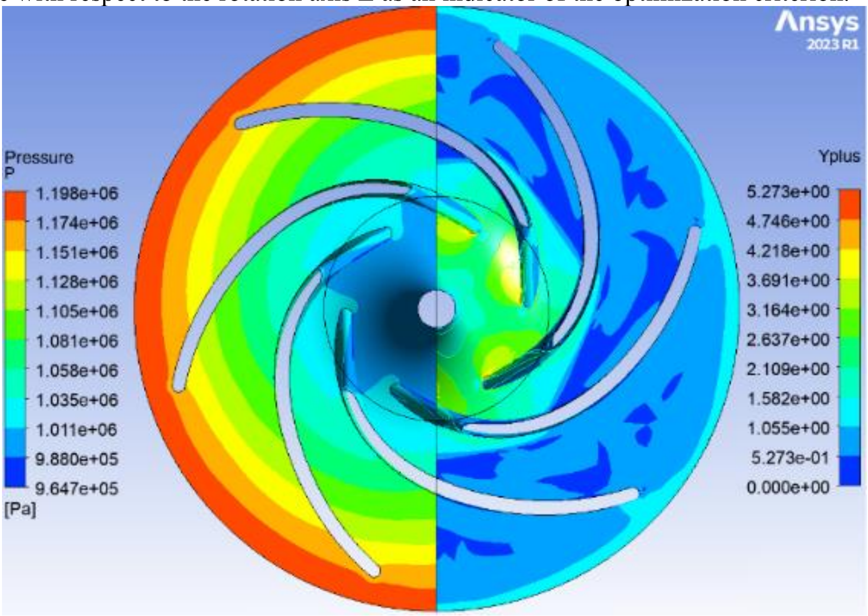


Fig. 10. Representation of the pressure field and the distribution of parameter y+ in ANSYS CFX post (Bostan and Petco, 2023-b)

Setting up the optimization process

The optimization process is based on coupling Computational Fluid Dynamics and evolutionary algorithm methods. The application of these methods is necessary due to the complexity of the fluid flow process in the pump impeller, thanks to the pronounced turbulence phenomenon, which does not allow to describe the flow by analytically solving the Navier-Stokes equations and the complexity of the multi-criteria optimization process, respectively. Therefore, this objective cannot be achieved by classical computational and optimization methods. The scheme of the applied optimization process is shown in Figure 11.

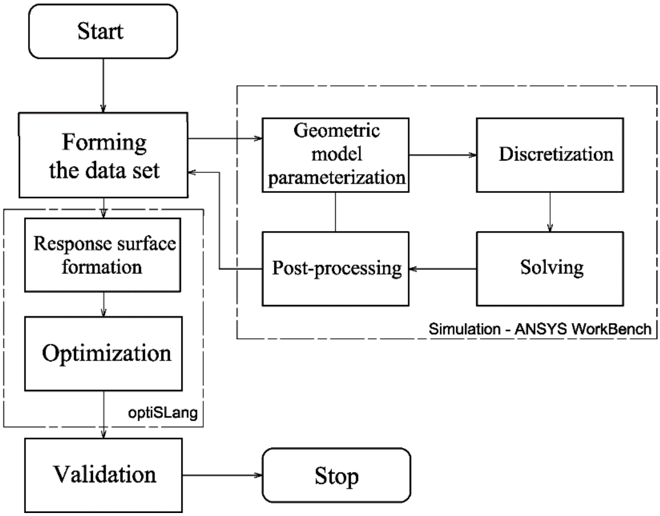


Fig. 11. Impeller optimization scheme

The optimization process includes the following procedural actions (Bostan and Petco, 2023.-c; 2023.-b):

1. Establish a reference point by performing a flow simulation at the initial geometric parameters of the pump impeller. At the same time, at this stage, numerical validation of the simulation results is carried out, as it can be compared with the results of the pump tests, performed in accordance with ISO 9906:1999–Hydraulic performance acceptance tests.

2. Choice of optimization parameters. Eleven parameters describing the shape and number of blades were selected as optimization parameters: blade angles $\beta_1 ... \beta_5$, angular coordinates $\Delta\theta_2 ... \Delta\theta_5$, inner diameter D_1 and outer impeller diameter D_2, and number of blades Z. In Figure 6, the angles θ are represented by the parameter M, which represents the linear position of the points $n_2 ... n_5$.

3. Establishing optimization criteria. Increased efficiency was selected as an optimization criterion, with the restriction of keeping the pump head constant.

4. Setting parameter variation limits. Parameter sampling between the set limits was performed using the Latin Hypercube method. This step is necessary to obtain random combinations of parameter values. A total of 1200 design points were received, 200 for each of the blades' number (z = 3÷8). Following parameterization, based on these parameter combinations, 974 successful geometries were created, based on which the optimization process was performed.

5. Carry out a series of simulations based on the geometric models obtained from the data received after sampling. Receiving a data set that has been loaded into ANSYS optiSLang (fig.12).

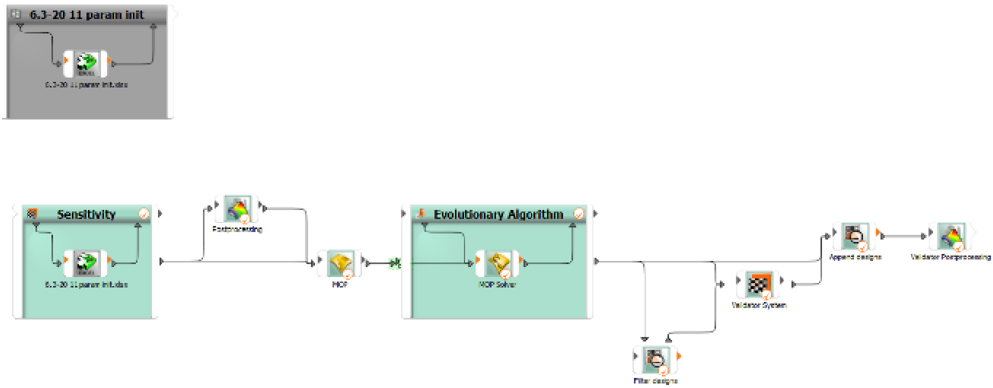


Fig. 12. Optimization process produced in ANSYS optiSLang (Bostan and Petco, 2023-b)

6. Apply a linear regression and Kriging to the data set received from the simulation series to obtain a response surface. The application of the response surface is rational because the application of direct optimization in the given case is computationally expensive and, due to the large number of input parameters, does not converge. Also, the correlation matrix used to analyze the correlation between variables in the dataset was obtained, which shows pairwise correlations between variables. The coefficient of performance (COP) matrix (fig. 13) was also obtained, which provides information about the influence of the parameters on the values of the optimization criteria.

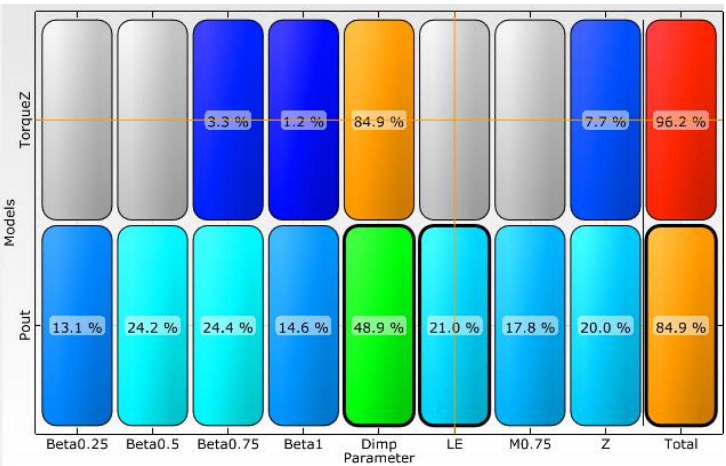


Fig. 13. Coefficient of performance (COP) matrix (Bostan and Petco, 2023-b)

Based on the COP matrix, we can identify the main parameters, which affect the impeller rotation moment, namely, the impeller diameter D and the number of blades z. The almost linear correlation between these parameters and the optimization criterion is shown in Figure 14 (b).

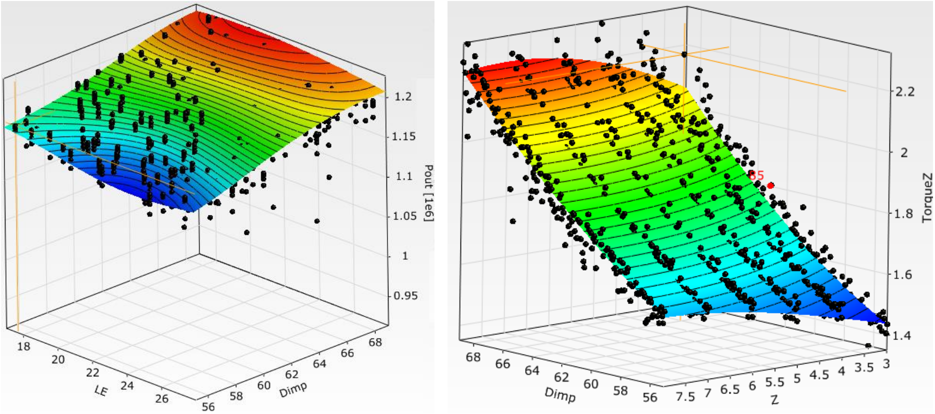


Fig. 14. Response surface: (a) Influence of impeller diameter and blade inlet diameter on pumping head, (b) Influence of impeller diameter and number of blades on impeller torque (Bostan and Petco, 2023-b)

7. Application of the evolutionary algorithm. Due to the fact that there is more than one objective function in the optimization process, the process is multi-criteria. The mathematical apparatus required to establish and solve such multi-criteria or multi-parameter problems is very extensive and represents a special branch of optimization theory (Papalambros and Wilde, 2017). As an optimization algorithm, an evaluative EA algorithm has been proposed by optiSLang as the most suitable optimization algorithm.

EA, being a recursive process, consisting of the following steps: creation of the initial population, evaluation of decisions, application of genetic operators (in this case mutation), evaluation and selection of solutions (Slowik and Kwasnicka 2020). The iterations are repeated until the optimal pump impeller parameters are determined. The evolutionary algorithm examined more than $2{\cdot}10^4$ samples. The geometry study is shown in Figure 15. Note that the selected geometry on the margin is marked in red.

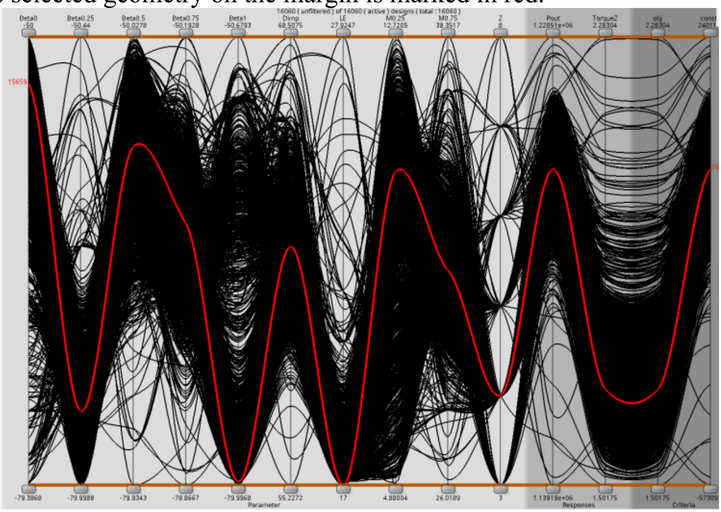


Fig. 15. Geometries explored by the evolutionary algorithm using response surface data (Bostan and Petco, 2023-c)

8. Perform fluid flow simulations in the modified pump impeller and compare the data with those obtained from the flow simulation in the impeller with initial geometrical parameters (Fig. 16).

Analysis of optimized geometry results

As a result of the optimization, the hydraulic efficiency of the pump has increased significantly. There is a pressure drop within the allowed ± 5 % of the BEP flow rate (Q_{nom} =20 m^3/h), but also an increase in impeller efficiency from 56 % to 61 %. (Bostan and Petco, 2023-b).

It can be seen that when the number of blades was changed from 6 to 4 (Fig. 16), the angle θ increased significantly. The comparison between the original and the optimized profile is shown in Figure 17.

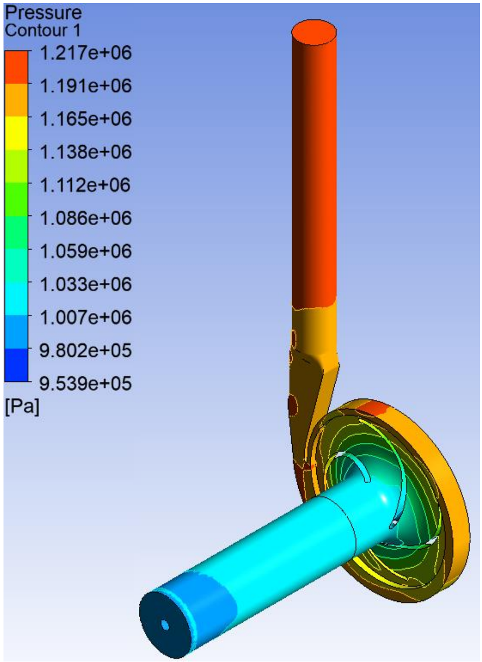


Fig. 16. Pump simulation results with an optimized **impeller** (Bostan and Petco, 2023-

In the second phase of the optimization, the pump impeller as a whole was optimized, including the shroud and hub surfaces. In general, the settings of the CFD simulations and the optimization process were kept identical to the previous phase.

Setting simulation settings

In the optimization process, the blade geometry as well as the surfaces of the hub and shroud were modified (Fig. 18). The blade geometry was parameterized at 3 points (n_1 ...n_3) by varying the blade angle β (β_1, β_2, β_3). The position of point n_1 is determined by the position of the diameter *d*, which describes the position of the leading edge, and n_3 by the diameter D_2 of the impeller, but the position of point n_2 by the angular coordinates $\Delta\theta_2$. The diameter of the impeller blade was not considered as an optimization parameter. As geometrical parameters describing the inner surface of the shroud the tilt angle α and the radius Rs of the shroud are selected. The hub surface is described by the radius RH, and the distance between the hub and the shroud by the width b2 of the impeller channel at the outlet.

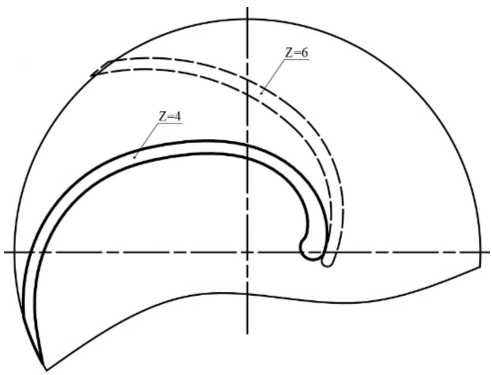


Fig. 17. Comparison between the shape of the original and the optimised blade (Bostan and Petco, 2023-b)

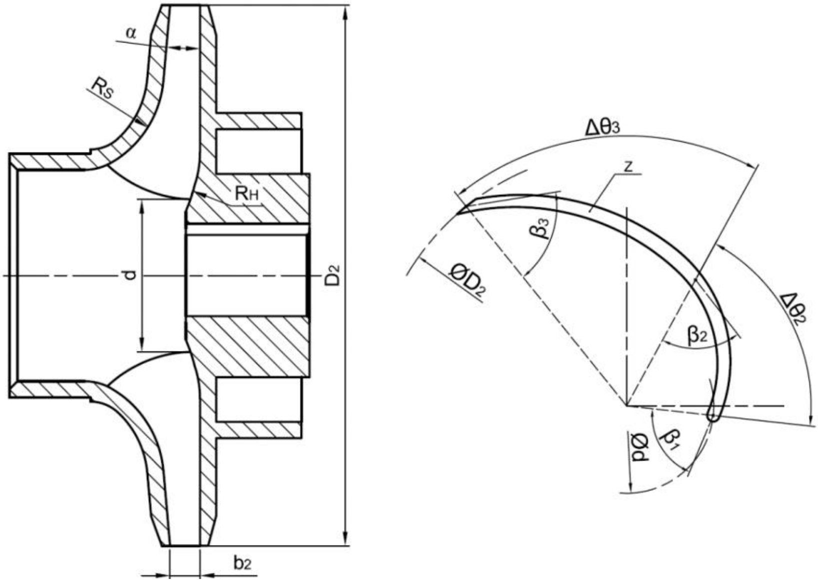


Fig. 18. Optimization parameters of the pump impeller model CH 6.3/20-1.1-2

The influence of the parameters on the parameterization criteria is shown in the forecast coefficient matrix (Fig. 19). From the above, we can see that the major influence on the pumping head as well as the impeller torque has the outer diameter of the impeller D_2. Also, at the pumping head more influence the number of blades z, followed by the shroud inclination angle α, as well as the diameter of the meridian of the inlet surface d. Also, at the torque to a small extent influence the number of blades z and the shroud inclination angle α. The CoP coefficient of the parameters describing the blade geometry is below 1%. This may be due to the shrinkage of the blade angle variation limit *β,* necessary to decrease the rate of "collapsed" geometries at the geometric model creation phase.

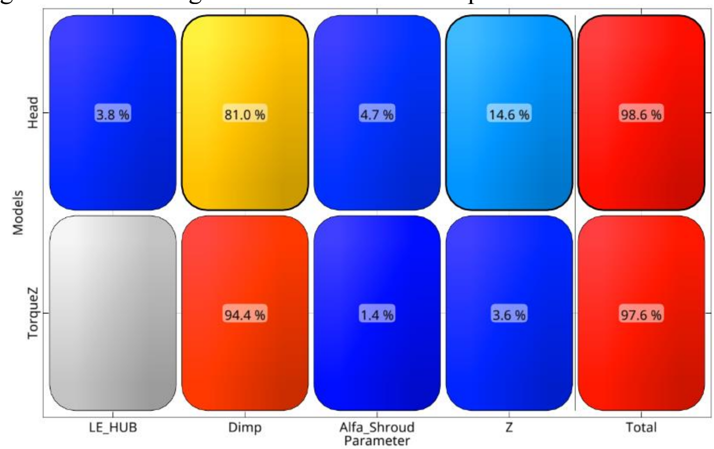
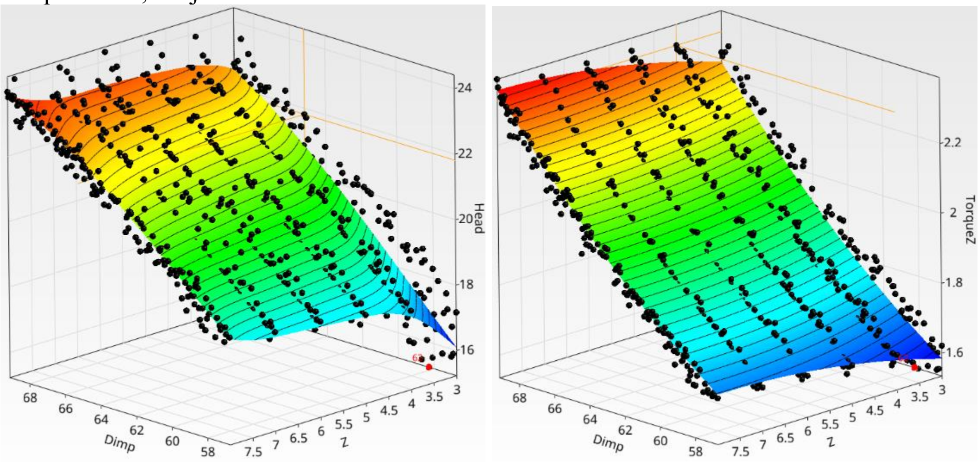


Fig. 19. Matrix of forecast coefficients (CoP) of parameters and criteria pump impeller optimization

Anisotropic Kriging for the pumping head and classical Kriging for the torque was used to form the response surface (Fig. 20). We can notice that, thanks to the choice of reasonable geometrical parameter variation limits, 853 successful geometries were obtained from 1500 sampled DPs, subject to CFD simulation.



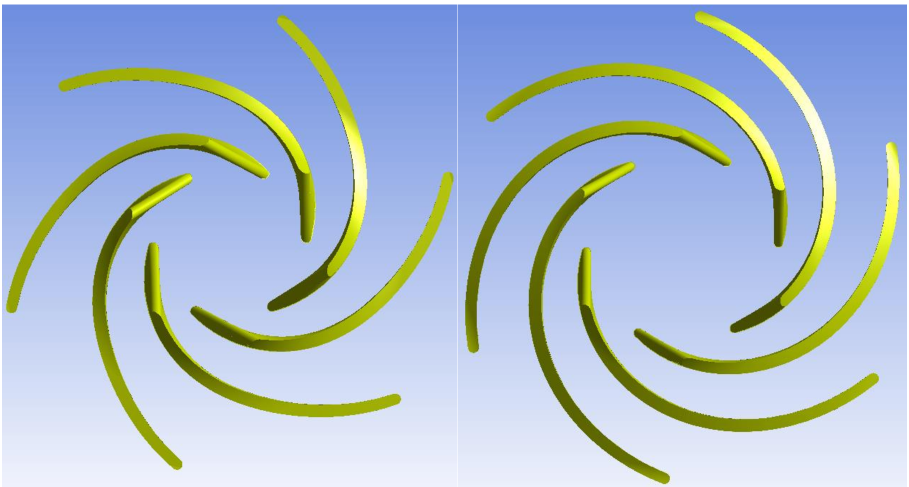
(a) (b)

Fig. 20. Response surface (a) for pumping head
(b) for torque

As an optimization algorithm the Evolutionary Algorithm (EA) was used, this algorithm was recommended by optiSLang being optimal for such a number of optimization parameters.

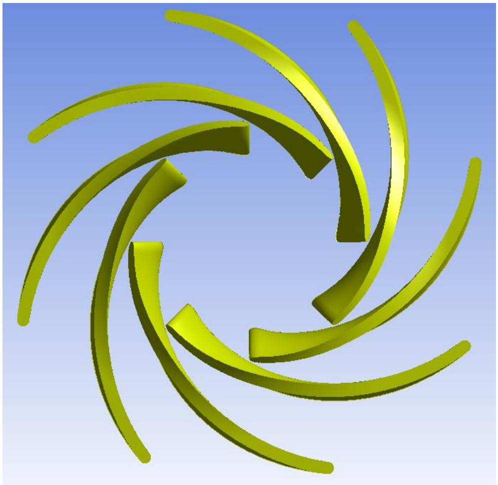
Impeller optimization results

In order to obtain the optimal pump impeller geometry for pump model CH 6.3/20 1.1-2, the optimization procedure based on the study of numerical simulation parameters and the optimization process exposed in chapter III of the thesis ware applied. In the optimization study of the CH type pump impeller, three geometrical models were obtained as shown in Figure 21.



(a) (b)

(c)



(d)

Fig. 21. Geometric model of the impellers obtained (a) of the original impeller, (b) of the impeller obtained by applying the analytical model, (c) the optimized blade impeller, (d) the optimized impeller as a whole

The comparison of the impeller characteristics obtained (Fig. 21) is shown in Table 1. The highest efficiency was obtained by the fully optimized impeller (blade, shroud and hub surfaces) $\eta_{rot} = 69.5\%$, followed by the impeller with optimized blades $\eta_{rot} = 61.9\%$ and the one obtained by analytical calculations $\eta_{rot} = 60\%$.

Table 1. Comparison of original and optimized pump characteristics

Impeller geometry	Pumping head, mH O_2	Torque, Nm	Impeller efficiency	Pump efficiency
Original	20,8	2,03	0,56	0,363
Analytically calculated	21	1,91	0,6	0,384
with optimized palette	19,9	1,776	0,619	0,396
fully optimized	21,54	1,696	0,695	0,445

It can be seen that the fully optimized impeller has 8 blades and the one with optimized blades has 4 blades. This is due to the fact that the impeller torque depends on the number of blades as well as the torque per blade. While in the case of blade optimization, the optimal variant was obtained with blades with angle θ of deployment and a reduced number z of blades, in the case of full impeller optimization, conversely, the impeller was obtained with reduced angle θ of deployment and increased number z of blades, which was increased from 4 to 8.

The final version of the pump impeller is also to be patented and used in the manufacture of the CH 6.3/20-1.1-2 model pump.

4.2. Design and optimization of the centrifugal wastewater pump impeller

Wastewater pumps are a type of specialized pump used to convey and manage wastewater, including various types of liquids with inclusions, and are used in both domestic and industrial or other applications. This type of pump plays a major role in waste water disposal (Gülich 2020).

The following task was set in the given study: Creation of the working parts of a pump for wastewater pumping with the following characteristics: *nominal pump flow rate* Q_{nom} = *110* m^3 /h, *pumping head of H = 8.5 mH2O, motor speed of n = 1800* min^{-1} *and diameter of particles that can pass through the impeller* d_p *= 80 mm, with maximum efficiency (optimization criteria)*.

The initial geometric model was obtained through the CFturbo environment. After testing, it was found that only the single-blade impeller pump allows the pump to operate at the prescribed hydraulic parameters and to pass particles with a maximum diameter d_p = 80 mm through the pump. It should also be noted that, as the type of delivery, the design with a volute casing was chosen. (Yonar 2018), similar to the pump shown in Figure 4.23.

A series of pump model simulations was carried out, consisting of three domains (Fig. 22): suction connection, impeller and volute with discharge connection.

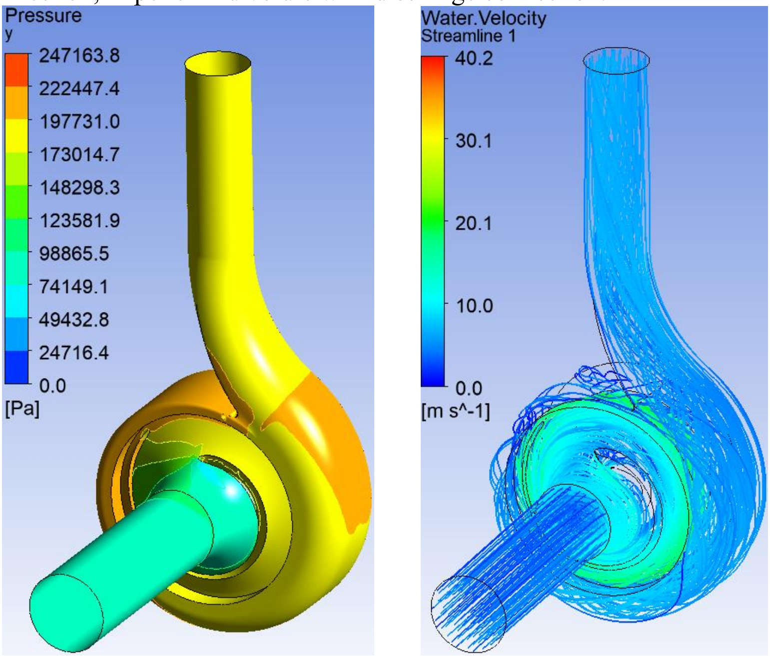


Fig. 22. Simulation results based on pump geometry obtained in CFtutbo (P_{inlet} = 10 mH_2 O)

Geometric model development

The blade geometry was parameterized by varying the angle β of the blade at 3 points n_1 ...n_3, with the thickness distribution of the blade ranging from 9 mm at the inlet to 7 mm at the outlet. The wastewater pump impeller contains a single blade, has variable curvature between their leading LE and trailing TE edges inscribed in angle $\theta = \sum \Delta\theta_i$ (Figure 23), located on the inner diameter D_1 and outer *diameter* D_2. The shape of the impeller blades is represented by the cumber line, which passes through the points n_1 ...n_3 determined by the angular coordinates $\Delta\theta_2$, $\Delta\theta_3$ and $\Delta\theta_4$ and blade angles respectively β_1, β_2, β_3 calculated by the software environment.

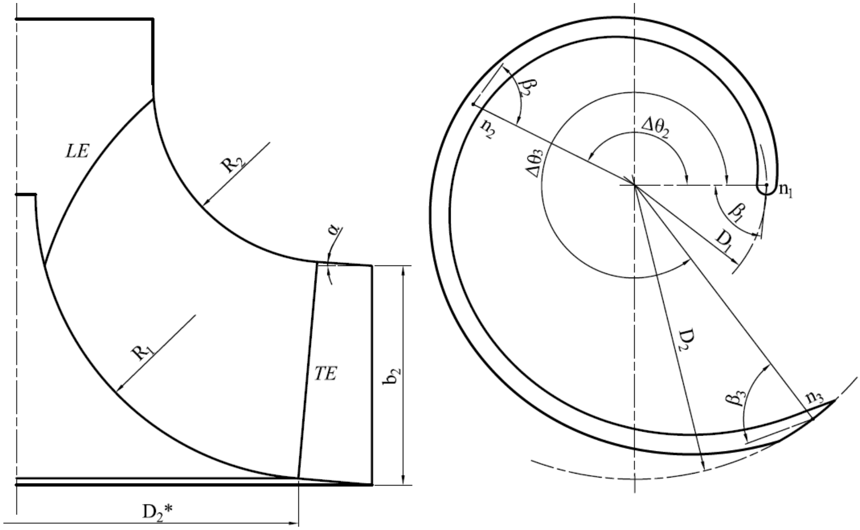


Fig. 23. Single blade wastewater impeller parameterization model

Discretization of the geometric model

Since the ANSYS TurboGrid module does not support grid generation for single-bladed impellers, the decision was made to apply the unstructured discretization grid generated in the ANSYS Mesher module (Fig. 24). The following parameters were used to generate the discretization grid:

For *calculations in the optimization process*: Maximum finite element size of ΔS = 2mm. On the surfaces of the hub and shroud walls was applied a layer of 25 finite volumes in depth and the thickness of the layer of 5 mm, and on the surface of the blade - layer of 28 finite volumes in depth and the thickness of the layer of 5 mm. Grids of about 1.5- $2 \cdot 10^6$ finished volumes were obtained.

For *calculations of validation* of the optimized impeller geometry. Maximum finite element size of Δ S = 1mm. Grids with ca. $14 \cdot 10^6$ finite volumes.

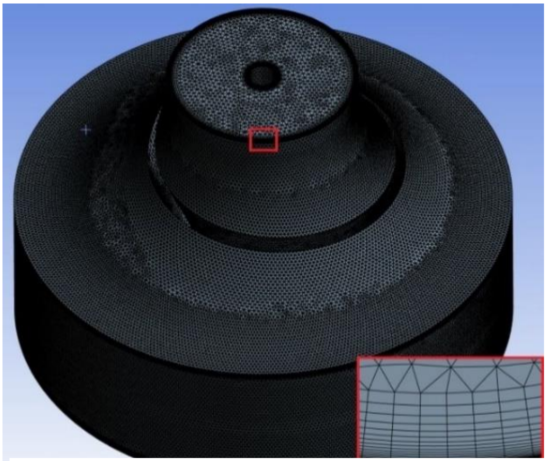


Fig. 24. Rotor discretization grid (at optimization phase) generated in ANSYS

The initial and boundary conditions remained simulated as in section 4.1, but with an impeller speed of 1800 min^{-1} and without the application of the periodic interface. Also, the processing and post-processing settings remained similar (fig.25,26).

Setting up the optimization process

The actual optimization process was performed in ANSYS optiSLang. The optimization scheme is similar to the one shown in Figure 11.

Algorithms based on EA and NLPQL were applied. We can mention that in case of the single-bladed impeller optimization process, the algorithms which were used have provided an optimized geometry with geometric parameters. We can note that for the hub and shroud radii (R_1 and R_2), the variation limits in the case of the following calculation should be increased, in turn the shroud angle *α,* being maximum, cannot be increased.

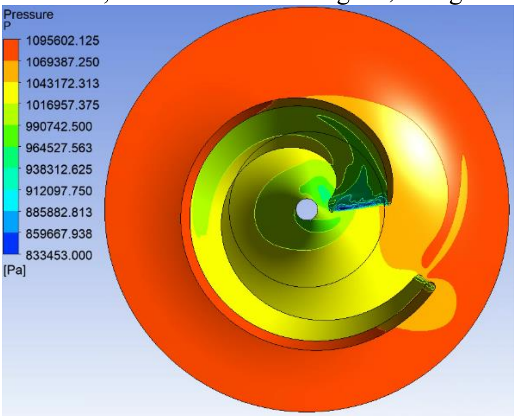


Fig. 25. Pressure field distribution in the pump impeller

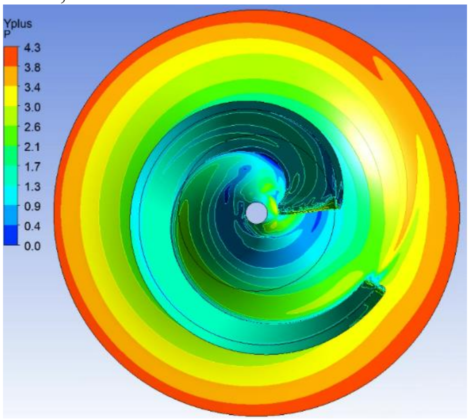


Fig. 26. Distribution of y parameters $^{+}$

Analysis of the results obtained

After sampling, the 600 geometric models of the wastewater pump impeller (single blade) were obtained. Due to the application of large variation limits, an increased number of incorrect geometries was rejected. A total of 168 successful pump impeller geometry models were obtained. Similar to the optimization procedure described in section 4.1, the simulation results were stored in a dataset.

Figure 27 shows the response surface obtained from the simulation results. Linear regression was applied to obtain the response surface.

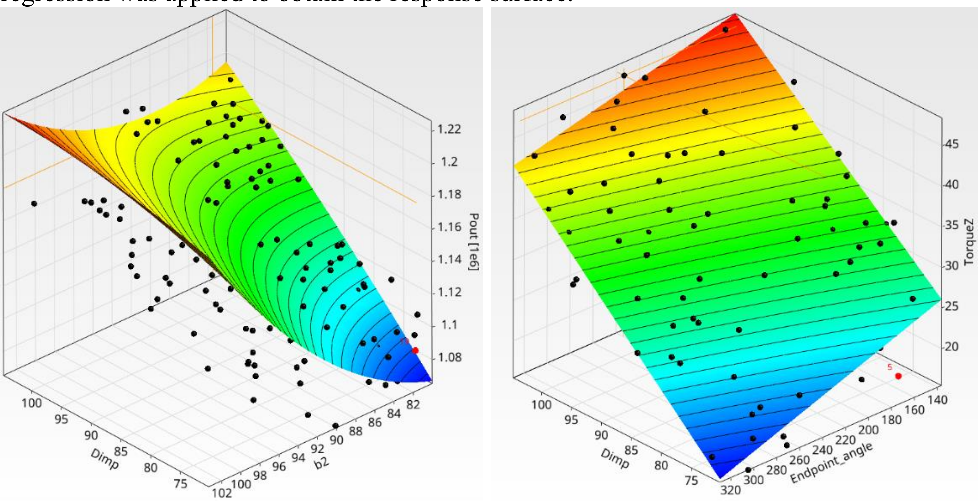


Fig. 27. Response surface (a) Influence of impeller diameter and blade width on pumping head, (b) Influence of impeller diameter and deployment angle θ_3 **on impeller torque.**

The greatest influence on pumping load and torque is the diameter D of the single blade impeller. The pumping load is also influenced by the width b_2 of the impeller channel.

The optimized impeller geometric model is shown in Figure 4.28. The pump efficiency increased from $\eta = 62.9\%$ (efficiency of the original geometric model obtained in CFturbo) to $\eta = 71.9\%$ (efficiency of the optimized pumping part). The optimization results are shown in Table 2.

Table 2. Comparison of initial and optimized working body parameters

Impeller geometry	Pumping load, mH O_2	Torque, Nm	Impeller efficiency	Pump efficiency
Originally	9,38	24,1	0,629	0,566
Optimized	10,7	22	0,785	0,707

4.3. Design and optimization of the CMP centrifugal pump impeller

The issue of reducing the NPSHr or, in other words, the net positive suction head (NPSH) of a pump is essential for its use in low-pressure closed hydraulic systems.

The following presents the optimization process of an impeller for a centrifugal pump of the CMP series (model CMP 1612-7 N2 and CMP 1612-8 N2), produced by CRIS Hermetic Pumps.

Description of the optimization process algorithm

Creating and setting up an optimization process is a difficult and time-consuming task. However, the optimization process is significantly superior to classical methods of obtaining pump part geometry, such as analytical models derived from empirical data (Bostan and Petco 2023).

The optimization process (similar to the one shown in Fig. 11) of centrifugal pump parts requires careful analysis, modeling, results processing and usually consists of (Parikh, Mansour, and Thévenin 2021; Zhang et al. 2011; Moisă, Susan-Resiga, and Muntean 2013):

- Formulation of the optimization problem and selection of optimization parameters and criteria.
- Creation of the geometric model based on the selected parameters, generation of the finite volume grid and CFD simulation to simulate the flow processes in the working parts of the centrifugal pump. Perform post-processing and data selection.
- Application of optimization algorithm to identify the optimal parameters of the geometric model.
- Validation of the geometry obtained by performing a flow simulation with the resulting impeller. The entire flow path volume of the centrifugal pump is used as the computational domain.

A desirable further validation of the optimized shape could include experimental testing and comparison of the numerical simulation results with experimental data and validation of the resulting impeller effectiveness.

Formulation of the optimization task.

The choice of an optimization criterion, parameters and constraints plays a crucial role (Parikh, Mansour, and Thévenin 2021; Zhang et al. 2011; Moisă, Susan-Resiga, and Muntean 2013) in the optimization process. In case of this study, it would make sense to use the NPSH3 level as an optimization criterion, simulating the testing process of a centrifugal pump described in ISO 9906:2012−Hydraulic performance acceptance tests (International Organization for Standardization, 2023) i.e., by gradually reducing the head until the total head decrease at constant flow reaches 3%. In this case, the entire model of the entire flow path of the pump should be used as the geometric model.

The iterative nature of the optimization process leads to a significant increase in the computational resources required (memory and processing time). In order to reduce them, it was decided to use a simplified geometric model. Instead of the extended computational domain, consisting of the flow parts of the suction and discharge pipes, the pump impeller and the impeller, a reduced computational domain (6.6 times) consisting only of the flow part of the impeller was considered. Also, the optimization criterion was changed from effectively reducing the NPSHr to maximizing the impeller head, as described in subsection 3.1.

Creating and discretizing the geometric model

ANSYS DesignModeler coupled with BladeEditor was used to obtain the geometric model. The geometric model represents the flow part of the centrifugal pump impeller, consisting of the volume between the blades, the hub and the shroud surface. The 2-blade scheme was chosen. The discretization model was generated using ANSYS TurboGrid (Fig. 28), which can accurately capture the geometry and flow characteristics of turbomachinery components (Bostan and Petco 2023).

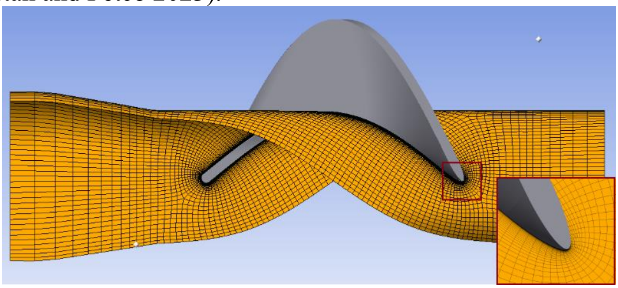


Fig. 28. Structured network obtained in ANSYS TurboGrid

The following parameters were used as network parameters: the desired achievable parameter y+ = 1, with the expected Reynolds number of the fluid flow in the impeller equal to $5 \cdot 10^5$. Single Round-Round Symmetric set was used as topological set. On average, between 1.5 and 2 million final volumes are obtained in a structured hexahedral grid with first layer thickness equal to $5 \cdot 10^{-6}$ m.

Data processing, post-processing and selection

Iterative calculations were performed in ANSYS WorkBench. The iterative process (similar to those shown in Figure 11) is stopped either after reaching the maximum number of iterations set to 250 or after reaching a residual error tolerance of 10^{-5}.

To monitor convergence, the following parameters were chosen: static pressures at the inlet and outlet, as well as the torque around the axis of rotation applied to the pump impeller and the domain imbalance. After completion of the calculation (Fig. 29), the desired values of the impeller height are displayed as an indicator of the optimization criterion.

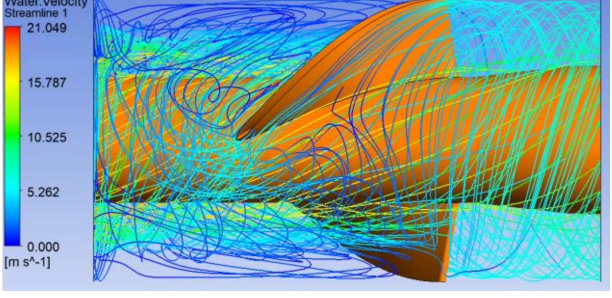


Fig. 29. Current lines with flow rate indication

Setting parameters and optimization criteria

ANSYS optiSLang software is used to perform the optimization. As a criterion of the optimization process, the maximum height developed by the impeller was chosen. The main advantage is the reduction of required computational resources. The disadvantage is that the mutual influence between the impeller and the pump impeller is not taken into account, because the impeller is considered separate from the rest of the flowing part of the centrifugal pump.

Impeller length L, impeller outer diameter D, hub diameter d and winding angle θ (Fig. 30) were chosen as optimization parameters. Parameter variation limits were chosen taking into account that the impeller was designed for an already manufactured pump, which significantly affected the limits for impeller outer diameter D and impeller length L.

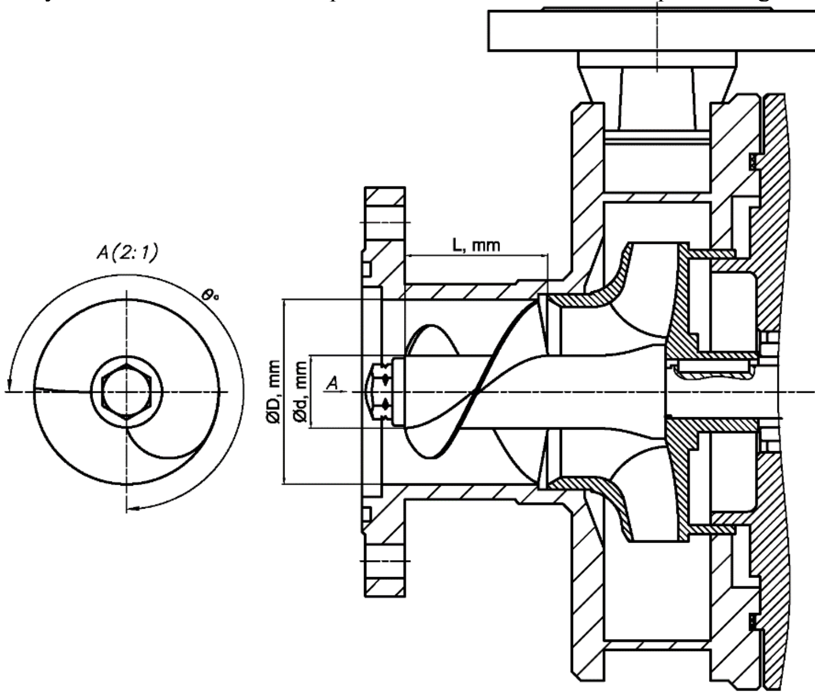
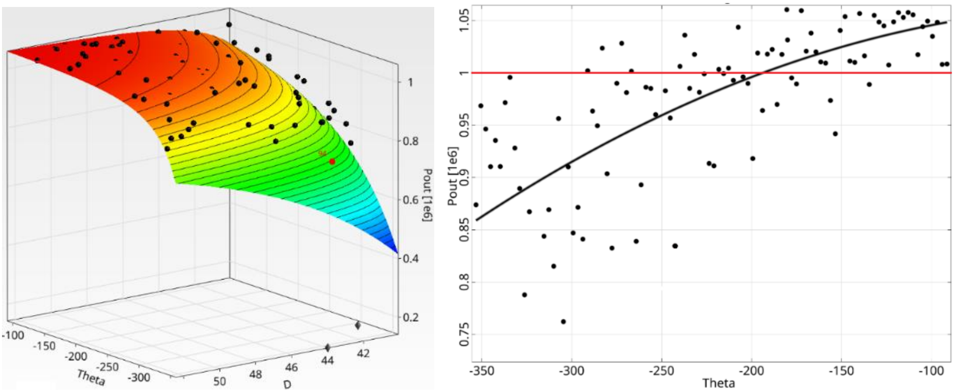


Fig. 30. Drawing of the pumping part of the centrifugal pump, with indication of optimization parameters

Parameter selection between the set limits was performed using the Latin hypercube method. A total of 120 calculated points were obtained. Sampling is necessary to obtain random combinations of parameter values.

Data analysis and processing were performed in ANSYS optiSLang

A series of simulations were performed based on geometric models obtained from the post-sampling data. The obtained data set was loaded into ANSYS optiSLang software. A total of 98 calculated points were considered. A linear regression was applied to the data set received from a series of simulations to obtain a response surface as shown in Figure 31.



(a) (b)

Fig. 31. Representation of the response surface
(a) Pumping head vs. winding angle θ and outside diameter D;
(b) Pumping head vs. winding angle θ (Bostan and Petco, 2023-a)

It can be seen from Figure 31(b) those impellers, whose winding angle θ is less than 200-250 degrees, almost always exhibit an outlet pressure lower than the inlet pressure, indicating that the impeller does not develop lift due to too small a cross-section of the flow zones.

The main parameters, which affect the pumping head exerted by the impeller are the winding angle θ and the impeller outer diameter D, to a lesser degree the impeller length L, and the hub diameter d hardly affects the impeller head.

An evolutionary algorithm (EA), nonlinear programming by quadratic Lagrangian (NLPQL) and adaptive response surface method (ARSM) were selected as optimization algorithms. The optimization results obtained by the above methods were compared. The best result was shown by the geometry obtained from the best parameter obtained from the sampled data set (Design Point - DP), which showed the pumping height of the impeller of approximately H = 51.5 kPa or 5.26 mH2O (Table 3).

Table 3. Comparison of the optimization results

Optimization algorithm	Bushing diameter d, mm	Outside diameter D, mm	Impeller length L, mm	Winding angle θ, °	Pumping height
EA	46.96	103.5	81.00	-90.00	4.63
NLPQ	46.04	104.8	66.00	-92.60	4.25
ARSM	47.7	104.86	50.00	-91.00	4.29
Best DP	41.12	104.12	77.18	-180.45	5.26

The results were digitally validated (Fig. 31−32) by simulating fluid flow through the entire pump and determining an approximate NPSH3 by gradually decreasing the inlet pressure.

It should be noted that at pressure values close to NPSH3, it is much more difficult to achieve convergence of the result as well as to eliminate the imbalance between the calculation domains. As a result of modeling at a pressure close to the required NPSH3, the cavitation cavities formed are similar to the experimentally captured cavities presented in the work. When the pressure drops below NPSH3 (Fig. 32), the cavitation cavities reach the leading edge of the impeller, marked in Fig. 33, zones where the volume of vapor increases the volume of water in the liquid phase.

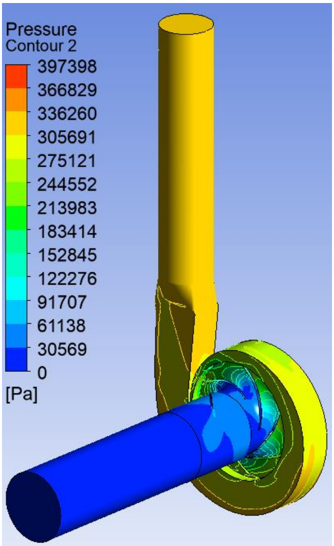


Fig. 32. Pressure field distribution

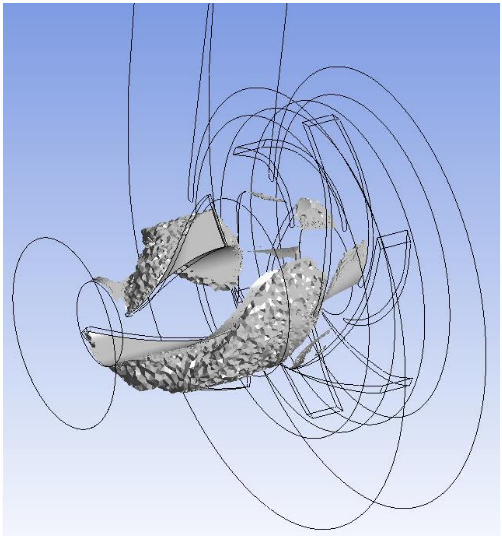


Fig. 33. Representation of cavities at pressure NPSH = 2,6 mH2O

Experimental validation of the optimization results

As an experimental verification of the centrifugal pump impeller optimization process, a CMP series centrifugal pump was tested. The optimized pump was tested in accordance with ISO 9906:2015.

The purpose of the test (fig. 34, 35), in addition to obtaining the main pump characteristics (fig. 36, 37), (pumping head exerted, current consumption and power), was also to obtain the value NPSH3, the system critical cavitation reserve (NPSHr), i.e. the net positive suction head available for the test pump at constant flow rate, when the pumping head is reduced by 3% due to cavitation caused by the decrease in available suction head.

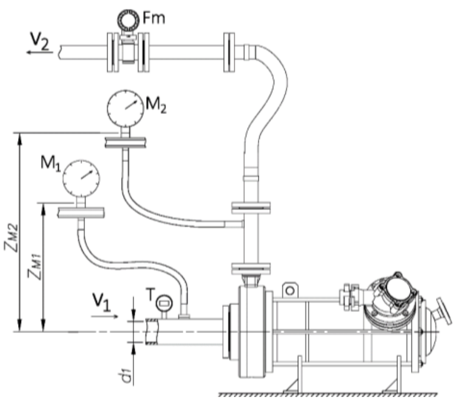


Fig. 34. Test scheme

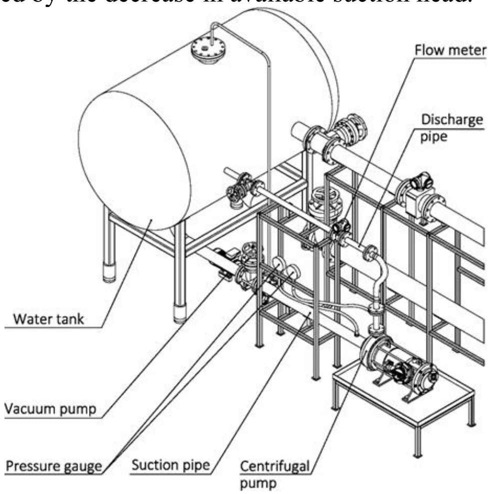


Fig. 35. Test station scheme

The NPSH3 value is required to avoid cavitation and is used to obtain the recommended NPSHr value:

$$NPSHr = NSPH3 + P_v + 0{,}5\ m(H2O).$$

Fig. 36. Testing the pump

Fig. 37. Impeller and inducer

The NPSH3 value was obtained equal to 2.60 meters at nominal flow rate (BEP), which corresponds to the technical specification. The test results are shown in Figure 38. From the figure it can be seen a proportional decrease of NPSH3 in general by 0.5 mH2O, which is in agreement with the theoretical data.

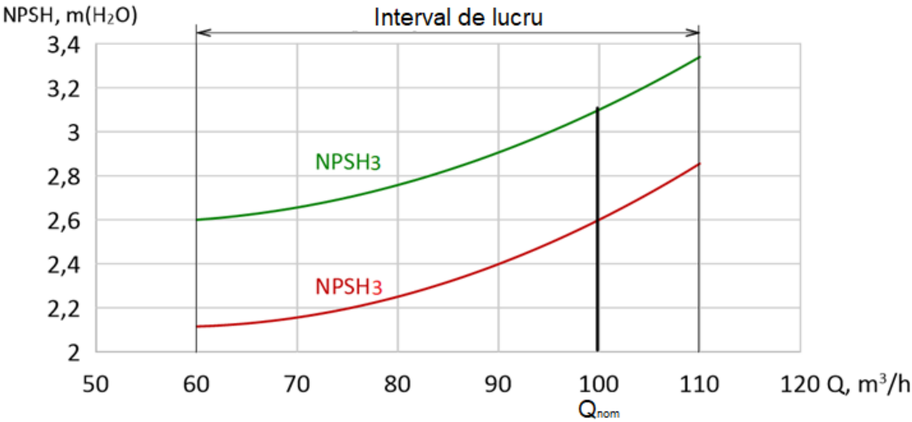


Fig. 38. Cavitational characteristics (*NPSH3*) of the pump with the original construction (green) and the impeller (red)

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The problem addressed in the thesis is devoted to increasing the energy efficiency of centrifugal pumps through mathematical modelling and numerical computation of fluid flow, carried out by creating a methodology for optimizing the working parts of centrifugal pumps based on computational fluid dynamics (CFD) methods coupled with the application of stochastic optimization algorithms.

The conclusions and recommendations formulated, as well as the results received, represent the original contributions which, in summary, are as follows:

1. The current state of the pump manufacturing industry in the RM (Petco 2019) has been described. We can observe a considerable decrease in pump production in the RM. In order to reverse this process, the directions of modernization of centrifugal pumps produced in RM have been established (Petco 2021; 2023).

2. The methods of geometry generation of the centrifugal pumps working parts were studied (Petco 2021; 2023) and the world experience of applying modern optimization models in solving optimization problems of centrifugal pumps was studied (Petco 2021; 2023).

3. Theoretical considerations on centrifugal pumps were presented and the centrifugal pump impeller calculated according to the presented empirical model was obtained. At the numerical validation phase, the obtained impeller showed higher hydraulic efficiency than the original one, but lower than the optimized ones, which shows that the given method of obtaining the impeller model can be applied, but is inferior to methods based on CFD simulations and optimizations (Bostan and Petco 2023b).

4. With the aim of obtaining the methodology of optimization of the working parts of centrifugal pumps, the study of the optimal settings of ANSYS modules applied in the optimization process was carried out. For solving was selected the module for parameterization and generation of geometric model– ANSYS Design Modeler, and as discretization module was selected, for unstructured grid–ANSYS Mesher, and for structured grid–ANSYS TurboGrid (Bostan and Petco 2023). At the same time, the convergence study found that the best option is to choose the finished volume size of the order of 1.5 mm and 15-20 layers of packing. The optimal settings of the simulation process were also determined. Following a comparison of turbulence models, the RANS SST turbulence model (Bostan and Petco 2023) was selected and the optimal parameters of the Zwart-Gerber-Belamri cavitational model used by ANSYS CFX were established. OptiSLang was chosen as the optimization algorithm.

5. Based on the presented methodology the optimization of the pump impeller model CH 6.3/20-1.1-2 (Bostan and Petco, 2023-b) was performed. The application of the design optimization resulted in an increase of the rotor hydraulic efficiency from 56% to 69.5% and the pump efficiency from 36.3% to 44.5%.

6. The geometrical model of the working parts of a centrifugal wastewater pump with a single vane impeller was obtained. Following the optimisation process, an increase in the hydraulic efficiency of the centrifugal pump from 62.9% to 78.5%, or in the pump efficiency from 56.6% to 70.7%, compared to the original model was found.

7. Based on the methodology the process of creating a centrifugal pump impeller was carried out. Following the cavitation test it can be seen that the use of the resulting impeller resulted in a decrease of NPSH3 by 0.5 mH2O at nominal flow, which corresponds to the technical specification. The resulting impeller was applied to two models of series centrifugal pumps with capped motor produced by CRIS Hermetic Pumps.

Future research directions and objectives:

For the future it is proposed to continue the research related to the optimization of the working parts of centrifugal pumps, i.e., vanes, pump casing volutes, etc. It is also proposed to apply transient CFD simulations for the numerical validation stage.

At the same time, we can mention that the given methodology can be applied not only to the optimization of the working parts of centrifugal pumps, but also to the optimization of the working parts of most dynamic pumps or dynamic hydro generators.

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ADNOTARE

la teza de doctor cu tema **„Majorarea energoeficienței pompelor centrifuge prin modelarea matematică și calculul numeric al curgerii fluidului**”, prezentată de către

Petco Andrei

pentru obținerea titlului științific de doctor în științe tehnice

la specialitatea 242.01. *Teoria mașinilor, mecatronică*, Chișinău, 2023

Teza cuprinde introducere, patru capitole, concluzii și recomandări, bibliografia din 113 de denumiri și 7 anexe. Volumul este de 137 pagini text, inclusiv, 115 de figuri și 14 tabele. Conținutul de bază al tezei a fost publicat în 5 lucrări științifice, din care 2 lucrări de unic autor, 2 lucrări în reviste recenzate și 1 brevete de invenție.

Cuvinte-cheie: pompe centrifuge, impeller al pompei centrifuge, modelarea curgerii fluidului, modele de turbulență, proces de cavitație, simulările CFD, algoritmi de optimizare, testarea pompelor centrifuge.

Domeniul de studiu se referă la optimizarea constructiv-funcțională a organelor de lucru ale pompelor centrifuge cu scopul majorării energoeficienței.

Scopul lucrării. Majorarea energoeficienței pompelor centrifuge și anume a randamentului pompei și a rezervei de cavitație prin aplicarea simulărilor CFD a curgerii fluidului cuplate cu algoritmi de optimizare.

Noutatea științifică și valoarea aplicativă a lucrării. Obținerea rotoarelor pompelor centrifuge cu caracteristicile sporite prin aplicarea simulărilor CFD cuplate cu algoritmi de optimizare și anume optimizarea impellerului pompei centrifuge model CH 6,3/20-1,1-2 cu randament majorat, obținerea impellerului pompei centrifuge pentru apă uzată și crearea unui impeller impulsor pentru pompe de tip CMP pentru micșorarea rezervei de cavitație.

Semnificația teoretică constă în elaborarea metodologiei de optimizare a organelor de lucru ale pompelor centrifuge bazată pe simulările CFD și algoritmi de optimizare.

Metodologia cercetării științifice constă în crearea metodologei de optimizare bazate pe modele și metode de calcul numeric și studiu experimental destinat optimizării constructiv-funcționale a organelor de lucru ale pompelor centrifuge.

Implementarea rezultatelor cercetării. Metodologia elaborată a fost aplicată pentru optimizarea impellerului pompei centrifuge model CH 6,3/20-1,1-2 și obținerea impellerului pompei centrifuge pentru apă uzată care urmează a fi produse de întreprinderea „CRIS” SRL și crearea unui impeller impulsor pentru pompe de tip CMP, fabricate și testate la întreprinderea dată. Totodată rezultatele tezei au fost utilizate în cadrul studiilor de licență la lucrări de laborator la disciplina „Proiectare asistată de calculator” .

АННОТАЦИЯ

докторской диссертации на тему **«Повышение энергоэффективности центробежных насосов путем математического моделирования и численного расчета потока жидкости»**, представленной **Петко Андреем** на соискании учёной степени доктора технических наук по специальности

242.01 - *Теория машин, мехатроника,*

Кишинёв, 2023 год

Диссертация состоит из введения, 4 глав, выводов и рекомендаций, списка литературы из 113 записей и 7 приложений. Объем диссертации в 137 страниц текста, включая 115 рисунков и 14 таблиц. Основное содержание диссертации было опубликовано в 5 научных работах, включая 2 без соавторов, 2 работ в рецензированных журналах и 1 патента.

Ключевые слова: центробежные насосы; колесо центробежного насоса, моделирование потока жидкости, модели турбулентности, процесс кавитации, CFD моделирование, алгоритмы оптимизации, испытания центробежных насосов.

Область исследований относится к конструктивно-функциональной оптимизации рабочих органов центробежных насосов с целью повышения их энергоэффективности.

Цель работы. Повышение энергоэффективности центробежных насосов, а именно КПД насоса и кавитационного запаса, путем применения моделирования CFD потока жидкости в сочетании с алгоритмами оптимизации.

Научная новизна и прикладная ценность работы. Получение колес центробежных насосов с улучшенными характеристиками путем применения CFD-моделирования в сочетании с алгоритмами оптимизации, а именно оптимизации колеса центробежного насоса модели СН 6,3/20-1,1-2 с повышенным КПД, получение рабочего колеса канализационного центробежного насоса и создание предвключённого осевого колеса для насосов типа СМР используемого для снижения кавитационного запаса насоса.

Теоретическая значимость заключается в разработке методологии оптимизации рабочих органов центробежных насосов на основе CFD-моделирования и алгоритмов оптимизации.

Методика научных исследований заключается в создании методологии оптимизации на основе моделей и методов численного расчета и экспериментальных исследованиях, направленных на конструктивно-функциональную оптимизацию рабочих органов центробежных насосов.

Внедрение результатов исследований. Разработанная методика применена для оптимизации колеса центробежного насоса модели СН 6,3/20-1,1-2 и получения рабочего колеса канализационного центробежного насоса готовящихся к производству на предприятии «CRIS» SRL и созданию предвключённого осевого колеса для насосов типа СМР, изготовленных и протестированных на данном предприятии. Также результаты дипломной работы были использованы при выполнении лабораторных работ по предмету «Компьютерное проектирование».

ANNOTATION

in the doctoral thesis with the theme **"Increasing the energy efficiency of centrifugal pumps through fluid flow mathematical modeling and numerical calculation**",
presented by **Petco Andrei** for the conferring of the scientific degree
Doctor of technical sciences,
speciality 242.01. *Theory of Machines, Mechatronics*, Chişinău, 2023

The thesis includes an introduction, four chapters, conclusions and recommendations, references with 113 titles and 7 annexes. The volume is 137 text pages, including 115 figures and 14 tables. The main content of the thesis has been published in 5 scientific papers, including 2 single author papers, 2 papers in peer-reviewed journals and 1 patent.

Keywords: centrifugal pumps, centrifugal pump impeller, fluid flow modeling, turbulence models; cavitation process, CFD simulations, optimization algorithms, testing of centrifugal pumps.

The field of study refers to the constructive-functional optimization of the centrifugal pump's parts with the aim of increasing energy efficiency.

The aim of the work. Increasing the energy efficiency of centrifugal pumps, namely the pump efficiency and the NPSHr by applying CFD simulations of the fluid flow coupled with optimization algorithms.

The scientific novelty and applied value of the work. Obtaining centrifugal pump impellers with enhanced characteristics by applying CFD simulations coupled with optimization algorithms, namely impeller optimization of centrifugal pump (model CH-6,3-20-1,1-2) with increased efficiency, obtaining of the centrifugal waste water pump impeller and creating an inducer for CMP type pumps to reduce pump NPSHr.

The theoretical significance consists in the development of the optimization methodology of centrifugal pump parts based on CFD simulations and optimization algorithms.

The scientific research methodology consists in the creation of optimization methodologies based on numerical calculation models and methods and experimental study aimed at the constructive-functional optimization of the working parts of centrifugal pumps.

Implementation of research results. The developed methodology was applied for the optimization of the centrifugal pump impeller (model CH-6,3-20-1,1-2) and obtaining the centrifugal waste water pump impeller to be produced by the "CRIS" SRL company and the creation of an inducer for CMP type pumps manufactured and tested at the given company. At the same time, the results of the thesis were used in the licentiate studies for laboratory work on the "Computer Aided Design" subject.

PETCO ANDREI

MAJORAREA ENERGOEFICIENȚEI POMPELOR CENTRIFUGE PRIN MODELAREA MATEMATICĂ ȘI CALCULUL NUMERIC AL CURGERII FLUIDULUI

242.01 – TEORIA MAȘINILOR, MECATRONICĂ

Rezumatul tezei de doctor în științe inginerești

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Universitatea Tehnică a Moldovei, Stefan cel Mare, 168, MD2004 Chișinău, Republica Moldova