



Doctoral Thesis Evaluation Form

- 1. Name of PhD candidate / e-mail:**
Ing. Radovan Galas / Radovan.Galas@vut.cz
- 2. Name of PhD programme:**
Design and Process Engineering
- 3. Title of PhD thesis:**
Friction Modification within Wheel-Rail Contact
- 4. Title and name of principal supervisor/e-mail:**
Prof. Martin Hartl / Martin.Hartl@vut.cz
- 5. Title and name of co-supervisor/e-mail:**
Dr. Milan Omasta / omasta@fme.vutbr.cz
- 6. Title and name of reviewer/place of employment/e-mail:**
Meierhofer, Alexander, Dipl.-Ing. Dr.techn./ Kompetenzzentrum - Das Virtuelle Fahrzeug
Forschungsgesellschaft mbH (ViF) / Alexander.Meierhofer@v2c2.at
- 7. Overview of the scope of PhD thesis**

Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

Top-of-Rail (TOR) products are contaminants that are applied to the wheel-rail contact in order to control the creep force of the wheel-rail interface. This is beneficial with regards to, e.g. damage, wear, and noise. The main aim of this thesis was to investigate the influence of the applied quantities and the chemical composition of different TOR products on their performance. Therefore, two different types of laboratory test were used: a commercial tribometer and self-constructed Twin-Disc test rig. A second aim of the thesis was the question if an overdose of these contaminants can still guarantee a safe braking distance. Therefore, as well as for the validation of the laboratory tests, field experiments were conducted on a light rail system. The findings showed that both, the composition and the applied quantity strongly affect the performance. In case of water-based TOR products, evaporation also showed a significant influence. Generally, it was possible to reduce wear and surface damage significantly but it seems difficult to achieve a significant reduction of noise without impacting the braking and traction capabilities.

- 8. Significance of the topic and clarity of problem statement:**

Evaluate using the following scale: ~~excellent~~ / very good / good / satisfactory / acceptable / unacceptable

Top-of-Rail (TOR) products have been used in the past few years to control the friction in-between wheel and rail. They are said to reduce wear, noise and damage while not significantly reducing the traction and braking behaviour. Such bold claims by the manufacturers demand a high level of validation, especially as this touches safety aspects. The here presented thesis uses several previously published investigations as a foundation to investigate the influence of applied quantity and composition on the performance on friction, noise, wear, and damage with three different experiments. This makes the thesis very significant as it tries to tackle every important part of the

problem but loses itself a little bit in the broad range of investigations and its own ambition instead of really delving deep into one specific part.

9. Knowledge of existing literature:

Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

The literature review was very extensive and contained a broad overview especially regarding the composition of friction modifiers and performance in previous tests. Nearly every presented paper was extensively summarized and I am sure that the state-of-the-art summary will be a good starting point for many people that want to learn more about friction management. But due to its ambition, the literature research seems unfocused and at times meandering, presenting results for sanded conditions or leaves when this was never addressed or investigated in the work. Also, a careful look shows that the literature contains only tribometer and Twin-Disc tests. While this is valid as this thesis mostly uses the same tests, scalability is always an issue and literature regarding field experiments or at least full-scale tests needs to be mentioned. Only one full-scale test was presented, but reading the source showed that it was also a twin-disc test. Another topic that was not given a lot of care was the theoretical part. E.g. the negative friction characteristic was never once explained, effects caused by contact geometry or temperature were completely missing, and the newest model discussed was from 1963, which is not state of the art anymore.

10. Choice of methods and technical soundness:

Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

Three different methods were used in the thesis: a tribometer, a twin-disc test rig, and field experiments. The choice of these methods was sensible, the reasons were explained satisfyingly. A lot of care went into the measurements themselves, a lot of questions were answered and a lot of different techniques were applied, which was really impressive. However, the influence of the contact geometry on the maximum Hertzian pressure as well as on the resulting force was never mentioned. Also, it was never discussed if there was a residue of friction modifier on the discs when the wear was measured on the balance. In general, the reliability of the tests, the possible errors of the measurements and the repeatability were never mentioned. While understandable due to cost constraints, it is still something that might have elevated the thesis further.

11. Quality, originality and significance of the results:

Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

As mentioned before, there is no information about the reliability, repeatability and errors of the test rigs. As such, the quality of the results is hard to judge. But given the presented information, great care was taken to get as much information from the tests as possible and nearly everything was considered. The results seemed very original and unique; especially the investigation of the different friction modifiers needs to be highlighted in this context. The scope of the work was quite extensive and maybe a little too ambitious: all twin-disc tests were performed with the same SRR/creepage instead of repeating them with different ones. But in general, the results are very significant, especially as a valuable stepping stone for further work on this topic by the same or other authors.

12. Quality of attached papers:



Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

The quality of the attached papers is generally very high but for a few missteps: In some of the papers, the information on the contact geometry is missing. A twin-disc test rig was built but never really explained in detail: how was the creepage/SRR controlled? Was it at stable values? What if you changed the SRR? Such investigations might lead to different conclusions regarding the SRR at which the maximum traction occurs (called saturation point in the thesis) and the change in the shape of the curve. Also, at one point it was mentioned that an SRR value of 5% equals a slip of 2.5%. If have no idea what this means as there was never a slip value introduced or defined. Also, the negative friction characteristic, obviously a focus of a lot of the work and in the presented papers, was never really explained or discussed in any introduction of the papers. But as said before, these seem like minor oversights and I believe they could be easily corrected, so I cannot judge them harshly.

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

Evaluate using the following scale: excellent / very good / good / satisfactory / acceptable / unacceptable

As mentioned before, the work presented in this thesis is quite extensive and ambitious and, thus, lacks focus at times. The structure of the thesis additionally draws attention to this. While it is optically beautiful, the content seems cluttered and, thus, is sometimes hard to read. These minor setbacks aside, the investigations are competently done and the results are of very high quality. It was especially interesting to see how different components influence the traction. I really hope that somebody will pick up where this work ended and start to look further into these things as I see a lot of future potential.

14. Other comments:

None

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.

Choose from following: YES/NO

16. Date and signature:



Please note

- A. Evaluate categories 8 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. In each category 8 to 13 explain reasons for evaluation using between 100–200 words.
- C. Overview of the scope of PhD thesis (Category 7) is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.
- D. E-mail the completed form to: Klara.Javorcekova@vut.cz



Faculty of Mechanical Engineering
Brno University of Technology

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- 6. Title and name of reviewer/place of employment/e-mail:**
Prof. Dr. Raphael Pfaff / Schienenfahrzeugtechnik, FH Aachen University of Applied Sciences / pfaff@fh-aachen.de
- 7. Overview of the scope of PhD thesis**

Evaluate using the following scale: very good

The thesis under examination sets out to address the issue of friction modification for top-of-rail application in railway systems. As energy efficiency and environmental protection against noise are increasingly becoming a focus in railway and tram operation, such products become more interesting to operators and infrastructure managers alike.

While studies in heavy haul operation exist, the thesis employs a combination of laboratory and field tests using a European tram operation to answer the following questions:

- What is the effect of quantity and composition of such products?
- Can a save braking be ensured under overdosage?

In addition to the purely railway mechanical problems, the question of rail noise is also addressed. Laboratory trials using a ball-on-disc tribometer and a twin disc machine are executed and are able to provide an answer to the questions. The field test makes use of a tram system and multiple passes, it applies the braking distance as an indication of effect of the friction modifier as well as noise measurements.

In a final series of laboratory trials, the effect of the individual ingredients as well the transporting agent (water) is investigated, which may be helpful in the design of specific friction modifiers.

- 8. Significance of the topic and clarity of problem statement:**

Evaluate using the following scale: good

The author introduces his problem setting, his scientific questions as well his hypotheses very clearly. The reviewer appreciates the formalisation of the questions and hypotheses by numbering them for later reference in the argument. The problem, question and hypotheses statement is clear and concise.

The topic of friction modification is very significant due to its high impact on operational performance, especially in conjunction with ATC systems. The reviewer expects that the knowledge of appropriately controlling the friction coefficient for a given stretch of track will rise even further in importance as soon as ETCS level 3 is operated, since in this way, individual trains may have their braking curve for the pass on the sprayed section.

9. Knowledge of existing literature:

Evaluate using the following scale: very good

The author provides a very thorough review of the topic itself as well as the relevant problems in railway maintenance and operation. These relevant problems not only include the obvious problems as corrugation and reduction of contact forces, but also the import topic of noise. Especially the review of third body layers in the wheel-rail contact is well researched and documented, as is the section on top of rail products.

While the number of citations is less than average, the bibliography is well researched and curated, thus a very good basis for the further development of the argument.

10. Choice of methods and technical soundness:

Evaluate using the following scale: very good

The selected methods replicate the wheel rail contact problem in railways reasonable well, limitations are the scale of geometry and forces. This trade-off between scaling and possibility to execute a high number of trials is frequent and therefore the choice of the author is right. Not only the scaling is investigated, but also the used materials are analysed in terms of chemical and mechanical properties in order to gain insight into the comparability of the tests executed. Laboratory tests are performed on tribometers and a specifically designed twin disc machine. The twin disc machine is able to replicate the situation in a railway contact patch quite well, however an extreme angle of attack (for small tram radii) has been chosen. This choice is explained. As the laboratory experiments, the field tests aim on the situation of tramways. The braking distance measurements indicates the braking distance as well the slip situation, which is a good indicator of the performance. Further, multiple passes of the train were analysed.

11. Quality, originality and significance of the results:

Evaluate using the following scale: very good

The results were achieved with a rather high number of samples, even in the field test. This makes the results practically repeatable and valid.

The reviewer is not aware of a combined laboratory and field test on the subject of top of rail products under European conditions, despite the interest in such products from European operators and infrastructure managers.

While the results are interesting and manifest a novelty, the research is rather short of recommendations for the operator or infrastructure manager. This would help to make it even more valuable. A further shortcoming of the present work, which however is given as an indication for further research, is the exclusion of climatic effects. This will provide further practical value to the results.

12. Quality of attached papers:

Evaluate using the following scale: very good

Paper A presents a pure laboratory study. The paper is well written and structured. The methodology is well described, the results are interesting in relation to the hypotheses set out for the authors PhD thesis. The negative result of not being able to replicate saturation is taken care of in the following paper.

Paper B makes use of the twin-disc machine as well as field measurements, which makes it valuable for the practitioner. It is also well written and structured. Shortcomings of this paper are that the potential negative results for the recommended amount of friction modifier from a brakes perspective, no improvement in sound level could be found and the lack of a recommendation.

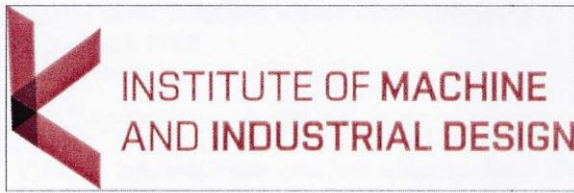
Paper C focuses more on the constituents of water based FM, which stronger addresses the underlying phenomena and the single substances. This may help to design specific friction modifiers for particular applications.

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

Evaluate using the following scale: very good

The thesis under review is a very well researched and structured cumulative thesis. The development of the topic from initial trials focusing on the amount via the field trials to the tests focusing on the individual constituents makes it very interesting. The strength of the research is the methodology and high number of trials as well as the evaluation of the data.

Shortcomings of the thesis are minor, however include the absence of recommendations concerning the amount of friction modifier for the case under investigation and the extreme focus on tram operation. The wider scope, including mainline operation under modern ATC system, may have improved the strength and significance.



Faculty of Mechanical Engineering
Brno University of Technology

14. Other comments:

Great work, should be integrated in a systems approach with e.g. braking curves as well as counteragents, e.g. sanding.

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.

Choose from following: YES

16. Date and signature:

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Principal supervisor's final report on the PhD study

1. PhD candidate

Ing. Radovan Galas / Radovan.Galas@vut.cz

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Design and Process Engineering

3. Title of PhD thesis

Friction Modification within Wheel-Rail Contact

4. Principal supervisor

Prof. Martin Hartl / Martin.Hartl@vut.cz

5. Co-supervisor

Dr. Milan Omasta / omasta@fme.vutbr.cz

6. Stays at other institutions (min. 7 days)

Technical University of Munich / Germany / 06/06/2016 / 12/06/2016

7. Teaching activities

CAD (3CD) / 52 hours
Machine Design and Machine Elements (CKP) / 156 hours
Machine Design – Machine Elements (5KS) / 234 hours
Machine Design – Mechanical Drives (6KT) / 156 hours
Machine Design – Mechanisms (6KM) / 104 hours
Mechanical Design Project (ZKP) / 26 hours
Team Project (ZIP) / 13 hours
Tribology (ZTR) / 15 hours

8. List of main publications

GALAS, R., D. KVARDA, M. OMASTA, I. KRUPKA and M. HARTL. The role of constituents contained in water-based friction modifiers for top-of-rail application. Tribology International, 2018, 117C, 87-97. IF 2.903

GALAS, R., M. OMASTA, M. KLAPEK, S. KAEWUNRUEN, I. KRUPKA and M. HARTL. Case Study: the Influence of Oil-based Friction Modifier Quantity on Tram Braking Distance and Noise. Tribology in Industry, 2017, 39(2), 198-206.

OMASTA M., R. GALAS, J. KNAPEK, M. HARTL and I. KRUPKA. Development of an adaptive top-of-rail friction modification system, 2017. In Proceedings of the Stephenson Conference: Research for Railways, IMechE, London, UK, 2017, 325-332.

GALAS, R., M. OMASTA, I. KRUPKA and M. HARTL. Laboratory investigation of ability of oil-based



friction modifiers to control adhesion at wheel-rail interface. *Wear*, 2016, 368–369, 230-238.
IF 2.531

SVOBODA, P., D. KOŠŤÁL, R. GALAS, I. KRUPKA and M. HARTL. Tribological behaviour of ultra-dispersed diamond- graphite in liquid lubricants. *Journal of the Balkan Tribological Association*, 2016, 22(4A), 4994-5009.
IF 0.737

GALAS, R., D. SMEJKAL, M. OMASTA and M. HARTL. Twin-Disc Experimental Device for Study of Adhesion in Wheel- Rail Contact. *Engineering Mechanics*, 2014, 21(5), 329-334.

9. Assessment of the supervision process

Very good

The supervision process and the candidate response were standard. The process was based on regular (two-month) meetings and other on-demand discussions with supervisor and specialist. The candidate was always adequately prepared and able to respond to the topics discussed. He was able to exploit new ideas as well as to reflect critical comments. Written work reports and other documents were prepared in time and in sufficient quality. Fulfillment of other obligations arising from the PhD, incl. teaching, leading of student projects and final theses, participation in other research projects etc., was excellent. The candidate was also active in publishing and attending conferences.

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

Very good

The candidate's work was independent, based on discussion with supervisor and supervisor specialist as well as with other experts (oil technology; rail traffic operators; etc). The framework of the PhD thesis was partially directed by research and development grant under the Technology Agency of the Czech Republic entitled „Research and Development of System for Top-of-Rail Friction Management in Rail Transport” (2014-2017), a project that Radovan Galas has worked on. This direction is particularly relevant in field testing; nevertheless, the experiments were fully designed and managed by the candidate. Other directions, like the effect of FM constituents, were defined by the candidate based on the state of the art. The candidate independently planned and co-operated with master and bachelor degree students. In the relevant research topic, he supervised three bachelor and three diploma thesis. All the publications where he is listed as a first author were managed and prepared by him.

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

Very good

The work covers a wide research area with different approaches, starting with basic tribology tests and ending with field tests. Different part carries different contributions on different levels. The part including detailed tribological investigation of the effect of different FM constituents undoubtedly shifts knowledge in the area and also extends into basic research. This is supported mainly by publication in *Tribology International*, Q1 IF journal targeting the papers with the highest scientific quality. The PhD work could be more systematically focused on this area. The second part of the work includes twin-dics and field tests with commercial oil-based top-of-rail products. The part is more oriented to practice, in line with the above-mentioned R&D project. Although there is a limited number of results in the public domain dealing with the influences of oil-based top-of-rail products and relevant safety issues, it cannot be assumed that the knowledge is new for rail industry. On the other hand, the number of relevant publications over the last two years increases, what the candidate's publications also contribute to.



12. Other comments

none

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

16. Date and signature

02/02/2018

Please note

- A. Evaluate categories 9 to 11 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent.
- B. In each category 9 to 11 explain reasons for evaluation using between 100–200 words.
- C. E-mail the completed form to: Klara.Javorcekkova@vut.cz