

Review of Doctoral Thesis

1. PhD candidate
Ing. Filip Jeniš/ Filip.Jenis@vutbr.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
Semi-actively controlled suspension system of railway vehicle
4. Principal supervisor
doc. Ing. Ivan Mazúrek, CSc. / Ivan.Mazurek@vut.cz
5. Co-supervisor
Ing. Zbyněk Strecker, Ph.D./ Zbynek.Strecker@vut.cz
6. Reviewer
prof. Bogdan Sapiński / deep@agh.edu.pl
AGH University of Kraków
7. Overview of the scope of PhD thesis¹
Very good
The main objectives of the PhD thesis are to investigate the possible ways of improving the MR damper's dynamic behaviour and the effect of the MR damper on passengers' comfort in a semi-actively controlled suspension system of a railway vehicle. In addition 3 sub-aims are formulated for investigation: 1) the possibilities of improving the damper's dynamic behaviour using the material and shape approaches to reduce eddy currents, 2) the effect of a fail-safe MR damper's (with a permanent magnet in the valve core) dynamic behaviour, 3) the influence of the damper's dynamic range and its response time regarding to the force rise and the force drop. Additionally, the author presents the detailed steps to achieve each of the sub-aims, asks 3 scientific questions and puts forward 3 hypotheses that he would like prove. The main findings of the PhD thesis relating to the set hypothesis are: 1) the MR damper piston should be made preferably either of grooved Vacoflux or from pure iron by selective laser melting technology, 2) the force response of the MR fail-safe damper is quite long and in order to obtain a shorter force response time the piston needs to be grooved, 3) the force drop response time is more important than the force rise response time for semi-active control performance and the acceleration driven linear algorithm seems to be the best suitable for damping lateral vibrations of railway vehicles. This proves that all the set hypotheses have been verified, so the work goals have been achieved.

¹ Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

8. Significance of the topic and clarity of problem statement

Very good

The topic of the PhD thesis can be considered as original and valid. The research problem is clearly formulated and the tasks are precisely defined. The research study is important and timely especially in the context of potential industrial applications. The work is valuable and thorough. The PhD thesis is an attempt to solve the problem of constrained optimization, i.e. designing an MR damper that meets specific performance requirements in terms of both force response time and dynamic range, and which could be successfully applied in the semi-actively controlled suspension system of railway vehicles. The author has a well-recognized scope of a missing research area, in particular the lack of knowledge that needs to be filled before developing an MR damper suitable for application in such suspension systems. The results obtained will certainly contribute to greater passenger comfort on a railway vehicle. The importance and interest in the topic and results obtained by the author are demonstrated by the continuation of the research in the field. This is proven by subsequent steps taken in cooperation with the industry, i.e., the development of a larger MR damper (than that considered and tested of approximately 1/5 scale in the study), which can be applicable as a bogie yaw damper in the suspension of a railway vehicle, and also a project to develop a complete system for an intercity low-floor railway unit.

9. Knowledge of existing literature

Good

The reference list of the PhD thesis contains 114 items, which seems to be adequate. A review of the literature and conclusions are briefly provided in Chapter 3 (pp. 38-42). That chapter is divided into 4 sub-chapters dealing successively with state of knowledge in the field of improvement MR valve behaviour (sub-chapter 3.1), failsafe MR dampers (sub-chapter 3.2), semi-actively controlled lateral dampers of a railway vehicle (sub-chapter 3.3) and also sub-chapter 3.4 that indicates the lack of knowledge and the main unexplored areas. The key points in this regard have been specified (pp. 41-42). Note that the order of these sub-chapters is different on pp. 38-42 than that announced in the thesis content (p. 8). The above proves that the author is aware of the challenges he faces, in particular the lack of knowledge that needs to be supplemented during the research study he has undertaken. The reference list shows that the author has a good understanding of the state of knowledge and research, and at the same time knows scientific groups conducting research on the topic of the PhD thesis. It should be noted that similar studies like to those studies that concern the PhD thesis were also carried out using ER/MR technology by Bullough et al. at The University of Sheffield during the 1990s.

10. Choice of methods and technical soundness

Good

The research carried out for the purpose of the PhD thesis shows that the author has good skills in conducting complex R&D experiments and measurements, and adequate use of software tools for numerical calculations, designing and data processing, and analysis. The methods are modern and known, and have been chosen accordingly to the research conducted, which have making it possible to achieve the assumed objectives. The created experimental set-ups and measurement systems (e. g., for magnetic behaviour measurement, force-velocity measurement and Hardware-in-the-loop-simulation tests) have been configured to meet the assumed research goals and specified sub-aims. Note that in terms of MR damper control, the author has not stopped at well-known strategies, but has developed the strategy according to his own idea. The selection of components for these systems such as probes, gauges, sensors, actuators, controllers, etc. and the ability to integrate them with the examined object/system using suitable software environments shows and confirms knowledge and skills in conducting research on the topic of the

PhD thesis. The research activities have been performed with great attention to technical soundness and that refers to both numerical calculations, simulations, measurements and tests.

11. Quality, originality and significance of the results

Very good

The quality of the obtained results can be considered as substantial. The findings resulting from the research are described in detail in Chapter 6 (pp. 59-62). These specified findings refer to the attached research papers: I, II and III, and main objectives as well as the sub-aims of the PhD thesis formulated in Chapter 2. The study shows that: the response time for force drop is more important than the the response time for the force rise, the highest control efficiency has been achieved with the force response time of 8 ms and the ideal dynamic range of the damper should be around 10. With such MR damper's features and with the control strategy by the author (acceleration driven damper linear), in an ideal case a 34% reduction in lateral vibration may be achieved. The results may provide guidelines in the area of both designing and manufacturing an MR damper featuring fast force response, and a reduction in eddy currents through structural modifications. These features of the engineered MR damper's generally meet the requirements to apply it in suspension systems of railway vehicles. This, in combination with the applied control strategy allows for improvements in passengers' comfort, which has been confirmed first in Hardware-in-the-loop-simulation tests and next in introductory running tests. In my opinion, the achieved results are original and have practical significance.

12. Quality of attached papers

Good

There are 3 journal research papers attached to the PhD thesis which form Chapter 6. The papers, co-authored by Mr Jenis, have been published in engineering journals with impact factors. The Paper I, "Novel Approach to the Design of an Ultra-Fast Magnetorheological Valve for Semi-Active Control" (Materials, 2021) refers to the approaches for achieving a short response of an MR valve by means of the material and shape (sub-aim 1), and has been created with the cooperation of Choi S.-B. The results obtained in the study are of scientific and engineering value, however, further research is required to meet the assumed requirements. The Paper II, "Insight into the response time of fail-safe magnetorheological damper is concerned with the dynamic behaviour of an MR damper with a permanent magnet in the valve core (sub-aim 2 in Section 7) and has been published in the top journal of Smart Materials and Structures, Technical Note. It has been created with the cooperation of the research workers from Brno University of Technology. The achieved results are of great importance but as the authors state still require research on the durability of the MR damper with temperature changes. The paper III, "Effect of the Magnetorheological Damper Dynamic Behaviour on the Rail Vehicle Comfort: Hardware-in the-loop-simulation" publised in the journal Actuators has been developed by a scientific group of Brno University of Technology and a research worker from the University of Pardubice. The article deals with dynamic MR damper behaviour and its influence on the efficiency of several algorithms for semi-active control. The research leads the authors to the conclusion that the acceleration driven damper linear is most suitable for the assumed application. The mentioned papers are characterized by a high scientific level and that confirms the quality of the research work. There are also 4 co-authored journal papers with impact factors more or less related to the topic of the PhD thesis and 12 other co-authored conference papers indexed in the Scopus/Web of Science databases.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

Very good

Strengths: the topic of the PhD thesis is significant and original; the problem is important and scientifically correct and technically valid; the assumed goals of the thesis have been achieved; the obtained results are original and have substantial cognitive; and application value; the research exhibit technical soundness; the author's findings are valuable; the conducted research shows the ability of the author to cooperate with a research team; the quality of the attached journal papers is good; and the structure of the study is appropriate and language used is generally understandable. Weaknesses: lack of real experimental verification (in-situ experiments); despite of the author's declaration of contribution to the research (as shown in Papers I and II), it is difficult to separate and evaluate his own contribution to the PhD thesis; in my opinion the attached Paper III concerning testing control strategies for the engineered MR damper should be reviewed/published in a scientific/engineering journal focused on control issues.

14. Questions and comments

Note that a railway vehicle usually travels over long distance and the temperature of the MR damper may increase. Also note that Hardware-in-the-loop-simulation tests involve combining real hardware (MR damper) with a virtual simulation environment. In this context the assumed simplified lateral vehicle 2 degree-of-freedom model does not take into account structural clearances and friction in the real system. What is the influence of these factors on the MR damper force response and efficiency of a railway vehicle suspension system based on it? The author considers 4 control strategies (skyhook, skyhook linear, acceleration driven damper, acceleration driven damper linear), conducts their tests and ultimately points out to the benefits of acceleration driven damper linear. These strategies, however, do not take into account the factors mentioned above. What is in this context the author's opinion on the approach presented in the PhD thesis by Eroglu M. A. "Observer based control of a magnetorheological damper" (2013)? It is expected that the author justifies the conditions of MR damper tests relating piston velocity of 0.2 m/s and input current of 0.5 A in the passive mode. The Papers I, II and III which make up Chapter 6, do not constitute independent contribution of the author's thesis. Unlike the Papers I and III there is no information about author's contribution to the Paper II. In the text of the PhD thesis there are editorial errors which should be corrected. In addition, the English vocabulary and grammar used in some fragments of the work need to be corrected. The development of drawings should be unified and the quality of several figures and plots should be improved.

15. Conclusion

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.

YES

16. Date and signature

29/08/2024

Please note

- A. Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.
- B. E-mail the completed form to: Klara.Javorcekova@vut.cz

Review of Doctoral Thesis

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6. Reviewer
Prof. Egidio Di Gialleonardo / egidio.digialleonardo@polimi.it
Politecnico di Milano
7. Overview of the scope of PhD thesis¹
Evaluate: good
The PhD thesis of Filip Jeniš investigates the possibility of establishing an optimal design of magneto-rheological damper to be employed in the secondary suspension of a railway vehicle. The scope of the thesis should be primarily discussed in the introduction. In Filip's thesis, the scope is generally appropriate but lacks clarity and depth in its form. Explicitly defining the research questions in the introduction (even if not in the detailed version provided in section 4), objectives, and methodology would provide a more focused and precise understanding of the thesis's contribution to the field. Regarding the main findings and scientific achievements, the conclusions offer a comprehensive summary and suggest promising ideas for future research.
8. Significance of the topic and clarity of problem statement
Evaluate: good
The topic is highly relevant. Many railway vehicles still employ passive suspension systems, and only a few examples of semi-active solutions are currently in use. One of the major challenges is the fault-tolerant design of active or semi-active suspension systems, which is addressed in this thesis. The study of semi-active solutions for railway vehicles is particularly important, as these systems offer significant

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advantages in terms of performance and adaptability compared to traditional passive solutions. Semi-active suspensions can dynamically adjust their behavior in response to changing operating conditions, improving ride comfort, stability, and reducing wear on both the vehicle and the track. In the context of increasing demand for efficient, reliable, and safer railway transport, the development and implementation of semi-active systems represent a crucial step forward in modernizing railway technology. The research questions are presented in detail in Chapter 4, although they should also be mentioned in the Introduction.

9. Knowledge of existing literature

Evaluate: **good**

The literature review is good, although it includes only a few recent contributions. Excluding the candidate's papers and those from his research group, only a couple of papers from the last five years are included, despite significant additional research on semi-active solutions in railway vehicles during this period. Furthermore, the state-of-the-art section presents the individual results of each analysed paper, but the candidate should have made an effort to synthesize the findings across the different topics covered in the literature review. The analysis reported in Chapter 3 is not satisfactory in this regard.

10. Choice of methods and technical soundness

Evaluate: **very good**

The methods used in this thesis are state-of-the-art. However, I would rate the work as excellent in terms of the design of the MR damper and its fail-safe version, while its application to a railway vehicle (as described in paper 3) can be evaluated as good. In this regard, the benefits of the semi-active solution were assessed using Hardware-in-the-Loop simulations, which, understandably, employed a simplified vehicle model. I believe that an evaluation using a more complete railway vehicle model, incorporating the MR damper model, would have been necessary to verify the effectiveness of the developed solution.

11. Quality, originality and significance of the results

Evaluate: **very good**

The design of the MR damper for railway applications and its fault-tolerant behavior was thoroughly analyzed in this thesis, with strong arguments provided to demonstrate its effectiveness. As mentioned in the conclusions, a possible follow-up to this work could involve its application on a real vehicle and the verification of its effectiveness through full-scale testing. Before that, it would be important to assess the solution through numerical simulations of the vehicle's running dynamics. Such simulations would provide a deeper understanding of the damper's performance in various operating conditions and help predict potential issues before moving to real-world testing. As a general comment, the development of fault-tolerant semi-active dampers significantly reduces the gap between research and the practical implementation of these solutions on in-service trains. By addressing the reliability concerns often associated with innovative technologies, this design makes it more feasible to adopt semi-active damping systems in current railway operations.

12. Quality of attached papers

Evaluate: **good**

The candidate is attaching three different papers to his PhD thesis. Two of the papers are published in Q2 journals (Materials and Actuators), while one is in a Q1 journal (Smart Materials and Structures). Given that the title of the thesis is 'Semi-actively Controlled Suspension System of Railway Vehicles,' I believe a

publication in a journal specifically focused on railway dynamics would have been more appropriate. Two of the publications are devoted to the design optimization of the semi-active damper, while only the third paper addresses its application in a suspension system for a railway vehicle. However, this last paper is published in a journal that focuses on general engineering problems rather than one specifically dedicated to railway issues.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

Evaluate: **good**

Overall Assessment: Filip Jeniš's PhD thesis presents a valuable contribution to the field of railway engineering, particularly in the area of semi-active suspension systems. The research is well-motivated, addressing a significant challenge in the industry. The thesis demonstrates a strong understanding of the subject matter and employs appropriate methodologies.

Key Strengths:

Relevance: The topic of semi-active suspension systems for railway vehicles is highly relevant and timely, given the increasing demand for efficient and comfortable transportation.

Methodology: The thesis utilizes state-of-the-art methods for designing and evaluating the MR damper and its fault-tolerant version.

Depth: The research provides a comprehensive analysis of the MR damper's design, fault tolerance, and application in a railway vehicle.

Weaknesses:

Clarity and Focus: The introduction could have been strengthened by explicitly defining research questions, objectives, and methodology to provide a clearer understanding of the thesis's contribution.

Literature Review: While the literature review is generally good, it could have benefited from a more extensive coverage of recent research, especially within the last five years. Additionally, synthesizing the findings across different topics would enhance the analysis.

Vehicle Model: The evaluation of the semi-active solution could have been further strengthened by incorporating a more complete railway vehicle model in the simulations.

Publication Choice: Given the thesis's focus on railway dynamics, publishing in a journal specifically dedicated to this field would be more appropriate for some of the papers.

Overall, Filip Jeniš's thesis presents a solid foundation for further research in semi-active suspension systems for railway vehicles. By addressing the identified areas for improvement, the thesis could make an even stronger contribution to the field.

14. Questions and comments

A general question should be raised about the simplifications introduced by the Hardware-in-the-Loop vehicle model. The implications of these simplifications are generally not discussed in either the main document or the attached papers. Additionally, it would be interesting to know the candidate's opinion on the use of vehicle dynamics simulations for assessing the effectiveness of the proposed solution. Are there possibilities for obtaining a reliable simplified model of the MR damper to be used in vehicle dynamics simulations?

15. Conclusion

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.



YES

16. Date and signature

Date: 14/09/2024

Please note

- A. Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.
- B. E-mail the completed form to: Klara.Javorcekova@vut.cz

Faculty of Mechanical Engineering
Brno University of Technology

Principal supervisor's final report on the PhD study

1. PhD candidate
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2. Name of PhD programme
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3. Title of PhD thesis
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doc. Ing. Ivan Mazůrek CSc. / Ivan.Mazurek@vut.cz
5. Co-supervisor
Ing. Zbyněk Strecker Ph.D. / Zbynek.Strecker@vut.cz
6. Stays at other institutions (min. 7 days)
Department of Control for Transportation and Vehicle Systems, Budapest University of Technology and Economics / Hungary / 1/9/2022 – 31/11/2022
7. Teaching activities
Course name / Total number of hours
Machine design / 260
Machine design – fundamentals / 208
Aventics Pneumobile Racing / 195
Experimental Methods / 156
Team Project / 49
CAD – Basics / 26
Mechanical design project / 17
8. List of main publications
JENIŠ, Filip; KUBÍK, Michal; MACHÁČEK, Ondřej; ŠEBESTA, Karel a STRECKER, Zbyněk. Insight into the response time of fail-safe magnetorheological damper. <i>Smart Materials and Structures</i> . 2020, roč. 1, č. 30, s. 1-13.
JENIŠ, Filip; KUBÍK, Michal; MICHÁLEK, Tomáš; STRECKER, Zbyněk; ŽÁČEK, Jiří et al. Effect of the Magnetorheological Damper Dynamic Behaviour on the Rail Vehicle Comfort: Hardware-in-the-Loop Simulation. <i>Actuators</i> . 2023, roč. 12, č. 2, s. 1-14.



STRECKER, Zbyněk; JENIŠ, Filip; KUBIK, Michal; MACHÁČEK, Ondřej a CHOI, Seung-Bok. Novel Approaches to the Design of an Ultra-Fast Magnetorheological Valve for Semi-Active Control. *Materials*. 2021, roč. 14, č. 10, s. 1-20.

9. Assessment of the supervision process

Ing. Filip Jeniš is a graduate of the Institute of Design, Faculty of Mechanical Engineering, BUT. He started his four-year doctoral studies at the Institute of Design on September 1, 2018. The topic of his dissertation is "Semiactively controlled suspension system of a railway vehicle". Throughout his doctoral studies, he has shown a good work ethic and conscientiousness in the carrying out of work tasks. His studies so far have been characterised by independence, both in during his own doctoral studies and in the fulfilment of the Institute's research tasks and his teaching duties.

10. Assessment of the candidate's ability to work independently

Ing. Jeniš is the successful researcher of the Faculty's junior specific research project "Development of a fail-safe magnetorheological damper" (2020). He is entrusted with the management of individual tasks in solving grants from the Czech Technology Agency (CK02000302 "Hydraulic semi-active damper for railway bogies", CK03000052 "Hydraulic semi-active damper for intelligent railway bogies", CK04000210 "Semi-active damping system for single-floor electrical unit"), which is followed by his PhD theses.

11. Assessment of the contribution that the research makes to knowledge in the field

In the case of solving the above-mentioned projects, he specialises in the algorithmisation of the control of semi-active damping systems. His work in this field, which focuses on the damping of railway vehicle suspensions, is irreplaceable.

12. Other comments

13. Conclusion

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.

YES

14. Date and signature

Date:

27.3.2024