RESULTS OF THE STUDY OF A TURBOGENERATOR WITH A PERIPHERAL-SIDE CHANNEL IN NON-DIMENSIONAL AND CRITERIAL COMPLEXES

SERGEJ VANEEV [1], VASYL MARTSYNKOVSKYY [2], MICHAL HATALA [4], DMYTRO MIROSHNICHENKO [3], YAROSLAV BILYK [2], DMYTRO SMOLENKO [1], ANDREY LAZARENKO [1], FRANTISEK BOTKO [4*]

[1] Sumy State University, Sumy, Ukraine;
[2] TRIZ Ltd., Sumy, Ukraine;
[3] TOV NVP ARMA-T Ltd., Sumy, Ukraine;
[4] Technical university of Kosice, Faculty of Manufacturing Technologies, Presov, Slovakia

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e-mail to corresponding author: frantisek.botko@tuke.sk

Dimensionless and criterial complexes are successfully used in many technical fields. They play an important role in research and design. There are a large number of dimensionless and criterial complexes, which have their advantages and are chosen depending on the topic and specific objectives of the study. The article considers dimensionless and criterial complexes most often used in studies of turbomachines, in particular vortex expansion machines - relative internal (isoentropic) efficiency, degree of pressure drop, adjusted wheel speed, speed coefficient, adjusted diameter, flow factor and coefficient. The authors processed the data of the experimental study of the turbogenerator with a peripheral-side channel and presented them in the form of graphical dependences using these complexes. The improvement of these energy-saving turbogenerators is important because they are used to generate electricity from excess gas pressure, are considered environmentally friendly and are needed for the development of distributed energy. Vortex expansion machines with a peripheral-lateral channel are also poorly understood, so the topic is relevant. In this study, their area of use was determined and reflected in the ns - Ds diagram among radial and other vortex expansion turbomachines to facilitate their comparison and design.

KEYWORDS

energy-saving turbogenerator, vortex turbine, criterial complexes, dimensionless quantities, processing of experimental test data.

1 INTRODUCTION

The use of dimensionless complexes in research is not only convenient but also a necessary step for the organization of effective research activities. They are complexes of dimensional quantities composed in such a way that they do not have their own dimension. Therefore, on the one hand, these complexes do not depend on the choice of a system of units of measurement, which is useful for the unification of the obtained data, since the problem presented in dimensionless form corresponds to a large number of dimensional problems. On the other hand, these complexes allow to reduce the total number of parameters that characterize the task for describing and predicting complex processes of technical systems in a simplified form, which speeds up and simplifies the design of new machines.

2 LITERATURE REVIEW

In various fields of research [Fesenko 2018], preference is given to the use of different dimensionless and criterial complexes to reflect the specificity of the topic more accurately [Timar 2005, Keep 2019, Albusaidi 2012, Mason-Jones 2012, Chelabi 2022]. In the theory and practice of turbomachines, in particular vortex expansion turbomachines [Merzliakov 2020], the following complexes are most often used: relative internal (isoentropic) efficiency η, degree of pressure drop π_T, adjusted circular velocity, speed coefficient (adjusted speed) ns, adjusted diameter Ds complex power factor N̅_comp.
The given circular speed, speed factor and flow factor are used as similarity criteria for calculations, modeling and comparison of different types of expansion machines.
A system of criterial complexes "adjusted speed - adjusted diameter" (ns - Ds) has been widespread in turbomachinery for a long time [Balje 1962]. This diagram is still successfully used to evaluate the efficiency of different expansion machines and their selection [Francesconi 2019] and is supplemented for less studied types of machines. The article [Francesconi 2019] is devoted to the consideration of the Wrankel turbine within the ns - Ds system, and in [Miroshnichenko 2019] the diagram of the area of use of vortex expansion machines with a peripheral channel is plotted on this diagram.
The article [Vaneev 2021] is devoted to the study of a vortex expansion machine with a peripheral-lateral channel. It shows the graphical dependence of the turbine efficiency on the adjusted wheel speed of the impeller (Fig. 1), which is used to characterize the turnover and load of the machine, as it combines parameters reflecting the physical properties of the working fluid and gas flow at the turbine inlet and outlet. The magnitude and frequency of rotation of the turbine shaft:

$$\overline{U} = \frac{U}{C_S} = \frac{\pi \cdot D \cdot n}{60 \cdot C_S}, \quad (1)$$

where D is the outer diameter of the impeller, m;
n is the speed of the impeller, rpm;
U is the circular speed of the impeller on the outer diameter, m / s;
C_S is the isoentropic gas flow rate, which characterizes the available specific work of the expansion machine, m / s.

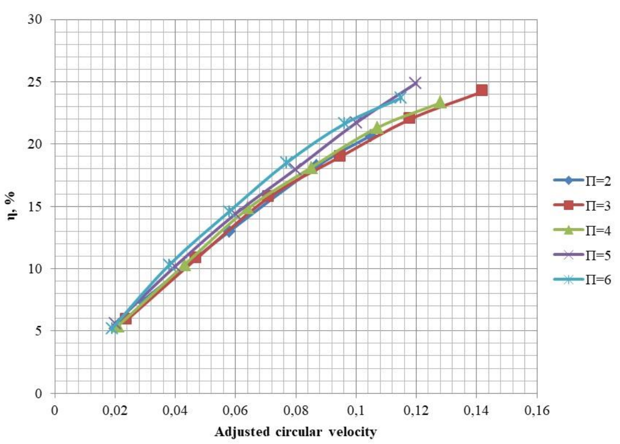

Figure 1. Dependence of turbine efficiency on the adjusted circular speed

3 RESEARCH METHODOLOGY

Given the advantages of using dimensionless and criterial complexes, the results of the experimental study of a turbogenerator based on a two-channel four-flow vortex expansion machine with a peripheral side channel (Fig. 2) [Vaneev 2021] were processed using the above criteria.

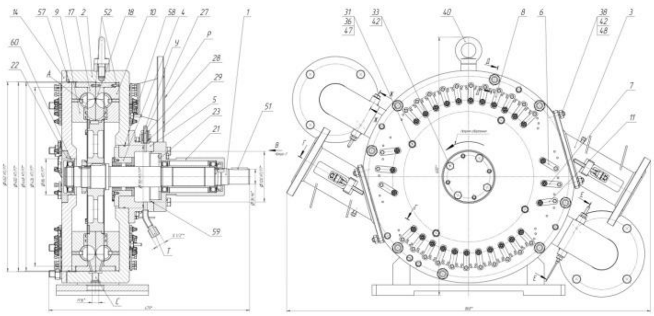

Figure 2. Turbine design

The relative internal (isoentropic) efficiency determines the efficiency of the expansion turbomachine. This efficiency considers hydraulic (gas-dynamic) energy losses in the flowing part of the machine, associated with friction on the surface of the flowing part of the machine, vortexing, shock flow around the blades, friction losses of the outer surfaces of the impeller on the gas and losses associated with flow gas in the flowing part through the gaps, etc. In vortex expansion turbomachines, it also considers the losses associated with the organization of the vortex working process and the losses caused by the transfer of gas from the outlet to the inlet of the stage in the interscapular channels of the impeller [Vaneev 2000]:

$$\eta = \frac{N_T}{G \cdot h_S} = \frac{N_T}{N_S}, \quad (2)$$

where N_T is the power on the expansion turbomachine shaft, kW;
N_S is the available power, k;
G – mass flow rate of gas in the expansion turbomachine, kg/s;
hs is the specific isoentropic difference of enthalpies, J / kg:

$$h_s = \frac{k}{k-1} \cdot R \cdot T_1^* \cdot \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right], \quad (3)$$

where k is the specific gas constant;
R is specific gas constant, J / (kg · K);
p_1, T_1 is the pressure and temperature at the entrance to the expansion turbomachine;
p_2 is the pressure at the outlet of the expansion turbomachine.
The efficiency of the vortex machine is determined in [Vaneev 2021] taking into account the mechanical losses in the turbine and the electric generator, including losses on the fan, i.e. practically - this is the efficiency of the turbogenerator.
A common dimensionless parameter for expansion machines is the degree of pressure drop. It is intuitive, easy to calculate and shows the magnitude of the pressure drop applied by the machine:

$$\pi_T = \frac{p_1}{p_2}, \quad (4)$$

Where p1 is the pressure at the inlet to the turbine, Pa;
p2 is the pressure at the outlet of the turbine, Pa.

The flow factor F2 (relative flow) is used to describe the performance parameters of vortex expansion machines. It combines the flow of the working fluid with the wheel speed and the outer diameter of the turbine impeller:

$$F_2 = \frac{V}{U \cdot D^2}, \quad (5)$$

where V is the volumetric gas flow at the outlet of the expansion turbomachine, m3 / s.
The criteria of the given speed ns and the given diameter Ds are used to describe the dependence of the wheel speed and the diameter of the impeller of the machine, the unit volume flow that passed through it and the unit difference of enthalpies used.
The adjusted speed (speed) is determined by the formula:

$$n_s = \frac{n \cdot \sqrt{V}}{h_s^{3/4}}. \quad (6)$$

The adjusted diameter for turbomachines is defined by the formula:

$$D_s = \frac{D_{ave} \cdot h_s^{1/4}}{\sqrt{V}}, \quad (7)$$

where D_{ave} is the average diameter of the turbine impeller disc coating (for vortex turbine D_{ave} = D).
To assess the efficiency of the expansion machine and its main parameters at the initial stage of design, the complex power factor is used, due to the fact that this complex is formed from the values specified in the initial calculation data:

$$\bar{N}_{comp} = \frac{N_T}{P_0^* \cdot \sqrt{T_0^*}} \cdot \left(\frac{n}{\sqrt{T_0^*}}\right)^2, \quad (8)$$

where - $\bar{N}_{comp}$ is the complex power factor, kW, $\frac{kW}{Pa \cdot \sqrt{K}} \cdot \left(\frac{rpm}{\sqrt{K}}\right)^2$;
P_0^* is the total pressure at the inlet to the expansion turbomachine, Pa;
T_0^* is the total temperature at the inlet to the expansion turbomachine, K.

4 RESULTS AND DISCUSSION

As a result of processing the study data of the turbogenerator with a peripheral-side channel, graphs of efficiency dependences on the main dimensionless and criterial complexes were constructed.
The dependence of the efficiency of the studied turbine on the degree of pressure drop at different adjusted circular velocities is shown in Fig. 3. At a constant degree of pressure drop, the efficiency of the turbine can increase 5 times with increasing adjusted speed. At constant adjusted circular velocity, the efficiency slowly increases in the range of 3% with increasing π_T in almost the entire considered range.

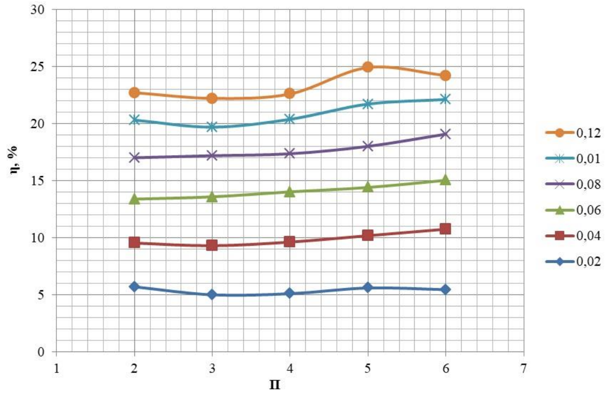

Figure 3. Dependence of efficiency on the degree of pressure drop in the turbine

As the coefficient of complex power increases, the efficiency of the turbine increases (Fig. 4). In the range π_T= 2… 4 the degree of pressure drop significantly affects the dependence of efficiency on the complex power factor, with a further increase in the degree of pressure drop, this effect is negligible.

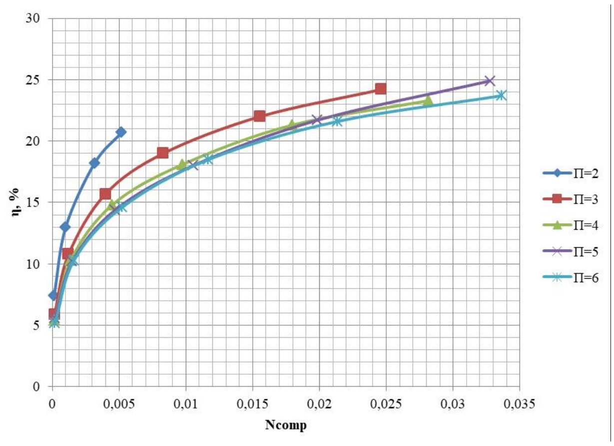

Figure 4. Dependence of turbine efficiency on complex power factor

As a result of the study, it was found that a decrease in the flow rate significantly increases the efficiency of the turbine (Fig. 5), ie vortex turbines with a peripheral side channel are low-flow turbines.

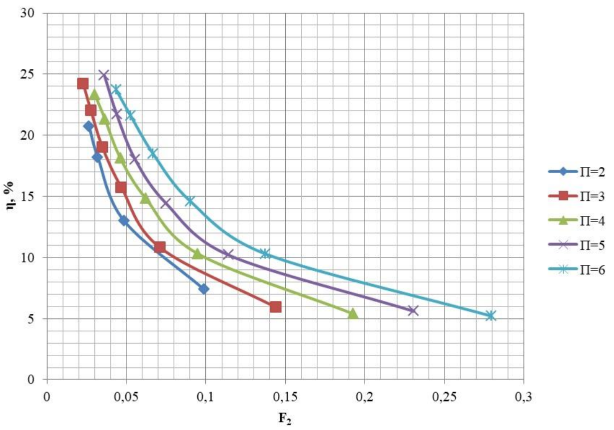

Figure 5. Dependence of efficiency on the flow factor

Graphical representation of the dependence of efficiency on the adjusted speed (Fig. 6) is almost a direct proportionality. The efficiency increases with increasing adjusted speed over the entire range studied, and the maximum difference in efficiency values for one value of ns is less than 3%.

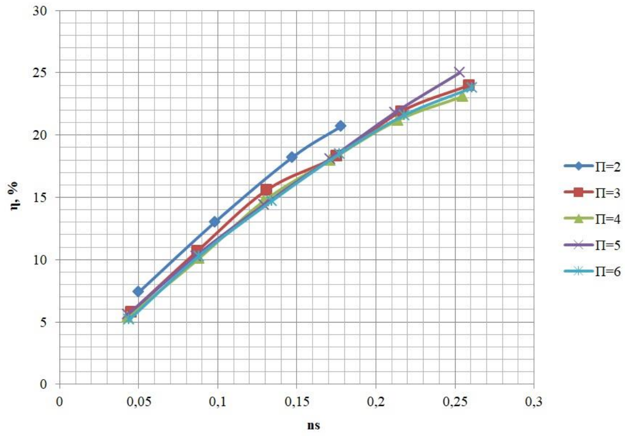

Figure 6. Dependence of efficiency on the adjusted speed

From the obtained results it is seen that the efficiency of the turbine increases significantly with increasing value of its adjusted diameter (Fig. 7). From the obtained data it is seen that with an increase in Ds by 0.2 efficiency increases by an average of 8%.

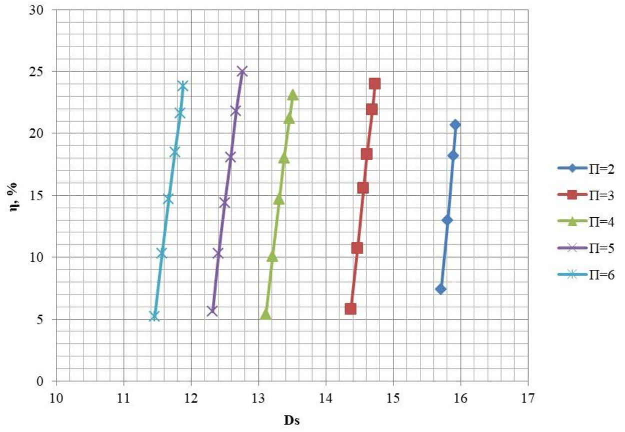

Figure 7. Dependence of efficiency on the adjusted diameter of the turbine

The graphical dependence of the adjusted diameter Ds on the adjusted speed ns is shown in Fig. 8. Smaller values of the degree of pressure drop provide larger values of the adjusted diameter of the turbine. The lines on the graph have almost the same slope, above them are the efficiency values corresponding to the experimental points. With an increase in ns 5 times Ds increases by an average of 1,035 times.

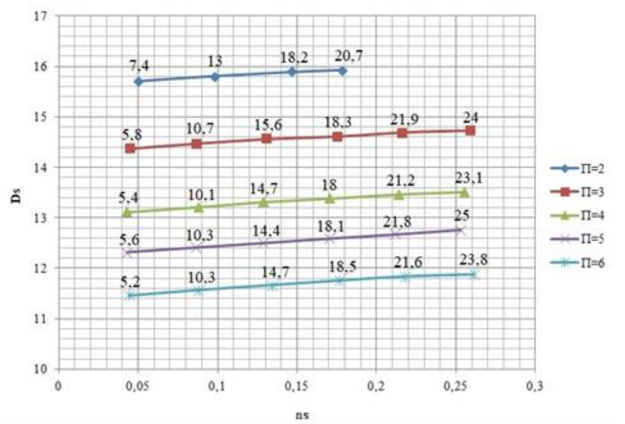

Figure 8. Dependence of the adjusted speed on the adjusted diameter of the turbine

Areas of rational use of vortex expansion machines are currently being supplemented due to the variability of flow parts and their relatively low level of research. The field of results of this experiment in the range of efficiency 15 - 25% was plotted on the existing ns - Ds diagram (Fig. 9), which is widely used in the theory and practice of turbomachinery [Miroshnichenko 2019]. Peripheral-side vortex turbines have lower speeds and are located to the left and above the area of radial expansion machines, but lower than the results available in the diagram for vortex turbines with an external peripheral channel.

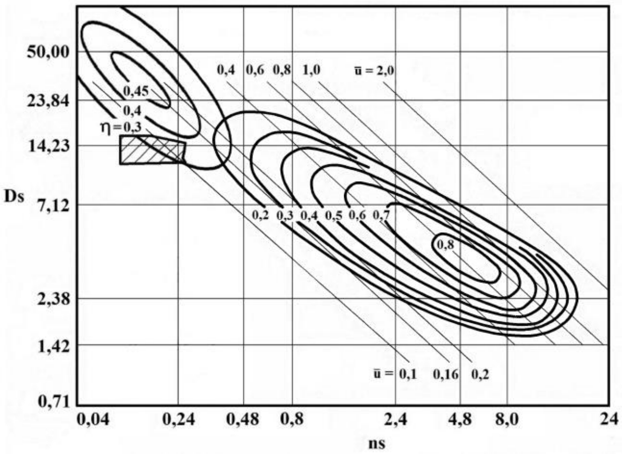

Figure 9. Scope of use of turbines with a peripheral-lateral channel on ns, Ds - the diagram among radial and other vortex expanding turbomachines

5 CONCLUSIONS

1. The data of experimental tests of the vortex expansion machine with the peripheral-lateral channel on the research stand and their representation in dimensionless complexes are processed. These complexes are generally accepted in the theory and practice of turbo machines.
2. Based on the obtained results, graphical dependences of turbine efficiency on the degree of pressure drop π_T, complex power coefficient $\bar{N}_{comp}$, flow factor F2, adjusted speed ns, adjusted diameter Ds, graph of dependence of adjusted speed ns on adjusted diameter were constructed. It was found that the efficiency of the turbine increases with a decrease in the flow rate and with an increase in the adjusted wheel speed, the coefficient of complex power, of the adjusted speed of the rotor, the adjusted diameter.
3. The field of experimental results in the efficiency range 15 - 25% is plotted on the existing ns - Ds diagram to facilitate the comparison of vortex turbines with a peripheral side channel with other types of turbines and simplify their design in the future. It was established that the area of rational application for vortex turbines with a peripheral-side channel in this diagram is located near the similar area of vortex turbines with an external peripheral channel (slightly below) and to the left and above the area of radial expansion machines.

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CONTACTS:

Dr. Sergej Vaneev, Ph.D.

Sumy State University, Department of Technical Thermophysics

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2, Rymskogo-Korsakova St., Sumy, 40007, Ukraine
s.vaneev@kttf.sumdu.edu.ua
+380 (542) 33-57-85

Vasyl Martsynkovskyy, Ph.D.
TRIZ Ltd
1, Mashynobudivnykiv St., Sumy, 40020, Ukraine
triz@triz-ltd.com
+38 (0542) 786-800

Prof. Ing. Michal Hatala, PhD.
Technical university of Kosice, Faculty of Manufacturing Technologies
Bayerova 1, 080 01 Presov
michal.hatala@tuke.sk
+421 55 602 6456

Dmytro Miroshnichenko, Ph.D.
TOV NVP ARMA-T Ltd.
1, Rymskogo-Korsakova St., Sumy, 40007, Ukraine
116mirdv@gmail.com
+38 (0542) 332345

Yaroslav Bilyk
TRIZ Ltd
1, Mashynobudivnykiv St., Sumy, 40020, Ukraine
triz@triz-ltd.com
+38 (0542) 700-075

Dmytro Smolenko
Sumy State University, Department of Technical Thermophysics
2, Rymskogo-Korsakova St., Sumy, 40007, Ukraine
d.smolenko@kttf.sumdu.edu.ua
+380 (542) 33-57-85

Andrey Lazarenko
Sumy State University, Department of Technical Thermophysics
2, Rymskogo-Korsakova St., Sumy, 40007, Ukraine
lazarenko.a@triz-ltd.com
+380 (542) 33-57-85

Ing. Frantisek Botko, PhD.
Technical university of Kosice, Faculty of Manufacturing Technologies
Bayerova 1, 080 01 Presov
frantisek.botko@tuke.sk
+421 55 602 6453