UNIVERSITÀ DEGLI STUDI FIRENZE
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

PhD. Thesis Evaluation Report

Name of the Ph.D Scholar : **Krzysztof Rusin**

School: **Silesian University of Technology Gliwice (PL)**

Title of the thesis: **Numerical and experimental study for the selection of Tesla turbine geometry**

Recommendations

Tick one of the following:

1. The thesis in its present form is commended for the award of the PhD. degree [ ]

2. The thesis is commended for the award of the PhD degree. However, my suggestions for improving the thesis should be considered in the final version before the discussions. The revised thesis need not be sent to me(*) [X]

3. The thesis should be revised as per the suggestions enclosed. I would like to see the revised thesis incorporating my suggestions before I give further recommendations. [ ]

4. The thesis is not acceptable for the award of the **PhD** degree [ ]

(*) *I think that the thesis is at the level of point 2, so don't need to be re-reviewed on my side. Nevertheless, the Scholar should consider the notes addressed in the review report.*

(Signature) Name: Daniele Fiaschi

Prof. Daniele Fiaschi
Dipartimento di Ingegneria Industriale - Centro Didattico Morgagni, Viale G. Morgagni, 40/44 – 50125 Firenze
Tel +39 055 4796776 | e-mail: daniele.fiaschi@unifi.it posta certificata: daniele.fiaschi@pec.unifi.it
P.IVA | Cod. Fis. 01279680480

UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIPARTIMENTO
DI INGEGNERIA
INDUSTRIALE

Name of the Ph.D Scholar:	**Krzysztof Rusin**
Department:	**Silesian University of Technology Gliwice (PL)**
Title of the Thesis:	**Numerical and experimental study for the selection of Tesla turbine geometry**

DETAILED REPORT

The PhD thesis deals with the detailed design and optimization of Tesla turbines to harvest low grade flows available from different possible industrial processes and utilities.
The introduction on the working principles and the possible applications is followed by a rather comprehensive literature review on the Tesla turbine technologies, simulations, experimental data, advantages and critical aspects, addressing the main issues and the expected/measured performance.
Then, the manuscript gets inside the core of its aim, i.e. design issues and optimization of Tesla turbine. At the beginning, an introduction and a rather complete literature review about the flow modelling with governing equations, turbulence and roughness/viscosity effects. Then, 5 models proposed in the last 50 years were summarized, addressing their main features.
Remarks: the placement of the Tesla turbine on the classic Balje diagram should be added, to make the reader easily aware of the turbomachinery feature. It would provide a quick categorization (turbomachinery approach).

The comments below is a full list of remarks I made when reading the PhD thesis. This means that the comments are different. Moreover, small technical/grammar comments have been included.

1) The **Abstract** is well written and is very informative. However, it should be put at the beginning of the thesis.
2) **Nomenclature**: Some improvements are needed because some quantities have incorrect names and some symbols are used more than once.
3) **Chapter 1** (*Introduction*): Well organized, however, in the motivation section, the Author should better address how the present work contributes to fulfilling the lack of literature info on modeling and experimental data on the design and operation of Tesla turbines.
4) **Chapter 2** (*Numerical modelling*): well written and adequately acknowledged the main 5 references from 1967 to 2018, as well as turbulence models, injcluding roughness. The Author should better address (shortly summarizing, even with the help of a schematic picture) which parts of the cited models has used in the present analysis.
5) **Chapter 3** *Preliminary Investigations*:
    a. Object of Investigation – A table on Pg. 31 should be added resuming all parameters described in the text, to improve the description of the turbine geometry.
    b. Pg. 33 an apex is required.
    c. Discretization – power could also be calculated through the variation of enthalpy. If not possible for experimental data to calculate it, on the other hand, a check of numerical calculations is required. Furthermore, you can confirm which of the other 2 methods is the one to be properly utilized.

UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIPARTIMENTO
DI INGEGNERIA
INDUSTRIALE

d. - **Modelling turbulence at rotor inlet**: is the specific power (e.g. W/m^2) referred to the actual fluid–disk contact surface or the overall disk surface? Power per unit area is the highest for SAS, which, on the other hand, better catches non – homogeneity of flow and a larger amount of vorticity compared to k-ε and SST. You address this larger vorticity as responsible for disturbances in the zone between the jet and the tip clearance and so of reduced performance due to negative velocity and compressor effect. So, going back to the initial point, the power per unit area is a loss, not a performance measure. It is power "eaten" by the vorticity, larger when modelled with the more accurate SAS: is this the sense of the chapter? Please improve it by trying to better explain this aspect. Fig. 3.22: is the comparison with experimental data, once modelled with k-ε and then with SST? Or was the assumed SAS model a reference for results? How does this compare with experimental results? SAS is claimed as the most accurate, but the related increase in computational time is not worth the accuracy improvement level: is that all based on comparison with experimental data or theoretical simulations? In the former case, how does the uncertainty compare to the differences found between the three turbulence models?

e. **Results of investigations** - First of all, the author should point out how the CFD points were achieved: is mass averaged values of CFD analysis in the relevant sections where the performance data are calculated? Wouldn't have it been worth a simplified 2D model (validated against experiments with an acceptable degree of uncertainty) to build up the machine's curves? Such a 2D model could become the basic design tool for the Tesla turbine, to be refined by CFD and experiments.

f. Why was it chosen to represent different rotational speeds between experimental and CFD results? Why only the 15000-30000 rpm range was selected? (Pg. 47).

g. "It can be said that all power characteristics were relatively flat", this sentence is not completely true. (Pg. 47)

h. There are some relevant assumptions done due to lacks in the experimental setup, e.g.: (I) missing mass flowrate measurement; (II) machine's manufacturing precision, (III) assuming always chocked nozzle, and (IV) data in the experiment recorded manually: how is the uncertainty level of the experimental data? It should be reported on the graphs. In this light, holding back to the turbulence modelling, how does it significantly rely on experimental data at such a presumably low level of reliability? Please discuss this aspect.

i. Please explain better the 7^{th} point a Pg. 49 (The applied numerical model failed to predict tangential shock waves at high rotational speeds). Does it mean that it predicts it well at low rotational speed?

j. How far would considering air humidity have influenced computational time? Connected to that somehow, if as you mention Temperature drops down to 175 K level, was in the experiments noticed the presence of icing in the nozzle and/or (at least) formation of liquid droplets? Where did you measure the temperature on the Tesla?

k. The blockage effects of tip edges at the clearance and disk friction were also reported and experimentally validated in a model on Talluri et al. *Applied Thermal Engineering* *174* *(2020) 115293*: despite working with an organic fluid, a comparison of the effects would be worth it. It should agree with what you call the enthalpy method for calculating efficiency. In this framework, do you think the stress method for the evaluation of efficiency is physically consistent?

l. The comparison of the results with those of Model 1 (Talluri et al.) is also affected by the different working fluids (e.g. real HFO and air): it should affect the results quite significantly. How can you address this aspect?
m. Please change the notation to Power. N is not an international standard. Replace it with W, for example.
n. Pg. 58. Fig. 3.34, The behaviour of models 1 and 2 of tangential velocity is very strange. Probably the correct value of velocity or mass flow rate was not chosen? Maybe a sensitivity analysis for different inlet conditions should be carried out.

6) **Chapter 4** *Investigations of the new turbine model*:
   a. Why ellipsoidal outlets were assumed? Why did you choose this configuration of the turbine outlet? Which advantages does it carry compared to the configuration proposed by Talluri et al., 2018?
   b. In Fig. 4.14 it is possible to note that Gap 0 is bigger than the "power gaps", why this choice?
   c. Fig 4.18, please provide a legend for temperature and pressure probes.
   d. Pg. 72, The accuracy of the pressure transducers, as well as of the thermocouples is not reported. Please add it. Furthermore, how this influenced the experimental results?
   e. End of Pg. 72, "n=9 400-9 600 rpm" not clear form. Furthermore, there are 2 spaces between 3 and 000rpm.
   f. Why did you perform the mesh independence study for pressure ratio 2 and rotational speed = 20000 rpm? (Pg. 74).
   g. Results of Investigations – A graph representing the behaviour and performance of the Tesla turbine as a function of tangential velocity ratio could be useful (Pg. 78, last paragraph).
   h. Table 4.2. The power distribution for each gap should be better explained.
   i. Temperature analysis – Why is it not possible to calculate total temperature if you know the velocity and static temperature?
   j. Pg. 83 "the flow field in the rotor what can be considered" should be changed in "the flow field in the rotor which can be considered"
   k. Fig. 4.39, which are the inlet conditions utilized for assessing the numerical models? Pressure? The direction of velocity?
   l. Pg. 91 Point missing at line 3.

7) **Chapter 5** *Optimization*:
   a. Pg. 92. Why is mass flow rate considered the most critical parameter for the performance of the Tesla turbine? Probably the velocity is more critical?
   b. Numerical Set-up- Why did you perform the simulation with the complete domain and not use a half domain to decrease computational time, as the domain is periodic?
   c. Why did you select the central channel, when it was demonstrated that the highest inefficiency is derived by the lateral channels?
   d. Can you justify this sentence: "It was assumed that the reduction of the domain did not entail a need for the new independence study"?

UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIPARTIMENTO
DI INGEGNERIA
INDUSTRIALE

e. Results of optimization- Why did you select 10-21° when, as testified by literature, the flow entering the rotor should be as much tangential as possible?
f. Pg. 102. Change obtained with obtain and there is a missing word (fluid?) in the second paragraph.

8) **Chapter 6** *Conclusions* are well organized.
9) **References**, please verify the format of the references.

On the whole, the manuscript is well organized. However, the main novelties against currently available literature info should be better addressed: among these, it may be an interesting reference to afford the full design of a Tesla turbine for small and micropower output. The whole analysis and design are addressed (correctly) to optimize the turbine efficiency. But, as the expander should work on a powerplant fed by low grade resources, a few considerations related to a design addressed towards maximization of the power output in order to reduce the kWh cost should be added.

Bottom Line
Generally, I find it a ***very good*** job at the Ph.D. degree level, especially for its relevant engineering aspects. I consider it of such quality that it makes a significant contribution to the advancement of knowledge in this field. Anyhow, the above reported issues and questions should be clarified and/or fixed in the final version of the thesis, in order to improve its quality.
Re – review is not required.

Name of Examiner:
Prof. Daniele Fiaschi;

July 16, 2021