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Gdańsk, 24.06.2021

Review of the doctoral dissertation by Krzysztof Rusin, M.Sc. Eng. as commissioned by Chairman of the Discipline Council of Environmental Engineering, Mining and Power Engineering of the Silesian University of Technology (letter RIE-BD/3/305/2020/2021 from 17.05.2021)

1. Introduction

The dissertation submitted by Krzysztof Rusin, MSc., Eng., entitled „Numerical and experimental study for the selection of Tesla turbine geometry" was elaborated at the Faculty of Environmental and Power Engineering Machines of the Silesian University of Technology under the supervision of Prof. Włodzimierz Wróblewski, PhD., DSc. The dissertation is 127 pages long, contains a table of contents, acknowledgements, a list of symbols, 6 chapters, a list of references (123 items), a list of figures, as well as a summary in Polish and English. Part of investigations was financed by the Polish National Centre for Science under project „The enhancement of momentum transfer efficiency in the flow between rotating discs".

2. Characteristics and evaluation of the dissertation

Tesla turbine is a type of expander that can be used in low power cogeneration systems. It is characterized by an exceptional simplicity of construction and ease of manufacturing. Unlike in bladed turbines where the torque is generated mainly by fluid pressure forces, in a Tesla turbine the torque is generated by the action of viscous forces. Tesla turbine is not a very widespread expansion device due to its rather low flow efficiencies achieved. Particularly great potential for improving the flow efficiency in a Tesla turbine lies in the disc-to-disc area itself, in the inlet and outlet areas, and in the area of a technological gap. Optimization of the Tesla turbine flow system and accompanying heat and flow investigations are therefore a desirable research direction.

The dissertation is concerned with investigation of a variety of Tesla turbine models in pursuit of finding optimum geometric as well as operating heat and flow parameters. In Chapter 1, the author explains the principles of Tesla turbine operation and presents a literature review of experimental, theoretical and numerical works in the field of Tesla turbines. Such works are still relatively rare and deserve to be continued. Form this literature review the main goal of the dissertation emerges, which is:

- determination of selected geometric features of the Tesla turbine to improve its efficiency.

This ambitious goal is achieved through:

- experimental, theoretical and numerical investigations of a commercially available small Tesla turbine model, focusing mainly on flow phenomena taking place there,
- elaboration, manufacturing and investigation of a new full-scale Tesla turbine model,
- numerical optimization of the efficiency of the above model and its validation.

The amount of work involved is considerable showing a complex approach to the task.

Chapter 2 is devoted to mathematical modeling of flow in the tesla turbine. The Author concentrates first on CFD models (RANS, choice of turbulence models k-ω SST, k-ε RNG, SAS, intermittency model, choice of wall treatment and modeling surface roughness, treatment of stationary/moving elements). Then, a few analytical models of Tesla turbine flow available in the literature are presented. They differ in assumptions concerning fluid, flow and boundary conditions, the most advanced models of Sengupta, Guha 2013, Talluri et al. 2018 providing complete pressure and velocity profiles in the turbine as well as yielding turbine power and efficiency. The author freely and successfully uses the mathematical and computational apparatus for numerical fluid mechanics. This reviewer did not find any major flaws in the presentation of the models, although a few improvements could be made in future presentations and publications.

On page 21, lines 6-8, the sentence does not seem precise. The Reynolds stress tensor is not the only term in compressible RANS to be modelled – terms describing turbulent heat flux, turbulent and molecular diffusion need also to be modelled, see eq. 2.6. There is a typo in the pressure term in Eq. 2.10. Perhaps the mass force term is needed in Eq. 2.10 to be consistent with Eq. 2.5. On the other hand CFD calculations are carried out in the stationary zone, so no body forces due to rotation appear in equations.

The k-ω SST model is characteristic of a blending function changing between k-ω and k-ε and also characteristic by redefinition of the eddy viscosity to assure a proportional relationship between the principal turbulent stress and turbulent kinetic energy.

Chapter 3 is devoted to investigation of a commercially available small Tesla turbine model with a single nozzle supply. This model was mounted at the air experimental facility and instrumented for pressure, rotational velocity and electric power measurements.

A numerical model was built and performance of different turbulent models was investigated. It was found that only calculations with y^+ below 2 can give plausible results. Only the SAS model was found capable of resolving the unsteady jet structure within the disc-to-disc space by virtue of its LES-like properties in the unsteady flow area. On the other hand, the k-ω SST model being less demanding in terms of computational costs yielded power values similar to those of SAS in the investigated range of pressure ratio and rotational speed, so k-ω SST was selected as a turbulence model for further investigations.

It was found that the free-slip condition in the outlet area was necessary to eliminate excessive recirculation in this area, and probably problems with convergence. However, I feel more insight is due to reveal the effect of free-slip condition on the results of calculations.

Figs. 3.23-24 illustrate the comparison of CFD computed and measured power and efficiency characteristics for a range of rotational speed and pressure drop. In CFD the power is computed from the torque. In measurements the electric power is measured, while the bearings efficiency as well as the generator efficiency are also estimated. The electric efficiency of the generator was approximated with a second order polynomial with respect to rotational speed and power. However, it is not explained if mechanical and electric losses are subtracted from the CFD calculated power to compare with the measured values in figs. 3.23-3.24. Are they? I did not find the answer although there is a section on explaining differences between the calculated and measured values.

On page 49, point 6, there is a comment on difficulties in modeling body force / turbulence interaction. For the computation of a Tesla turbine the situation seems quite different than in bladed turbines. Flow is calculated in the stationary domain, only disc walls are rotating, so in fact there are no body forces due to rotation in the equations and the problem is generally reduced to high curvature / turbulence interaction. True, not taking into account both problems in the eddy viscosity models may lead to erroneous prediction of eddy viscosity.

Table 3.3 illustrates the distribution of generated power between the disc-to-disc gaps. The effect of surface roughness in gathered in Table 3.4. The table provides also values of the so-called jet power. How this jet power is defined and separated from the field?

The comparison of CFD and theoretical distributions of pressure and circumferential velocity in the Tesla turbine is shown in Fig. 3.34. An important difference in the velocity is at the inlet part, most possibly due to supersonic expansion in the jet modelled by CFD and at the lower part due to action of viscosity.

On page 56, also on other pages there is a comment that „...rotor was working as a compressor...". This formulation is farfetched. In fact quite a considerable part of the rotor disc may not yield work, and may possibly consume work, as a result of windage in stagnant fluid outside the expansion jet and entrainment zone. On page 50, the expression „a relatively high inter-disc gap" could read better as „a relatively wide disc-to-disc gap".

A new Tesla turbine model was investigated in Chapter 4. The model consists of two inlet nozzles, plenum chamber, four-point supply, five-disc rotor and five-point axial outlet. The rotor is mounted on the shaft with a generator. The design point of this Tesla turbine was found with the help of gas dynamics relations. The model was investigated experimentally, theoretically and numerically. Numerical investigations started with mesh independence studies and choice of turbulence model between the k-ω SST and k-ω SST with intermittency. It was found from the latter model that only a limited area was characterized by fully turbulent flow, so the latter model was used for further investigations to avoid excessive eddy viscosity in flow. By the way, the distribution in Fig. 4.23 is in disc-to-disc direction or axial direction, as the normal direction sounds ambiguous (most probably understood as normal to the main turbine direction - turbine axis).

The presented results show the comparison of CFD computed and measured power, mass flow and efficiency characteristics for a range of rotational speed and pressure drop. The highest flow efficiencies found from CFD amounted to above 10%. The measured powers and efficiencies (this time recalculated from the measured torque, which enables a direct comparison with the CFD values) were lower, the measured efficiency just above 8%. The measured-to-computed power or efficiency difference seems to be similar along the characteristics within a wide range of rotational speed and mass flow rate.

Tables 4.1 - 4.2 gather the distribution of power between the subsequent disc-to-disc gaps. In the next part, the effect of disc-to-disc gap width on the Tesla turbine power and efficiency is evaluated. The trend illustrated shows that the power and efficiency increase with the increasing gap width within 0.3 to 1.2 mm. With further increasing the gap width this trend could be reversed and it would be informative to show at which gap width this trend is really reversed.

The comparison of pressure and circumferential velocity in radial direction between CFD and analytical models shows generally similar results (with some exceptions) in all methods. Fluid particles experience from below one to above two revolutions within the disc-to-disc space depending on the pressure ratio and rotational speed.

Chapter 5 is devoted to optimization of the Tesla turbine performance while assuming the isentropic efficiency as an objective function. The optimization was performed with the help of the Response Surface Method and Design of Experiment Technique available in Ansys Software. Among independent geometric parameters were disc radius, tip clearance, disc-to-disc gap width and inlet nozzle parameters. Among independent flow variables were inlet and outlet pressure, inlet temperature and rotational velocity. One disc-to-disc gap was calculated. Optimization was carried out using a meta-model based on the Kriging method.

The obtained results are presented in the form of dependence of tangential velocity ratio and efficiency on the aspect ratio, nozzle angle, partial admission coefficient, dynamic similarity number, load coefficient. The highest obtained efficiency exceeded 34% for a single disc-to-disc gap.

My remark concerns the used nomenclature. The parameter ε is called the partial admission coefficient, which may be misleading when recalling the bladed turbine supply. This parameter assumes very low values and changes within a very narrow range of variation, so possibly the jet supply coefficient could read better there.

The full numerical model built based on the optimum geometry of the single disc-to-disc gap – the five-disc model I think as in Chapter 4 (no explicit information on the full model elements in Chapter 5) yielded the efficiency of 17%. This model was experimentally validated. The obtained measured efficiency was found at 13.8% (electric or recalculated from the measured torque?).

An important part of dissertation is Chapter 6 where major scientific discoveries described in previous chapters are summarized. This chapter concludes with prospects for future work and development of Tesla turbine technology. Directional roughness, micro-channels and application of fluids with nano-particles are conceived as a means to intensify the momentum transfer from the fluid to the Tesla turbine rotor.

The whole PhD. dissertation of Krzysztof Rusin, MSc, Eng. is edited very carefully, well written in correct English, using the correct scientific and technical terminology. The results of calculations are properly illustrated. The description of figures does not raise any objections. In extensive dissertations one can find a number of typos, inaccuracies, and clunky wording. There are very few of them in the reviewed work and they can be eliminated by careful proof-reading. I suggest the list of symbols be expanded as not all symbols are explained in the list. Quite important symbols such as n, N, AR, D_s , ε (as a partial admission coefficient questioned before) and other are missing there.

3. Final conclusion.

The submitted doctoral dissertation has a high scientific value. The high evaluation of the dissertation is not undermined by the critical and debatable remarks formulated in the review. The author himself solved a complex problem, using a number of scientific methodologies extending on experimental, theoretical and numerical investigations. He presented a great deal of knowledge in the field of fluid mechanics, rotating machinery and theory of optimization. He also showed that he has the ability to reliably present and interpret the results of his work.

In conclusion, I state that the doctoral dissertation of Krzysztof Rusin, MSc. Eng. meets the requirements set out in the Act on Academic Degrees and Scientific Title and I submit an application for admission of his dissertation to public defense. Due to the complexity of investigations carried out, their high scientific value confirmed by a number of publications in renowned journals such as Web of Science journals, including Energy, International Journal of Numerical Methods for Heat and Fluid Flow, Journal of Theoretical and Applied Mechanics, Journal of Mechanical Science and Technology, the dissertation of Krzysztof Rusin, M.Sc. Eng. qualifies for the award provided that the public defense is successful.