INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Kazumi Sakai / Kazumi.Sakai@vutbr.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Study of correlation between grease film formations and mechanical losses on various surfaces

4. Principal supervisor
Prof. Ivan Křupka / krupka@fme.vutbr.cz
5. Co-supervisor
/

6. Reviewer
Dr R. Glovnea / R.P.Glovnea@sussex.ac.uk
University of Sussex

7. Overview of the scope of PhD thesis[1]
Very good
There are two main objectives of this thesis: to obtain a correlation between rolling bearings' frictional torque, on one side and greases' formulation on the other; to evaluate the correlation between grease behaviour and their properties. It was found that: 1) Greases' yield stress can be an indicator of bearing torque, when greases with similar thickener are compared. 2) At large speeds grease channelling is responsible for an increase of bearing torque, when there is no resupply of lubricant to the contact. 3) There is no direct correlation between thickener structure and frictional torque performance. 4) There is a correlation between thickener type and film thickness, however thicker lubricant film does not always translate into lower bearing torque. 5) The ability of greases to form thick film was related to the entrainment of the thickener into the contact area, which, in turn depends of the polarity of the thickener.

8. Significance of the topic and clarity of problem statement
Very good
There is a continuous effort nowadays towards increasing efficiency of machine components, reducing the usage of lubricants and increase their working life. The thesis subscribes to this scientific effort, by tackling the area of grease lubrication, with application to rolling element bearings. Rolling element bearings are

[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.

the second most numerous machine components with some 50 billion working at any time across the Globe. Given the fact that the vast majority of rolling bearings are lubricated by grease, efforts for understanding their mechanisms of lubrication in order to reduce friction torque are welcomed. From this point of view the thesis is well timed and relevant to the field of research. The author states clearly the scientific questions which they want to tackle in this research, following a thorough literature review.

9. Knowledge of existing literature

Good

There are a huge number of papers published on various aspects of grease lubrication. The author had a difficult task in sieving through and selecting those publications most relevant to the topic of the thesis. I have two comments to make: 1) There is a good number of papers which relevant to various aspects of this thesis which should have been included. For example: Eriksson, et al (2000), Proc. Inst. Mech. Engrs., 412, part J., pp. 309-316; Errikson et all (2000), Proc. Inst. Mech. Engrs., 412, part J., pp. 317-325; Cann, P.M., and Lubrecht, A.A., (2007, J. Phys., D: Appl. Phys., 40, pp. 5446-5451; 2) Papers on grease lubrication employing methods other than optical interferometry, should have been included; for example papers by Dyson and Wilson A. R.

10. Choice of methods and technical soundness

Very good

The methods used in this experimental investigation are appropriate and technical sound. The method of optical interferometry has proved to be most accurate in simulating real-life operation of EHD contacts. Moreover the method of optical colorimetric interferometry developed at the host laboratory has received wide appreciation from the researchers in the field. In my opinion a brief presentation of the principles of optical interferometry, with relevant references should have been included. The author also introduces a test rig for measuring the friction torque in rolling element bearings, however it is not clear whether that rig was designed and manufactured within the research frame of this thesis. This should be clarified. A schematic of this rig and detailed explanations of the operation should have also been included.

11. Quality, originality and significance of the results

Good

The results are significant in the context of the research carried out in this thesis. Some questions still arise. The load used in measuring the bearing torque was only 50N in redial and axial directions. This is very modest load especially for a medium size bearing. The author did not give an explanation to this choice. This is more striking when the bearing torques measured were in the region of 10 mNm to 50 mNm. It would have been interesting to see some results carried out a varying load so the load effect on the torque can be evaluated. The results concerning the behaviour of grease lubricants in dented surfaces are original and in my view their novelty and relevance should have been emphasised more in the thesis.

12. Quality of attached papers

Good

The author has published an important number of research papers and has presented his work at high calibre, international scientific event. These show sustained research commitment and effort over a long period of time. The published papers as well as the conference presentations are totally relevant to the topic of the thesis and are of good quality. The papers on the viscoelastic properties of greases and on the

effect of the formulation of greases upon the bearing torque are particularly notable. They are published mainly in Tribology Online, a high quality research journal, although I would have preferred to see a wider range of journal in this list.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Good
This thesis is the culmination of continuous research carried out by the author over a number of years. It approaches a topic which is of great actuality, enriching our understanding of the behaviour of the operation of greases in rolling element bearings. This potentially can lead to better design of grease as well as the surfaces of rolling element bearings, for better efficiency and durability. My assessment is that the thesis should have emphasised more strongly and clearly the novelty of the results and the contribution of the research to the field. Very often statements showed uncertainty or hesitation. In a thesis, especially in the discussion and conclusions chapters words like possible, could, seem, should be replaced by stronger words like believe, should, conclude, etc. I also expected more in terms of interpretation of the results which would reveal the physics of the phenomena described. On the other hand the thesis was written as if a potential reader has as close familiarity with the work as the author himself. Hence more detailed explanations were needed in some parts.

14. Other comments
The English is passable but a reader needs in places, to make great effort to understand the meaning of various statements. I have made a number of corrections as highlighted in the attached text, which I believe are crucial to improving the standard of the thesis.

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	
10/06/2018	

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*

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INEGI - INSTITUTE OF SCIENCE AND INNOVATION IN MECHANICAL AND INDUSTRIAL ENGINEERING

7. Overview of the scope of PhD thesis[1]
Good
The candidate proposes to find the relationship between the grease formulation and the tribological behaviour, in what concerns rolling bearing friction torque. With the work performed for this thesis, the author also aims to understand the correlation between the grease formulation and its rheological parameters, mainly yield stress and viscosity. The ability to form a lubricant film and the ability of the grease of adapting to different surface conditions was also the main focus of the candidate. In order to fulfil these objectives, the applicant performed rheological measurements of the tested greases, analysed their thickener structure, performed film thickness and traction measurements in ball-on-disk devices and has performed full rolling bearing tests in a dedicated test rig. The candidate correlated the behaviours observed in rolling bearings tests with the film thickness measurements and, based on the results obtained from rheology and electronic microscopy, tried to identify which grease property correlated better. Although some of the conclusions are open to discussion, the candidate performed an interesting analysis, clearly explaining, in his understanding, the behaviours which he observed experimentally. The author attributed the different film thickness and rolling bearing torque observed at high and low speeds, to the breakdown of the thickener material into smaller elements. This behaviour was also used to explain the different flow patterns found at the downstream of the contact. Since the tested greases are formulated with the same base oil, the differences between greases where attributed to the different

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chemical characteristics (polarity) of their thickeners but also its rheological properties (yield stress and apparent viscosity).

8. Significance of the topic and clarity of problem statement

Good

Grease lubrication has a very small share of the lubricants' market when compared to oil. However, millions of rolling bearings are used worldwide and the vast majority of them are actually grease lubricated. Furthermore, as stated by the candidate in the introductory chapter, the mechanisms which rule grease lubrication are far from being understood, hence the significance of this study. Friction in mechanical components constitutes up to 40% of the total power loss of a mechanical system and the rolling bearings can be one of the major contributors to this friction loss. Therefore, any study which contributes to the understanding of grease lubrication in rolling bearings can greatly contribute to the development of energy-efficient products. Besides, the number of publications related to grease lubrication and/or related to rolling bearings friction torque are very small, which makes the candidate's work a valuable contributor to the research field. The applicant presented an interesting introduction to the research topic and also a well-founded literature review which allowed him to clearly identify his work's objectives and the problem statement.

9. Knowledge of existing literature

Good

The candidate presents a very comprehensive chapter on the state of the art regarding grease lubrication, showing a very good knowledge on the most recent investigations and contributors to the research field. Although I would have liked to see the literature review presented in a different order, the candidate covers all the major topics from rheology of the greases, thickener structure and chemistry, EHL film thickness, surface texturing, grease behaviour in rolling bearings and rolling bearings friction torque. However, I was expecting to see a more detailed section on grease rheology (which could justify the choice of the methods used later on) and on the grease friction behaviour, which is very important when analysing the rolling bearing friction torque.

10. Choice of methods and technical soundness

Good

The main results reported in the candidate's work are obtained from simple ball-on-disk and full rolling bearing tests. It is necessary to first understand the grease lubrication mechanisms in simple ball-on-disk tests in order to understand the full rolling bearing tests, which the candidate did successfully. The ball-on-disk tests are very important because they allow to evaluate the grease behaviour in a more controlled environment, allowing to measure film thickness or friction with all parameters set constant and only changing one variable at time. These results can then be extrapolated to contacts that are more complex and more difficult to understand. The full rolling bearing tests are also of utmost importance because they represent the main-application of grease lubrication. In this type of tests, it is not possible to control the slide-to-roll ratio and grease replenishment, and the successive-over rolling can also affect the results. However, some of the operating conditions were not well justified and their presentation was sometimes confusing. The author performed tests with Li thickened greases which are the most used greases and have the largest share in the market.

11. Quality, originality and significance of the results
Good
The candidate presents a very large amount of experimental work, which is the base of the scientific method. These experimental results were measured in different equipment in order to answer the hypothesis stated in the aim of the thesis. These results are of good quality and those results related to the film thickness of grease-lubricated contacts in the presence of surface indentations are particularly original and never seen before. Grease lubrication is far more complex than oil lubrication, grease can be particularly chaotic and the deviations of the measurements can be very high due to the amount of variables involved (grease spreading, sample homogeneity, temperature and humidity deviations, etc). Therefore, performing experimental work with greases can be very difficult and sometimes frustrating, but it is very important to make a large experimental work to have statistical background. The results found by the author come to confirm and validate the results of other authors while shedding light on some behaviours, which are new and difficult to attribute to a single parameter or grease characteristic. The results are very significant, although their analysis could have been more thorough. The presentation and analysis of the results of film thickness in the presence of surface indentations could particularly be improved.

12. Quality of attached papers
Satisfactory
The candidate presents 5 papers in international journals and 7 papers in conferences. However, only 2 from the 5 papers in international journals are directly related to this PhD thesis. Regarding the conference papers, the candidate has participated in some important conferences in the tribology field (NORDTRIB, ECOTRIB, ITC and STLE) where the work developed during this thesis was presented.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Good
The candidate has performed a well-founded, solid work. The document is well organized in general, despite the English being poor. The main strengths of the thesis are the large amount of experimental work performed with a difficult product - lubricating grease - and the correct choice of methods to evaluate the hypotheses. The main weaknesses are the lack of justification of testing conditions and the poor analysis of some of the results. Still, the conclusions found are interesting and valuable for the tribology research field.

14. Other comments
The written English needs revision.

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.
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