REVIEWER'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Design and Cold-air Tests of a Single-stage Axial Micro Turbo expander for an ORC Power System**
Author's name:	*Bc. Jan Špale*
Type of thesis :	master
Faculty/Institute:	Faculty of Mechanical Engineering (FME)
Department:	Energy Engineering
Thesis reviewer:	Prof. Dr.-Ing. Andreas P. Weiß
Reviewer's department:	Faculty of Mechanical and Environmental Engineering, Technical University Amberg-Weiden

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **challenging**

Evaluation of thesis difficulty of assignment.

The complete design and testing of various ORC micro turbines with an additional focus on 3D printing in plastics is an extremely broad and challenging field of engineering activity.

Satisfaction of assignment **fulfilled**

Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.

The task is fully accomplished beside few minor mistakes, no serious shortcomings.

Method of conception **outstanding**

Assess that student has chosen correct approach or solution methods.

The chosen and implemented approach is very comprehensive, appropriate and has become very clear in the thesis.

Technical level **A - excellent.**

Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.

The candidate has proven a very good and broad knowledge of specific literature. He applied the corresponding physics quite successfully for designing the test turbines and analyzing the collected experimental results. The developed, built and investigated plastic turbines, manufactured by 3 D printing, are quite new – only very few other similar approaches have been published so far. However, this approach is very promising for future small ORC plants.
What could be improved or has not become fully clear, respectively, is the distinction between static and stagnation state quantities in the thermodynamic approach and calculations.

Formal and language level, scope of thesis **A - excellent.**

Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.

No complains concerning the language. However, the graphical layout of the content rich diagrams with very thin lines, without symbols, does not support legibility – it is rather poor. That is a pity.

Selection of sources, citation correctness **A - excellent.**

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

As already mentioned, student´s knowledge of relevant literature, physics is impressive. He applied the state of the art knowledge in this field. Furthermore, distinction between his performance and results/knowledge from others has always become quite clear.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

The primary goals of this thesis

- definition and implementation of a design approach for micro ORC turbo expanders (3D printed in plastics)
- testing this approach experimentally
- investigation and testing of different methods to print micro turbo expanders in plastics for low temperature ORC applications

have been fully and successfully accomplished

The entire thesis proves a high level of engineering science. Mr. Špale showed beside this, additionally a high level of craftsmanship and persistence during the experimental investigations which he carried out on our compressed air turbine test facility at OTH-AW.

Furthermore, he can already been proud on several relevant international publications – by the way: his English is very good.

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

Summarize thesis aspects that swayed your final evaluation. Please present apt questions which student should answer during defense.

The task of the thesis has been very challenging. Mr. Špale had to work in many very different fields of engineering (thermodynamics, turbomachinery, additive manufacturing, data acquisition and processing etc.). He worked out the basics and perfectly prepared the next important steps to introduce 3D printed plastic micro turbo expanders as a standard solution in ORC.

<u>Questions to Mr. Spale:</u>

Concerning Eq. 2.4 loading coefficient

- what is wrong?
- beside adiabatic flow, further constraints must be fulfilled that the Euler work is identical with the static enthalpy drop in the rotor – which?

Concerning Fig. 2.1 h, s-diagram

- please, explain the definition of the degree of reaction in the h, s – diagram (h_{12}, h_{23}?)
- please, show the Euler ($\Delta h_{0,13}$) work of the stage in the h, s –diagram
- what is the difference between $\eta_{is, tt}$ and $\eta_{is, ts}$ – explain by means of the h, s-diagram?

Definition 2.10 and 2.11 (Ns, Ds): why do you use the interstage volume flow rate V_2 (which you initially do not know) instead of the outlet volume flow rate V_3? What are the advantages?

Concerning Eq. 2.12: PR

- Pressure ratio is physically reasonable/defined with stagnation pressures PR = p_{01}/p_{03}

- Sometimes, in turbocharger or ORC business, where single stage turbines are often in use, PR is defined with the total to static pressure ratio PR = p_{01}/p_3 for simplicity.

Why do you use PR = p_0/p_3?

Concerning Eq. 2.16 W_{Eul}: I do not agree – what is wrong!?

Page 17, section 2.2.2: What is the striking feature of a Lungstrom turbine and its advantage/disadvantage?

Page 20, last three paragraphs:

Your write "Another factor is the high molar mass and the molecular complexity of the organic fluid which results in low volumetric flow rates and volumetric ratios," and in the following "High volumetric ratios for very complex molecules lead to difficulties in processing the large difference in the volumetric flow rate in a single-stage"

This seems to be a contradiction – what is correct?

Page 37, last three paragraphs:

Your write concerning the 2nd generation turbine "The rotor blades were designed with a constant blade length, and the buckets were shaped according to the continuity equation for non-compressible fluids." And concerning the 3rd generation turbine "This generation partially builds upon the rotor design methodology introduced in the second generation."

However, for the 3rd generation you apply compressible flow evaluation and the blade length varies – correct?

Page 40, Eq. 4.3: shouldn´t it be $\Delta H_{is} = h_{01}-h_{3is}$ – can you please comment?

Page 44 Eq. 4.18: $Ma_{r2} = 1.01$ – which difficulty or problem could occur concerning an inlet Mach number of almost unity?

Page 46, Eq 4.23: ΔH_{Rotor} is (must be) be negative! I.e. the degree of reaction is - at least mathematically - < 0 as well! Physically, I would not call it "degree of reaction". In my point of view R = 0 physically because there is no pressure drop in the buckets. The static enthalpy increase in the bucket channel is a result of dissipation (see Fig. 4.5). Can you please comment?

Page 47, Eq. 4.29: is it $\eta_{is,\,tt}$ or $\eta_{is,\,ts}$?

Page 50, bottom: Can you explain the idea of the ZWEIFEL criterion?

Page 52, mid paragraph, you write "The increase in specific volume along the streamline is accounted for by means of linearly increasing blade length along the chord line of the blade." This is not the case. The specific volume $v_2 \approx v_3$ because $p_2 = p_3$ and $T_2 \approx T_3$. So, why does the blade height have to increase?

Page 87 you write "Calculation of the span-wise variation of the flow quantities." Which improvement do you expect for blades with $h/d_m \leq 0.1$?

Last question: why do you use such thin lines in your diagrams, no symbols? Legibility is rather poor.

I evaluate handed thesis with classification grade **A - excellent.**

Date: **5.1.2021** Signature: