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Review Report on the PhD Thesis of Mr Paweł Lasek

« Analysis and examination of selected methods of pulsed-field magnetization of high-temperature superconductors»

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The presented review report is organized in the following sections: presentation of the candidate, introduction, general description and evaluation of the thesis, followed by a final conclusion.

1. *Presentation of the candidate*

Mr Pawel Lasek received his Master of Science in Electrical Engineering in 2016 from the Faculty of Electrical Engineering, Silesian University of Technology, graduation with distinction and FCA award for best master thesis.

The topic of master thesis was on the new generation of energy efficient axial flux permanent magnet synchronous motors for automotive applications.

He began his PhD thesis in 2016. He already published 8 papers in international review and participate to 6 international conferences

2. *Introduction*

The Dissertation of Pawel Lasek contains 163 pages, 7 chapters, 1 appendix, and bibliography with 172 cited documents, related to the topic. The dissertation, supervised by Mariusz Stepien, PhD, DSc and co-supervised by Dr Janusz Hetmanczyk, has contemporary and modern aspects described by the research objectives.

The PhD thesis of Mr Paweł Lasek focuses on Pulsed Field Magnetization (PFM) of High Temperature Superconductors (HTS).

3. General description of the thesis

The thesis begins with an introduction presenting general background and motivation, then the Pulsed-Field Magnetization (PFM) in the literature is presented and finally the aim and the objective of the research is exposed. The objectives of the thesis are to determine the best electric parameters of the PFM system and design the best magnetization coil. The purpose of the thesis work is clearly exposed by Mr Lasek.

The second and third parts are dedicated to the state of art related to the objectives of the thesis. The second part presents general background information on superconductivity and applications. HTS bulks and losses are more detailed because there are link to the objectives of the thesis. The third part describes the process of magnetization of HTS bulks. Three kind of magnetization exist and are detailed: Field Cooling, Zero Field Cooling and PFM. The candidate clearly explained why he focused on PFM. This is to have more flexible system for future applications. Mr Lasek gives useful details on PFM as the flux pump, source of magnetization, and the kinds of coil used for PFM.

Chapter 4 deals with the design of the PFM system. This is the most interesting chapter of the thesis. Firstly, the description of the flux pump is done. The lumped circuit model allows analytical solution of voltage and current waveforms. The solutions depend on components values. Secondly the description of a magnetic circuit is done. The influence of a number of turns of the magnetic circuit on the resistance and inductance is studied. Thirdly the influence of circuit parameters on results is presented. Fourthly, the designing of the solenoid coil used specifically for magnetization of HTS bulks is exposed. This chapter is very clear, well organized and complete with a lot of analytical calculations. It is very useful for future designers of PFM system.

Chapter 5 deals with the experimental validation of the PFM system design. Three different magnetization coils were used. One HTS bulks was magnetized and a lot of magnetic sensors are placed close the surface of the bulk. This is a tricky and precision work. It allows to give a lot of information about the magnetic field distribution during transient state and steady state. Mr Lasek analyzes very carefully the results of the measurements and conclude what it is the best way to magnetize HTS bulks. Mr Lasek should considered the influence of magnetic field on the critical current density in his analysis.

Chapter 6 presents the numerical electromagnetic modelling of the PFM. Firstly, the classical Maxwell equations and PDE formulation are presented. The specific behavior of HTS is the nonlinear resistivity. The influence of magnetic field on the critical current density should be added in this section. Mr Lasek used finite element method software to numerically modelling the PFM of HTS bulk. He describes precisely all the steps of this numerical modelling. The results are well presented and the figures are clear. Mr Lasek compared the numerical and experimental results. He's aware that numerical results differ from experimental results because of some simplifications in his numerical modelling.

The thesis ends with a conclusion and some prospects. Mr Lasek summarized the work done from the design of magnetization coil and the flux pump to the construction of the system and the numerical modelling. He proposed interesting solutions both experimentally and numerically.

4. Evaluation of the thesis

- Originality, relevance to the field:

The manuscript is fully completed with relevant to the field of applied superconductivity and represent an advancement in the field of PFM of HTS bulks. The idea beyond this work is to design PFM system to optimize the process. The main and remarkable contribution of this thesis work is to study the complete process of HTS bulk magnetization from the current pulse generator to the experimental validation and the numerical modelling. That is a hard and long time work especially in term of experimentation. The main negative point is that the candidate did not be able to go further with experiments and improve his numerical modelling during the time of the thesis. On these two points the work done lack of originality.

- Consistency of theory and experimental work:

The theory of PFM process is based on electric model, magnetic model and electromagnetic model. This is well described by candidate. The experiment is high level but the very interesting possibility of multiple pulses process was not done during the thesis.

Analysis of experimental results should be reconsidered by taking account the strong influence of magnetic field on the critical current density $J_C(B)$. In section 2.5.2 on Hysteresis losses, the $M(H)$ cycles deduced from Bean model and Kim model are not described. The influence $J_C(B)$ on these two cycles could be useful for analysis of experimental results. The candidate should develop this section considering new reference:
B. Douine, J. Lévêque, S. Mezani, $J_C(B)$ determination method with the help of the virgin magnetization curve of a superconducting cylinder, I.E.E.E. transactions on applied superconductivity, vol. 20 (2), pp.82-86, 2010.
In section 2.6 and 6.5 the influence of $J_C(B)$ should be added.
In section 5.2.3, page 98, the influence of $J_C(B)$ has to be consider in the analysis of the experimental results especially for strong applied magnetic field (>2T).
In section 6.1.4, the $J_C(B)$ relationship has to be added.
In section 6.4.1, the choice of the parameters (n = 13, $Jc = 1.6 \cdot 10^8$ A/m2, Bc = 0.25 T) is not well explained. The candidate should develop the process to choose these parameters.
In section 4.4, the formula (4.60) on the relationship R(T) is not explained and without reference. The candidate should explain how he calculated this formula. Is the temperature T in °K or °C?

- Publications:
The candidate published 4 papers in international reviews on this topic.

- Writing quality and clarity:
The presentation of the works is well organized and pleasant to read. The analysis of results is logical, rigorous and based on strong scientific background

- Editorial comments:
  - Page 6, Nomenclature, it misses *Js(t)* current density source
  - Page 22, "The following thesis has been divided into seven (instead of eight) chapters"

5. *Final conclusion*

The following positive points can be stressed:

1. The research subject is relevant in applied superconductivity field

2. The optimization of the PFM process, done by Pawel Lasek, is very useful for applied superconductivity community.

3. The research topics, the methodology and methods are consistent, corrected and used appropriated.

4. The results are derived logically and well described. They are analyzed and interpreted in accordance with the scientific standards.

5. The literature references are correctly cited.

6. The thesis clearly demonstrates that Pawel Lasek can conduct independent scientific research and future research

The following points have to be mentioned as potential weakness of the thesis:

1. For lack of time, the experimental work and numerical modelling lack of originality

2. The physical analysis of experimental results can be improved by taking account all the physical parameters of the HTS bulks.

The PhD study of this thesis is dedicated to the PFM process including the design of PFM system, experimental validation and numerical simulations. This work is very useful for applied superconductivity community and well appreciated as shown by the four papers accepted in international reviews. The minor weakness points cannot influence of the final assessment of the thesis results. I therefore recommend the acceptation of the thesis without reserve.

Done on Nancy, the 31st of January 2021

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