

## Jury Member Report – Doctor of Philosophy thesis.


**Name of Candidate:** Dmitry Smirnov

**PhD Program:** Engineering systems

**Title of Thesis:** Innovative technological pathway for new commercial applications of Stirling cycle-based systems

**Supervisor:** Assistant prof. Henni Ouerdane

**Name of the Reviewer:** Lorenzo Ferrari

<p>I confirm the absence of any conflict of interest</p> <p>(Alternatively, Reviewer can formulate a possible conflict)</p>	<p><b>Signature:</b></p>  <p><b>Date: 30-09-2019</b></p>
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*The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.*

*If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.*

### Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

The thesis investigates new criteria for the design of an energy conversion technology from a general point of view by approaching all the stages of the design process: from the concept development to the commercial ramp-up. As an example, the methods and the processes were applied to the development of a Stirling machine. The topic is of interest as it is quite unusual to face the design process from a holistic point of view as in the way proposed by the candidate. The topic itself of a Stirling machine has some innovation. Even though these machines have a long history of testing, their design has still some elements that need to be investigated and optimized.

The methods proposed by the candidate are multiple and differ according to the step of the development process. At the concept level, the author proposes an extensive review of the literature and the patents related to Stirling machines. This analysis allows the identification of several interesting aspects related to Stirling system design (engines and refrigerators) according to the geographical region, year of development and type of development (research or commercial). At the system level, an elaboration of data on Stirling machines allowed the tradespace exploration and the detection of the main relations between design choices and economic impacts. As for the design stage, the game theory was applied by considering two different design units for the mechanical and thermal aspects. Interesting solutions with different power/affordability twins were identified. At the testing and refining stage, the author showed the impact of a detailed investigation on the piston-cylinder sealing, which led to an improvement of tested system performance. As for the production ramp-up, the candidate developed a dedicated model based on the experimental results of the thermal chamber of a tested Stirling machine that provided a step forward in the existing literature.

The dissertation has several innovative contents, both from the methods proposed and some of the technical results achieved. In this respect, to increase the impact of his study, this reviewer would encourage the candidate to stress more the technical aspects related to his work. Only a few details to the developed in-house machine are reported in the last chapters of the dissertation. The design of a Stirling machine is an interesting topic from the research point of view as many technical issues still hamper their performance. In this sense, the contribution of Chapter V and VI is relevant. Probably a full description of the developed device and its details would deserve a standalone chapter. This would also avoid the repetition of Stirling machine scheme and data as for pictures in page 159 and 180.

The tradespace analysis brings several interesting results that would be worth investigating in more detail. At page 80, figure 20, only the power vs cost map is reported. It would be interesting to have similar graphs that are related to other technical characteristics of the machine, such as borehole diameters, typical stroke lengths, efficiencies, etc., and provide a comment on that. The candidate reports a reference to one of his published studies, but some additional consideration in the text would increase the comprehension of the complexity of the study.

Regarding the game theory application, which is one of the main innovative approaches proposed by the candidate, this reviewer would encourage to provide further details on the models adopted to estimate the machine performance and heat exchanger dimensions and costs. For the performance estimation, a reference is proposed in the dissertation to an author's publication (page 101), but a brief description would help the reader to have a better comprehension of the study. It would be also interesting to have further details on cost and heat transfer function estimations (only a reference is provided also for these). In addition, it would be of interest to comment on the technical solutions that were identified as optimal in the Case 2 not only in terms of P and A but also in terms of other technical parameters as borehole diameters, stroke values, temperatures, etc.

In summary, as stated in the review, the thesis deal with the design of an energy conversion technology (with specific reference to a Stirling machine) from several points of view, from the conceptual design to the economic ramp-up. Several of the proposed approaches and some of the specific technical results are innovative and relevant for the engineering community. The thesis is well written and organized. The objectives and the achievements are clearly exposed and commented. The writing is clear. The candidate authored three publications. Two of them were published in high-ranking international journals whereas the third was published in conference proceedings (open access and indexed by Scopus). The quality of the publications is good and the role of the candidate in developing the paper content is clearly indicated. To improve the impact of this study, this reviewer suggests that the author strengthen the technical content of the thesis by including additional details that are already available to the author (as from some of the cited publications). The inclusion of these elements will improve the relevance the study and make the comprehension of the impact of the study even more apparent. The summary of these issues, which should be considered as minor revision and not obstructing to the formal defense, is (please refer to previous text for further details):

- Improve the description of the in-house Stirling machine that has been used in the tests of Chapters V and VI
- Extend the reported results of the tradespace analysis to additional technical parameters other than cost and power for the different configuration schemes (page 80, figure 20)
- Improve the description of the models used for the application of the game theory to the design of a Stirling machine (only cited as references)
- Further comment on the results achieved with the game theory approach for Case 2 in terms of technical parameters other than power and affordability (such as borehole diameters, stroke values, temperatures, etc.)

In this reviewer opinion, the candidate may deal with these issue by the date of the formal defense.

#### **Provisional Recommendation**

*I recommend that the candidate should defend the thesis by means of a formal thesis defense*

*I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

*The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*