ŽILINSKÁ UNIVERZITA V ŽILINE
Strojnícka fakulta
Katedra energetickej techniky

PhD Thesis Review and Evaluation Report

Reviewer:	prof.Ing. Radovan Nosek, PhD.
PhD Student Name:	MSc. Bartlomiej Rutczyk
Supervisor:	***prof. dr hab. inz. Ireneusz Szczygiel.***
Title:	Experimental and mathematical investigation into the heat-transfer processes within the heat exchangers of an α type Stirling engine
University:	Silesian University of Technology, Gliwice

A. topicality of the chosen topic

Stirling engines have a major advantage over other comparative processes in that the combustion here occurs in an external combustion engine. Stirling engines provide many advantages over other technologies, for example, different types of fuel can be used and very low emissions can be produced. Therefore, investigation and improvement of Stirling engine can provide environmental and economic benefits in the world.

The submitted PhD thesis is **topical and deserves considerable attention**.

B. Aims

The PhD thesis deals with investigation of heat transfer coefficients formulas influencing the accuracy of simplified mathematical modelling of Stirling engine. The author improved and did the validation of different heat transfer correlations within zero-dimensional mathematical model.

The objectives of the research work were categorized as follows:

- To review the Stirling engine mathematical models.
- To develop the zero-dimensional mathematical model.
- To validate mathematical model and perform the pre-experimental tests.
- To build the experimental setup and carry out the experimental measurements.
- To validate the mathematical model and make the fine-tuning of correlations.

Conclusion to the Point B

I declare that Mr. Bartlomiej Rutczyk fulfilled the objectives of his PhD thesis.

C. Selected processing methods and solution procedure

The presented PhD thesis is categorized into six Chapters. The first Chapter describes the history of Stirling engine and the state of the art. Chapter 2 concerns of the Stirling engine modelling and describes the first version of the author's mathematical model. In the next Chapter is written about the construction of the experimental stand. Chapters 4 and 5 describe the validation of the developed mathematical model and the adjustment process of the selected heat transfer correlations. In the last Chapter are summarized the results and conclusions. The author created the mathematical model by employing the assumptions and methods previously coined by other researchers. The novelty in this work is assumption of using a real gas as the working fluid. The mathematical model was validated before employment by comparison to CFD data, and experimental data obtained for the Cleanergy Stirling engine.

Conclusion to the Point C

In the submitted study were selected methods and procedure to improve the mathematical model by implementing a more complex model with focus on heat transfer formulas. I consider that Mr. Bartlomiej Rutczyk applied correct approach and process to solve this problem.

D. Evaluation of the results obtained by the dissertation

The author created and validated a mathematical model of Stirling cycle engines. The creation and investigation of mathematical model was focused how the quality of heat transfer coefficients formulas influences the accuracy of zero-dimensional mathematical. After validation, the mathematical model was improved by implementing a more complex regenerator model. The results show that small gains in regenerator effectiveness with the high value range have a huge influence on engine efficiency. The advantage of the mathematical model is that can provide the ability to test many variants in a relatively short time. Based on the mathematical models results it is clear that the heat capacity of the material has small effect on regenerator performance for commonly used materials. On the other hand, the porosity of the material has a huge effect due to affecting both the heat transfer area, convective heat transfer coefficients and the solid mass of the regenerator. The experimental verification was done in regard to the heat transfer correlation validity. The results show that the correlations of Kanzaka and Iwabuchi, Annand and Pinfold and Toda lead to the most accurate results.

Conclusion to the Point D

In this work, the author used the mathematical and numerical calculations that represents a significant contribution to optimization of Stirling engine efficiency.

E. Significance for practice or for the development of a scientific discipline

As the outputs of this PhD thesis, the issues and current approach to the development of zero-dimensional mathematical model. The PhD thesis highlighted the possibilities to increase the engine efficiency by gaining in regenerator effectiveness. The effectiveness of the regenerator shows itself to be higher at lower engine speeds. The results showed, that the heat capacity of the material has a minor effect on regenerator performance within the range of heat capacities of commonly used materials.

Conclusion to the Point E

The research work can be of great help to the Stirling engine engineering applications due to the highlights of possibilities to increase the engine efficiency, improvement the quality of heat transfer coefficients formulas and ability of modelling many variants in a relatively short time.

F. Publication Activity

I appreciate the fact that the PhD student has publications in high impact factor journals and articles published in indexed WOS and Scopus databases. The total amount of publications is nine.

G. Formal adjustment of the dissertation and language level

The submitted PhD thesis is processed on a very good professional and aesthetic level. The structure of the work is elaborated appropriately and the chapters have a logical continuity. The content of the thesis is balanced: the theoretical part and literature review take the minor part comparing to the essential part of work. There are several grammatical errors that do not influence the overall quality of PhD thesis.

H. Comments on the dissertation

The comments below are list of remarks I made during the reading of PhD thesis. Moreover, small technical and grammar comments have been included. There are also questions addressed to the author.

- Page 11. There is double the word “and” in the following sentence “The first alpha type engine, that is the same type as the subject of this work, without a displacer but

with separate compression and expansion pistons was manufactured by Rider in 1875, which is also interesting due to the presence of a regenerator made from a bank of flat plates, and and the elongation of cylinders and pistons to increase the heat surface area."

- Page 17 and 20.: The author should not use the abbreviation "don't".
- Page 41 and 42. There is a mistake in the numbering of references: [30, 30] (or [28, 28], because there is different numbering between printed and electronic version). Author should also chronologically organize the references.
- Page 75. The author compares the results of the polytropic and adiabatic models, in the text. In fig. 2.19 and 2.20 it is not clear which results are for the polytropic model.
- Page 134. The author should not use the evaluation of results as follow: "small influence" "small gain" "tremendous influence". Numbers or percentages should be given for better understanding.

Questions:

- Page 56. Fig. 2.4: Why is the mass flow in negative numbers?
- Page 73. Tab. 2.3: What does it mean the abbreviation "ZP"?
- The natural gas (NG) can be used as a fuel for Stirling engine and the current research deals with blending of hydrogen to NG. What can be the influence of hydrogen-enriched natural gas on power of the Stirling engine?
- Page 93. Fig.4.1.: Why the value of indicated power for the Genoa ML3000 starts from -150 W?
- Page 93. Fig.4.1.: Why is the maximal power around 300W? (The power of Genoa ML300 is up to 3 kW)

Final evaluation

The PhD thesis is interesting, has a scientific soundness and I appreciate that Mr. Bartlomiej Rutczyk put a lot effort to do such excellent work. I consider the submitted work to be of very high quality and I recommend to defend it and

I recommend giving doctoral degree "doctor" - Ph.D.

In Žilina

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