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Review of doctoral dissertation
by Mohammadsadegh Pahlavanzadeh, MSc Eng
entitled: "Assessment of the possibility of improving the momentum transfer in the flow between rotating discs"

1 . Basis for the review and general information

The basis for the review is a letter from the Chair of the Discipline Council for Environmental Engineering, Mining and Power Engineering at the Silesian University of Technology, Prof. Krzysztof Labus, PhD, dated 3 October 2025, informing me of my appointment as reviewer of the doctoral dissertation of Mr Mohammadsadegh Pahlavanzadeh, MSc Eng.

The doctoral dissertation entitled "Assessment of the possibility of improving the momentum transfer in the flow between rotating discs" was written by Mr Mohammadsadegh Pahlavanzadeh, MSc, under the supervision of Prof. Włodzimierz Wróblewski, PhD, Eng., and assistant supervisor Krzysztof Rusin, PhD, Eng.

2. Relevance of the dissertation topic

The search for and development of new design solutions for expansion machines is one of the most important areas of research in the field of modern energy and machine construction. This applies in particular to machines intended for use in small and medium-power energy systems, which may be used in the future in distributed and prosumer energy systems based on alternative energy sources. The Tesla turbine is an example of an expansion machine whose design is not yet fully understood and scientifically described, and its practical application is mainly limited to prototype machines. Currently, these turbines are the subject of development, laboratory and model research, and the research work being carried out concerns the development and improvement of the design in order to improve the operating characteristics of the machine and to increase its power and efficiency. Considering the design, operating principle, performance characteristics and nature of the thermal flow phenomena occurring in Tesla turbines, it should be emphasised that these issues are complex from a scientific point of view. The choice of the doctoral dissertation topic can therefore be considered appropriate. Its implementation allows the doctoral student to demonstrate their knowledge and independence in the field of mathematical and numerical modelling of thermal flow phenomena occurring in power machines.

3. Characteristics of the dissertation

The doctoral dissertation submitted for evaluation combines a collection of five thematically related publications, of which the doctoral student is a co-author, with additional research results concerning flow analyses of Tesla turbines that use low-boiling working fluids in ORC systems. The content of the dissertation constitutes a guide detailing the doctoral student's achievements in specific areas of research, the results of which have been published in scientific articles included in the collection of publications. These articles have been published in the following journals: *International Journal of Numerical Methods for Heat & Fluid Flow*, *Energies*, *International Journal of Heat and Mass Transfer*, and *Physics of Fluids*. These journals have an Impact Factor and are included in the list of the Ministry of Science and Higher Education.

The collection of publications includes the following articles:

1. Pahlavanzadeh, M., Rusin, K., Wróblewski, W., (2023). "Evaluation of dynamic correction of turbulence wall boundary conditions to simulate roughness effect in minichannel with rotating walls". *International Journal of Numerical Methods for Heat & Fluid Flow*. https://doi.org/10.1108/HFF-03-2023-0160.
2. Pahlavanzadeh, M., Rulik, K., Wroblewski, W., Rusin, K., (2024). "Application of roughness models to stationary and rotating minichannel flows". *International Journal of Numerical Methods for Heat & Fluid Flow*. https://do1.org/10.1108/HFF-05-2024-0379.
3. Pahlavanzadeh, M., Wróblewski, W., Rusin, K., (2024). "On the Flow in the Gap between Co-rotating Disks of Tesla Turbine with Different Supply Configurations: A Numerical Study". *Energies*. https://doi.org/10.3390/EN17174472.
4. Pahlavanzadeh, M., Wróblewski, W., Rusin, K., (2025). "Evaluation of nozzle configuration impact on flow structures and performance in Tesla turbine". *International Journal of Heat and Mass Transfer*. https://doi.org/10.1016/J.IJHEATMASSTRANSFER.2025.126900.
5. Pahlavanzadeh, M., Rusin, K., Wroblewski, W., Rulik, S., (2025). "Roughness effects on flow in Tesla turbine with parametric adjustment of porous layer model". *Physics of Fluids*. https://doi.org/10.1063/5.0247548/3329214

The dissertation is presented on 70 pages, divided into a table of contents, a list of publications included in the collection which forms the basis of the dissertation (with a descriptive indication and percentage of the author's contribution to individual publications), an abstract, a list of symbols, 5 chapters, a summary and conclusions, a list of references and appendices (in the form of the content of the 5 articles which constitute the basis of the doctoral dissertation).

In Chapter 1, entitled *Introduction*, the doctoral student discusses the motivation that encouraged him to undertake the research topic addressed in the dissertation. He also presents a detailed literature review of experimental research, CFD modelling of flow phenomena and numerical modelling of the surface roughness of Tesla turbine discs conducted by other researchers. In the summary of Chapter 1, the doctoral student points to the following main scientific problems that he wants to find answers to through his research:

1. What numerical approach provides the most accurate simulation of flow between rotating discs with a gap width similar to that used in the Tesla turbine, taking into account turbulence models, numerical grid quality and surface roughness?
2. What is the effect of reducing the size of the gap between rotating discs on the characteristics and formation of the flow?
3. How does surface roughness affect the shear stress on the disc walls and the flow characteristics in the channel and in the gap between the rotating discs?
4. Which method of modelling surface roughness best corresponds to the experimental results and those obtained from a review of the literature?
5. How does the direction of the working medium flow using a nozzle affect the flow characteristics between the rotating discs compared to the case without inlet nozzles?
6. How do the number of inlet nozzles used and their configuration affect the aerodynamics, efficiency and power output of the Tesla turbine?
7. What is the effect of the interaction of the inlet nozzles with the disc edges and the wall layer on the flow characteristics and stability in the gaps between the rotor discs?
8. How well do k-ω turbulence models in SST and LES perform in predicting the flow characteristics and efficiency of Tesla turbines?
9. How can the influence of actual surface roughness be more accurately represented in CFD simulations, particularly in the context of modelling of Tesla turbines?

10. How does the surface roughness of the discs affect the performance of a Tesla turbine operating with selected working fluids used in ORC systems?

Chapter 2: *Investigation of flow characteristics in a minichannel with stationary and rotating walls - Papers I and II* discusses the results of research conducted by the doctoral student and published in publications No. 1 and No. 2 on improving the modelling process of the impact of the roughness of flow surfaces constituting the walls of narrow flow gaps, which correspond to the flow conditions in the gaps between the surfaces of Tesla turbine discs. The author discussed the most important parameters influencing the phenomena, which are: gap size and domain narrowing, height and shape of roughness, nature of the flow (laminar and turbulent), shear stress at the walls, vortex viscosity, the influence of disc rotation on the interaction of wall layers, momentum diffusion and turbulent kinetic energy distribution.

The author then presented and discussed the mathematical model used for numerical calculations and the modelling results obtained with the use of Ansys Fluent software. The modelling was carried out for two cases: flow with zero pressure gradient over a rough plate and flow between rotating discs.

The most important result of the conducted research was the confirmation of the possibility of using the *k-ω SST* turbulence model in combination with the Aupoix roughness method, which proved to be suitable for conducting flow simulations in both stationary and rotating mini-channels. The use of the model reduces the calculation time while maintaining sufficient accuracy. Importantly, the results of the research showed that the rough elements that were used narrow the cross-section of the flow, which leads to discrepancies between the experimental results and theoretical predictions, and that the height of the surface roughness plays an important role in the behaviour of the boundary layer. It was demonstrated that increasing the surface roughness led to an improvement in the efficiency of the machine.

Chapter 3, entitled: *Investigation of flow characteristics between corotating disks of Tesla turbine - Papers III and IV*, discusses the results of the work presented by the doctoral student in publications No. 3 and No. 4. The subject of the research was the analysis of momentum and kinetic energy flow in a narrow gap between rotating discs, with particular emphasis on the complex flow behaviour resulting from the rotational movement of the discs and the occurring turbulence. Comparative studies of two turbulence models were discussed: the *k-ω SST* model and LES which uses the Smagorinsky SGS model. The way in which each model reflects the essential features of the flow was evaluated.

Furthermore, the results of studies analysing various inlet nozzle configurations were discussed, comparing the configuration in which a single nozzle feeds a single gap between the discs with variants in which a single nozzle feeds multiple gaps. The research was conducted for two inlet system configurations: one consisting of six nozzles and one consisting of forty nozzles. The research determined the impact of the number of nozzles on, among other things, turbine efficiency and the distribution of shear stresses on the disc walls. The most important conclusions from the analysis were that the *k-ω SST* model provides a sufficiently accurate representation of flow parameters with significantly shorter calculation times, while the LES model is more accurate, especially in areas near the outer edge of the discs, where vortices are generated. An important observation was that the number and configuration of the inlet nozzles used significantly affects the flow characteristics and performance of the machine. The use of a larger number of nozzles leads to an increase in the mass flow rate and power output of the machine, but at the same time leads to flow disturbances and a reduction in machine efficiency compared to the case where a smaller number of nozzles are used.

Chapter 4, entitled: *Simulation of roughness using Porous Medium Layer (PML) - Paper V*, presents the results of research on the simulation of disc surface roughness using a porous medium layer, which were published in publication no. 5. The aim of the research conducted in this area was to propose an original method of modelling the roughness of turbine discs, based on the introduction of a porous medium layer on the modelled disc surface and the comparison of the obtained modelling results with the results obtained using the "sand grain" model, which is standard in this case. The validation of the proposed porous medium model was discussed based on experimental data obtained during an experiment involving pressure drop measurements during flow through mini-channels, followed by numerical simulations for 7 different cases of smooth and rough surfaces using *k-ω SST* and LES turbulence models. The most important result of the analysis was the development and validation of the porous layer model and the proof that the method can accurately reflect the actual geometry of a rough surface, which reduces the calculation time while maintaining adequate accuracy. The results of simulations carried out for different rotational speeds and cases with and without a rough layer indicate that the introduction of a rough layer leads to an increase in machine efficiency.

Chapter 5, entitled: *Roughness modelling by Porous Medium Layer model in Tesla turbine working on ORC fluids*, presents the scope and results of research conducted on modelling the impact of the roughness of Tesla turbine discs on flow phenomena occurring in the gaps between the discs for working fluids used in ORC systems. The research was conducted for two low-boiling working fluids: R1234yf and n-hexane. As an introduction to the chapter and background to the issue of the use of Tesla turbines in ORC systems, a brief literature review is presented, followed by a discussion of the mathematical model used and the procedure for its validation based on the results of experimental research conducted on a test stand in the form of a mini flow channel. Then, the procedures and results of numerical tests were discussed, including the simulation of Tesla turbine operation, taking into account the roughness of the disc surfaces and various turbine operating conditions and working fluids. The most important result of the analysis was to demonstrate that the proposed roughness model is suitable for modelling real gas flows over a wide range of operating parameters and that the application of roughness to the surface of the discs can significantly improve the efficiency of the Tesla turbine.

The last part of the dissertation is a summary and list of the most important conclusions and a bibliography of 85 items.

4. Evaluation and comments on the substantive content of the dissertation

The doctoral dissertation submitted for evaluation concerns the scientifically and practically important issue of the development of Tesla turbine designs, which may in the future find practical application in low-power energy systems intended for the use of alternative energy sources, such as ORC systems. The dissertation presents a comprehensive simulation analysis of the impact of the design configuration of the turbine flow system and various operating and working conditions on its performance. The analysis covers the impact of both different configurations of the gas inlet nozzles to the turbine and the roughness of the turbine working discs.

The research topic undertaken by the doctoral student is a complex problem combining thermodynamic and flow issues with surface shape engineering.

The doctoral student developed numerical models of the Tesla turbine flow system and used them to perform numerical simulations of turbine operation in Ansys Fluent software for various design parameters and variable operating conditions of the machine. He compared two turbulence models in the simulations: the *k-ω SST* model and the LES model. He demonstrated that the *k-ω SST* model can be used to model flow phenomena in Tesla turbines while maintaining adequate accuracy and computational efficiency. He also showed that, compared to the *k-ω SST* model, the LES model offers better accuracy, especially near the outer edges of the disc, which makes it useful for high-accuracy simulations. In his simulations, the doctoral student also compared different roughness models and pointed out that models of standard roughness do not reflect the influence of actual roughness geometry on flow conditions with sufficient accuracy. He proposed the use of an original PML model validated on the basis of experimental data, which proved to be a suitable tool for modelling surface roughness. The results of the numerical simulations carried out by the PhD student clearly showed that the introduction of roughness on the surface of the turbine discs leads to improved flow conditions and increased turbine power and efficiency. In his simulations, the doctoral student also analysed the impact of turbine design parameters and operating factors on the performance and operating parameters of the machine. He pointed out that increasing the number of inlet nozzles can lead to an increase in turbine output power, but can also lead to a decrease in its efficiency, and that the type of operating factor used has a significant impact on its performance. He published the results of his work in five articles in which, according to the declaration of authorship included in the guide, he made a majority contribution.

When assessing the achievements of Mr Mohammadsadegh Pahlavanzadeh, MSc. Eng., it should be noted that the tasks presented as the objectives of the doctoral dissertation required the doctoral student to demonstrate scientific independence and to possess and skilfully apply advanced knowledge in the fields of fluid mechanics, thermodynamics, mathematics and computer techniques for numerical modelling of thermal flow processes. The content of the dissertation clearly shows that the doctoral student has demonstrated the ability to select appropriate methods for conducting his research. These methods included the use of advanced mathematical and numerical models, numerical simulations and experimental research, and the interpretation of their results.

Analysing the content of the dissertation in terms of its substance, it should be concluded that the objectives of the doctoral dissertation set by the doctoral student in Chapter 1 have been fully achieved and the answers to the research questions posed have been obtained.

The doctoral student reviewed the literature in the field of issues related to the design and modelling of Tesla turbines, demonstrating his ability to use global literature resources. In his dissertation, he referred to 85 literature sources, many of which are articles recently published in peer-reviewed journals with an impact factor (IF). His knowledge of the literature allowed him to accurately define the research questions, direction, scope and programme of the work that is the subject of his doctoral dissertation.

Having analysed the doctoral dissertation, I conclude that the doctoral student has demonstrated his ability to formulate a research problem, find appropriate tools to solve it, perform numerical simulations of the problem and draw conclusions from them.

The most important achievements of the doctoral student in the field of engineering and technical sciences in the discipline of environmental engineering, mining and energy should be considered to be:

1. Conducting numerical simulations of the Tesla turbine using *k-ω SST* turbulence models and the LES model, and comparing the results obtained,
2. Demonstrating that the introduction of roughness on the surface of the turbine discs leads to improved flow conditions and increased turbine power and efficiency.
3. Development of an original PML model and demonstration that it is a suitable tool for modelling the roughness of Tesla turbine blades,
4. Assessment of the impact of the turbine inlet system configuration on machine performance by modifying the number of inlet nozzles.

The substantive part of the dissertation is a model analysis and has been developed to a high standard.

While reading the dissertation, I had the following observations and questions, which I would like the PhD student to clarify:
1. In the doctoral student's opinion, what should be the design features of Tesla turbines used for the expansion of working fluids in the form of technical gases and low-boiling fluids?
2. Based on the results obtained by the doctoral student, is it possible to formulate a method for designing Tesla turbines dedicated to a specific application (e.g. in an ORC system or a steam system)?
3. Why were variants with 6 and 40 nozzles selected for the analysis of the impact of the number of inlet nozzles to the turbine?
4. In the PhD student's opinion, what roughness parameters should be used in Tesla turbine discs designed to work with working fluids in the form of technical gases and what parameters should be used in the case of low-boiling fluids?

5. Specific comments on the editorial aspects of the work

The doctoral dissertation has been carefully prepared and meets the editorial requirements customary for doctoral dissertations. The author uses correct technical terminology. The illustrative material in the form of drawings has been prepared in a legible manner and raises no objections.

6. Summary

An analysis of the doctoral dissertation submitted for evaluation by Mr Mohammadsadegh Pahlavanzadeh, MSc. Eng., indicates that this work constitutes an original solution to a complex scientific problem. The doctoral student has demonstrated that he possesses and skilfully applies theoretical knowledge in the fields of fluid mechanics, thermodynamics, mathematics and computer techniques for numerical modelling of thermal flow processes. The doctoral student demonstrates the ability to conduct independent scientific research. He is able to analyse and use scientific data available in the literature, formulate analytical and numerical models of the machine, and use them to model its operation, then discuss and interpret the results obtained and, on their basis, formulate conclusions and disseminate the results of his work in publications. The doctoral student has achieved valuable results that may contribute to the continuation of research.

In summary, I conclude that the doctoral dissertation of Mr Mohammadsadegh Pahlavanzadeh, MSc, meets the requirements for doctoral theses and fulfils the conditions specified in the Act of 20 July 2018 on Higher Education and Science - Journal of Laws of 2023, item 742, as amended. On this basis, I request the Discipline Council for Environmental Engineering, Mining and Power Engineering at the Silesian University of Technology to accept the doctoral dissertation of Mr Mohammadsadegh Pahlavanzadeh, MSc, Eng., and to admit him to the public defence.

Furthermore, bearing in mind the high research standards and original approach to solving complex scientific issues, I request that the Discipline Council award the dissertation with a distinction.

[signature] Piotr Kolasiński