



ELECTRICALLY DRIVEN ROTARY VOLUMETRIC PUMP EFFICIENCY

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This paper presents the development and experimental validation of a rotary volumetric pump with profiled rotors designed for domestic water supply systems. The proposed solution integrates an electric drive system coupled with frequency control to improve hydraulic and energy performance. A constructive concept, mathematical modeling, and an experimental prototype were developed at the National University of Science and Technology POLITEHNICA of Bucharest. Comparative studies with conventional centrifugal pumps highlight significant improvements in energy efficiency, lower power demand, and the ability to convey viscous fluids or suspensions without performance degradation. Experimental installations equipped with sensors and monitoring instruments confirmed theoretical predictions, demonstrating that integrating electrically driven rotary volumetric pumps can reduce operational energy consumption and increase reliability in civil building services. These results underline the potential contribution of the proposed pump to sustainable energy management in water distribution systems.

1. INTRODUCTION

Rotary volumetric pumps with profiled rotors are key components in water supply installations, offering high efficiency, compact design, and reliable performance in various operational conditions. The internal flow within these pumps is inherently complex, influenced by rotor geometry, blade profiles, and interactions with the casing, which affect both flow uniformity and pressure characteristics. The lifting method, a refinement of the lift line theory originally applied to axial flow pump blades, is widely used in pump rotor design [1–3]. Rotor design based on this method considers airfoil type, maximum airfoil thickness, stagger angle, angle of attack, chord length, camber angle, and airfoil stacking line [4]. Applications of the lifting method to underwater propulsion systems have been reported by Cox et al. [5,6] and domestically by Wang Guoqiang et al. [7,8]. Further advancements address boundary problems under full three-dimensional conditions [9] and develop wake-adapted propeller design suitable for pump jets [10]. Research on pump jet optimization has mostly focused on single-factor effects, but orthogonal optimization methods allow efficient multi-parameter studies [11–19]. These approaches, combined with computational and experimental methods, support the design of rotary volumetric pumps with lower flow irregularity, enhanced mixing capability, and minimized wear, providing both theoretical insights and practical improvements for water supply systems.

From an electro-energetic perspective, modern pumping installations rely on electrically driven systems, where the coupling between pump performance and the electrical drive significantly impacts the overall efficiency of building services.

Recent research on rotary volumetric pumps and related propulsion devices has explored both experimental and computational optimization techniques. In [20], a tetragonal rotor pump based on the Wankel engine was developed, with prototypes showing reduced flow irregularity, enhanced mixing, lower rotor–chamber wear, and compact design. Surrogate-assisted design optimization for centrifugal pumps was reviewed in [21], highlighting low-fidelity models (response surface, kriging, neural networks) for rapid exploration of design spaces, improving efficiency, and reducing development costs. Gerotor pumps were studied in [22] using 3D scanning and analytical algorithms to improve tightness and fluid accumulation by 16%, enhancing

volumetric efficiency. Computational topology optimization combined with finite-element and CFD simulations was applied to centrifugal pump rotors in [23,24], achieving up to 38% improvement in hydraulic efficiency and 35% reduction in vorticity while reducing design time and cost. Sliding vane rotary pumps for micro-ORC units were optimized in [25] with a validated 0D–1D thermo-fluid model, increasing pump efficiency by 25% and ORC unit power by 37%. Positive displacement compressors were optimized using a two-stage Bayesian approach in [26], improving isentropic and volumetric efficiency across varying speeds and pressures. Roots pumps handling gas-liquid mixtures were experimentally investigated in [27], showing increased efficiency with higher gas fractions, while numerical models matched experiments within 7.53%. Finally, high-thrust-efficiency pump jets were optimized via center-of-gravity stacking line design and orthogonal multi-parameter optimization in [28], achieving a 7.23% increase in thrust efficiency and improved flow patterns. Recent papers have also addressed the optimization of electrically driven pumping systems and motor control techniques for energy efficiency [29–33]. These works confirm the growing interest in coupling electromechanical design with intelligent energy management for pumping applications.

Collectively, these studies demonstrate the effectiveness of combining advanced computational methods, experimental validation, and multi-parameter optimization to enhance pump performance, reliability, and efficiency across a range of industrial and propulsion applications. At the same time, the results highlight the importance of connecting hydraulic optimization with electrical energy performance, ensuring that pumping solutions contribute not only to improved fluid transport but also to reduced electricity demand and improved sustainability indicators.

2. PROPOSED TECHNICAL SOLUTION

The rotary volumetric pump with profiled rotors represents an original constructive approach intended for domestic water supply systems in buildings. The pump consists of two specially profiled rotors rotating synchronously inside an oval casing (Figure 1). Their motion is transmitted via a cylindrical gear, while sealing between low- and high-pressure zones is achieved by the geometry of the rotating pistons.

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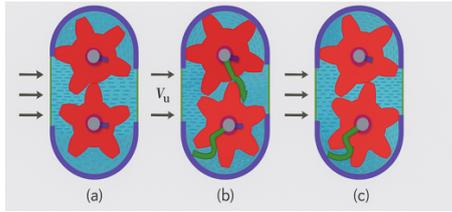


Fig. 1 – Principle of operation of the rotary volumetric machine.

At each complete shaft rotation, a useful volume is displaced, ensuring a constant flow rate and high efficiency.

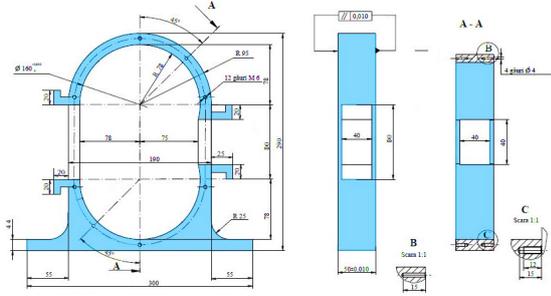


Fig. 2 – Execution drawing of the oval casing.

Compared with centrifugal pumps, the proposed solution eliminates translational motions of moving parts, increases reliability, and enables the pumping of viscous fluids or suspensions.

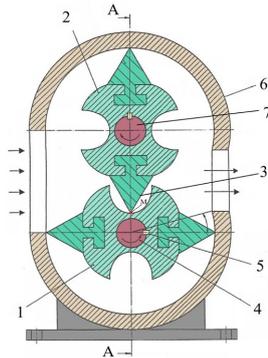


Fig. 3 – Section through the rotary working machine; 1- lower rotor; 2- upper rotor; 3- triangular piston; 4, 7 - shafts; 5 - wedge; 6 - upper casing.

The rotor profile was determined mathematically, with the coordinates of the contour established for accurate manufacturing (Fig. 3). An experimental transparent plexiglass model was built (Fig. 4), which was confirmed by tests that good sealing and stable operation can be achieved.

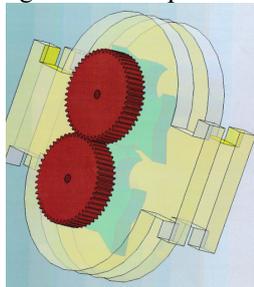


Fig. 4 – Axonometric view of a positive displacement pump model with two profiled rotors

A useful volume is defined as the product of the cross-sectional area (A) and the rotor length (l), measured perpendicular to the plane of the figure; the cross-sectional area is bounded by two consecutive vanes and the lower casing (1).

$$V_u = 2 \cdot A \cdot l \quad [m^3]. \quad (1)$$

During a full 360° rotation of the shaft, two working volumes are conveyed from the suction side to the discharge side (9).

$$\dot{V}_u = 2 \cdot \left(\frac{\pi R_c^2}{2} - \frac{\pi R_r^2}{2} \right) [\text{m}^3/\text{rot}]. \quad (2)$$

$$R_c = R_r + z. \quad (3)$$

This type of pump has the advantage that it can transport to the discharge chamber (2) any viscous fluid or with suspensions that enter the suction chamber (1) or other fluid substances that do not attack the material from which the rotors and casings are constructed [31, 32].

3. COMPARATIVE ANALYSIS

Two constructive variants were investigated:

- Variant I: a domestic cold-water installation equipped with centrifugal pumps.

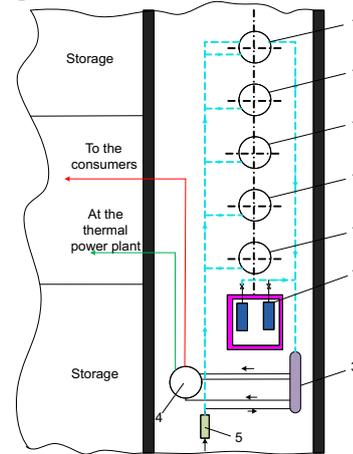


Fig. 5 – Scheme of the cold-water installation (drinking + domestic) and hot water - variant I; 1- polyethylene water tank $V = 500$ l, 2 – pumping group (1F+1R) $H = 60$ mH₂O, $P = 2.2$ kW, 3 – water distributor, 4 – booster tank, $V = 100$ l, 5 – water meter.

The building at Muzeul Zambaccian Street, number 15, sector 1, Bucharest, the building studied in this paper, includes living spaces and a basement. The basement consists of a parking space (16 spaces), a room with household pumps - water and central heating; a living space (with a total capacity to accommodate 45 people). The living space includes 8 apartments located as follows: one two-room apartment, 6 three-room apartments, and one four-room apartment.

Their distribution is: 2 three-room apartments on the ground floor; 2 three-room apartments on the first floor; 1 two-room apartment and two three-room apartments on the third floor; 1 four-room apartment on the third floor + fourth floor.



Fig. 6 – Overview of the building.

- Variant II: the same installation using the proposed rotary volumetric pump with profiled rotors. The solution proposed by the authors consists of a rotary volumetric pump with

profiled rotors (Fig. 1 to 4), developed and tested within the Faculty of Mechanical and Mechatronics Engineering. The pump was coupled to a three-phase motor and instrumented with pressure and flow sensors.

The measurements carried out on the prototype indicated the following operating range: $\dot{V}=5\div 100$ dm³/h, rotational speed: $n = 100 \div 500$ rpm, discharge pressure: $1 \div 2$ bar ($\approx 10 \div 20$ mH₂O).

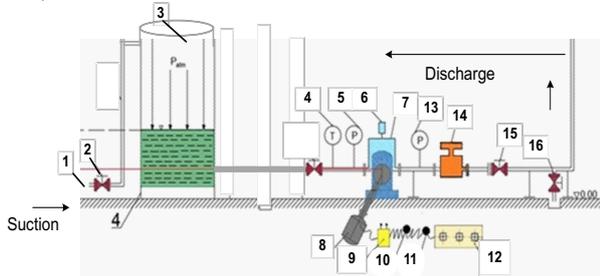


Fig. 7 – Sketch of the pumping installation, in open circuit; 1 – pipe; 2 – tap; 3 – water tank; 4 – thermometer; 5 – pressure gauge; 6 – differential pressure gauge; 7 – rotary displacement pump; 8 – electric motor; 9 – frequency converter; 10 – amperemeter; 11 – multi-meter; 12 – 380 V alternating current source; 13 – pressure gauge at the pump discharge; 14 – electromagnetic flowmeter; 15 – flow regulation valve; 16 – assembly drain valve.

Although the prototype operates at reduced capacity compared to the centrifugal pumps in the studied building, the comparative analysis is relevant for energy efficiency evaluation. Results showed that for the same conveyed flow within its range, the rotary volumetric pump required significantly lower driving power, with reductions exceeding 20% compared to centrifugal pumps of similar size. Figures 6 and 7 present the schematic diagrams of the two variants, while

4. EXPERIMENTAL INSTALLATIONS

To validate the proposed solution, two experimental installations were conceived and built within the Faculty of Mechanical and Mechatronics Engineering, Department of Thermotechnics, Engines, Thermal and Refrigeration Equipment.

The installation with the rotary volumetric pump was instrumented with pressure and flow sensors, enabling monitoring of performance under different regimes. Flow rates measured through the collector were correlated with theoretical predictions.

For the first variant, Fig. 8 and 9 present photographs of the cold-water supply system of the facility at Muzeul Zambaccian Street, number 15, Bucharest.

Figure 8 shows the 6 water tanks, each with a volume of 500 l.

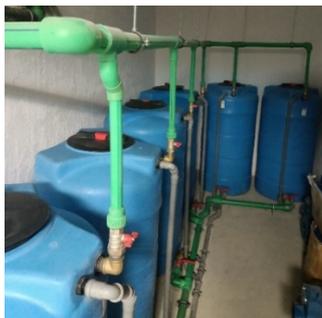


Fig. 8 – Domestic water tanks.

Figure 9 shows the pumping station: one pump in operation, two in reserve; the pumps are centrifugal and can

provide: $\dot{V}=1.38$ dm³/s, $H = 60$ mH₂O, $P = 2.2$ kW. These values ensure the water demand of the building, but at the cost of relatively high electrical consumption.



Fig. 9 – Pumping station.

For the domestic water supply of the building on Muzeul Zambaccian Street, the solution proposed by the authors is a pump with two profiled rotors consisting of 2 separate processed rotors that rotate at the same angular speed because, on the outside of the machine, two gear wheels with the same pitch diameter are engaged.

The experimental research aimed to determine the operating characteristics of the rotary volumetric pump and to compare them with the classical centrifugal pump solution.

The rotary pump with profiled rotors is coupled to a three-phase motor. Figures 8 and 9 show photographs of the real installation of Variant I (storage tanks and centrifugal pumping station).

The comparative analysis demonstrated that:

- Centrifugal pumps of the building installation operate at higher flow rates and heads, but with absorbed power of 2.2 kW per pump.
- The rotary volumetric pump prototype confirmed superior efficiency and lower energy consumption within its tested operating range.
- The constructive design allows pumping of viscous fluids or suspensions without affecting efficiency.

Thus, scaling up the rotary volumetric pump design would enable its application in building water supply systems, with measurable reductions in electricity consumption and increased reliability compared to conventional centrifugal solutions.

5. CONCLUSIONS

The study demonstrated the feasibility of using a rotary volumetric pump with profiled rotors in domestic water supply systems, emphasizing both hydraulic and energy performance. The proposed pump achieved higher efficiency compared to conventional centrifugal pumps, ensuring reliable operation and the ability to handle fluids with suspensions. By integrating the pump with an electrical drive system and frequency converter, significant reductions in energy consumption were observed, confirming its advantages for sustainable building installations. The constructive solution eliminates translational motions of moving parts, reduces wear, and increases reliability, which

are essential aspects for long-term operation.

Experimental installations validated the theoretical assumptions, showing good agreement between predicted and measured performance. The comparative analysis with centrifugal pumps highlighted the potential energy savings and lower operating costs, contributing to improved energy efficiency indicators in civil building services.

Overall, the research underlines the potential of rotary volumetric pumps with profiled rotors to support sustainable energy management, aligning with modern requirements for electrically driven, energy-efficient, and reliable water distribution systems. Future developments may include advanced control strategies and smart monitoring to further enhance integration with energy management systems in buildings and industrial facilities.

Future developments could extend toward the integration of control and optimization strategies like those proposed in recent literature, further improving the energetic performance of electrically driven rotary volumetric pumps.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mihaela Constantin: conceptualization, methodology, experimental design, supervision, writing – original draft.

Cătălina Dobre: theoretical analysis, validation, data curation, writing – review and editing.

Gabriel Fischer-Szava: experimental investigation, data acquisition, visualization, review, and editing.

REFERENCES

1. F. Xie, R. Xuan, G. Sheng, C. Wang, *Flow characteristics of accelerating pump in hydraulic-type wind power generation system under different wind speeds*, International Journal of Advanced Manufacturing Technology, **92**, pp. 189–196 (2017).
2. N. Zhang, X. Liu, B. Gao, X. Wang, B. Xia, *Effects of modifying the blade trailing edge profile on unsteady pressure pulsations and flow structures in a centrifugal pump*, International Journal of Heat and Fluid Flow, **75**, pp. 227–238 (2019).
3. N. Zhang, M. Yang, B. Gao, Z. Li, D. Ni, *Investigation of rotor-stator interaction and flow unsteadiness in a low specific speed centrifugal pump*, Strojniški Vestnik – Journal of Mechanical Engineering, **62**, pp. 21–31 (2016).
4. S. Han, *Optimization design and experimental research of high-power density axial flow pump*, PhD Thesis, Tsinghua University, Beijing, China (2022).
5. G. Cox, *Corrections to the camber of constant pitch propeller*, Transactions of the Royal Institution of Naval Architects, **103**, pp. 227–243 (1961).
6. D. Greeley, *Marine propeller blade tip flows*, PhD Thesis, Department of Mechanical Engineering, MIT, Cambridge, MA, USA (1982).
7. G. Wang, J. Yang, *Estimating propeller cavitation using the lifting surface method*, Journal of Shanghai Jiao Tong University, pp. 9–18 (1993).
8. G. Wang, J. Yang, *Theoretical design method of cavitation propeller lifting surface*, Ship Mechanics, **6**, pp. 11–17 (2002).
9. S. Dong, *Refined treatment of the theoretical boundary value problem of propeller lifting surface*, Ship Mechanics, **8**, pp. 1–15 (2004).
10. T. Tan, Y. Xiong, *Propeller lifting surface design based on B-spline*, Journal of Naval Engineering University, **17**, pp. 37–42 (2005).
11. L. Lu, G. Pan, P.K. Sahoo, *CFD prediction and simulation of a pump jet propulsor*, International Journal of Naval Architecture and Ocean Engineering, **8**, pp. 110–116 (2016).
12. I.M. Călușaru, N. Băran, Al. Păulea, *The influence of the constructive solution of fine bubble generators on the concentration of dissolved oxygen in water*, Advanced Materials Research, **538–541**, pp. 2304–2310 (2012).
13. A.M. Nicolau, *Sustainable perspectives using human beings: the sensory properties of a bio-based material compared to a synthetic material—an overall assessment based on an innovative blind method*, Sustainability, **15**, 9145 (2023).
14. I.M. Călușaru, N. Băran, A. Costache, G.L. Ionescu, O. Donțu, *A new solution to increase the performance of the water oxygenation process*, Revista de Chimie, **64**, pp. 1143–1145 (2013).
15. Al. Păulea, I.M. Călușaru, N. Băran, *Research regarding the measurements of the dissolved concentration in water*, Advanced Materials Research, **550–553**, pp. 3388–3394 (2012).
16. R. Ciobanu, G. Arhip, O. Donțu, C.I. Rizescu, B. Grămescu, *Additive manufacturing meets gear mechanics: understanding abrasive wear evolution in FDM-printed gears*, Polymers, **17**, 1810 (2025).
17. M. Liu, L. Tan, S. Cao, *Design method of controllable blade angle and orthogonal optimization of pressure rise for a multiphase pump*, Energies, **11**, 1048 (2018).
18. J. Yuan, M. Fan, P. Giovanni, R. Lu, Y.J. Li, Y.X. Fu, *Research on orthogonal optimization design of high specific speed axial flow pump*, Vibration and Impact, **37**, pp. 115–121 (2018).
19. Y. Zheng, A. Sun, C. Yang, W. Jiang, *Multi-objective optimization orthogonal test of axial flow pump*, Journal of Agricultural Machinery, **48**, pp. 129–136 (2017).
20. Z. Gui, X. Zhou, Y. Zeng, F. Zhang, Y. Huo, W. Zhang, M. Ma, X. Huang, J. Zhang, *Design and experimental study of a tetragonal rotor pump based on Wankel geometry*, Sensors, **22**, 6608 (2022).
21. M. Hamid Siddique, A. Afzal, A. Samad, *Design optimization of the centrifugal pumps via low fidelity models*, Mathematical Problems in Engineering, 987594 (2018).
22. N. Baroiu, V.G. Teodor, V. Pănuoiu, G.-A. Moroșanu, I.-C. Dumitrescu, *Reverse engineering used to profile a gerotor pump rotor*, Applied Sciences, **13**, 11069 (2023).
23. X.A. Arcentales, D.A. Arcentales, W. Montealegre, *Design of rotors in centrifugal pumps using the topology optimization method and parallel computing in the cloud*, Machines, **13**, 307 (2025).
24. X.A. Bastidas, W. Montealegre-Rubio, *Design of rotors in centrifugal pumps using the topology optimization method*, 14th IEEE International Conference on Industry Applications (INDUSCON), São Paulo, Brazil, pp. 126–133 (2021).
25. F. Fatigati, G. Di Giovine, R. Cipollone, *Model-based optimization of a sliding vane rotary pump for micro-organic Rankine cycle*, Energies, **18**, 1, 97 (2025).
26. K. Lu, T.H. Phung, I.A. Sultan, *On the design of a class of rotary compressors using Bayesian optimization*, Machines, **9**, 219 (2021).
27. K. Qin, Y. Zhang, T. Yan, Q. Guo, K. Luo, *Experimental investigation and numerical validation of a Roots pump's performance operating with gas-liquid mixtures*, Processes, **12**, 1918 (2024).
28. X. Zhang, Z. Dai, D. Yang, H. Fan, *Investigation on optimization design of high-thrust-efficiency pump jet based on orthogonal method*, Energies, **17**, 3551 (2024).
29. K. Venugopalan, J. Varghese, J. Thankaswamy, *African vulture optimized integrated control technique for PV-fed open-end winding induction motor pump application*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, 1, pp. 27–32 (2024).
30. M.I. Abdelwanis, A.A. Zaky, *Maximum power point tracking in a perovskite solar pumping system with a six-phase induction motor*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, 1, pp. 15–20 (2024).
31. E. El-Sherif, E. Ahmed, *A novel design of a photovoltaic system based on a linear induction motor and reciprocating pump*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **70**, 1, pp. 45–52 (2025).
32. A. Bălan, M. Enache, *Study of the automated pumping station with its drive*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **70**, 2, pp. 111–118 (2025).
33. M. Hamza, A. Waheed, *Progressive step maximum power tracker for photovoltaic systems feeding induction motor drives*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, 1, pp. 21–26 (2024).
34. A.G. Roza, A. Almaslamani, E. Tănase, N. Băran, M. Constantin, *Determining the energy performance of a rotating machine for fluid flow*, E3S Web of Conferences, **112**, 01005 (2019).
35. A. Almaslamani, M. Constantin, N. Băran, M. Stoican, *Experimental study of the performance and prediction of cavitation phenomenon for a variable speed centrifugal pump*, Journal of Science and Arts, **50**, pp. 225–240 (2020).