



## Review of Doctoral Thesis

### 1. PhD candidate

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### 2. Name of PhD programme

Design and Process Engineering (Mechanical Engineering Design)

### 3. Title of PhD thesis

Development of film thickness in elastohydrodynamically lubricated compliant contacts

### 4. Principal supervisor

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### 6. Reviewer

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### 7. Overview of the scope of PhD thesis<sup>1</sup>

#### Very good

The presented manuscript deals with lubrication of gears made of soft materials such as polymers, as it is nowadays a common situation, though lubrication literature mainly considers hard rubbing surfaces. The experimental campaign involves a ball-on-disc tribometer and a dedicated optical interferometry technique. The main findings are an experimental evidence of the formation of a lubricant film in all tested situation (involving a non-zero entrainment speed). In total 3 published papers and 1 conference proceeding are discussed. Above the glass transition temperature, as the entrainment speed increases, the circular shape of the contact is lost, becoming wide elliptical. But contrary to literature on soft EHL, the minimum film thickness stays at the side lobes (not the exit) of the contact. As the temperature increases, the film thickness surprisingly increases (compared to hard-EHL), presumable because of the influence of temperature on constitutive polymer material behaviour. Below the glass transition temperature, isoviscous-elastic EHL models from literature suit best the shown experiments (40°C), while at higher temperature, piezoviscous-elastic models are better. This is a counter-intuitive result that is explained by the fact that temperature influence both the lubricant rheology and the viscoelastic response of the polymer.

<sup>1</sup> 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

##### Excellent

The significance of the proposed thesis is excellent since few works in the literature address the soft-EHL problem. However, it is nowadays a very common challenge. More than that: the literature results are not consistent and conclusions often differ. Most of the literature results are based on numerical modelling and until now very few experimental evidences were shown. This work is then a perfect piece of work to fill the gap. The manuscript exposes very clearly the objectives and the scientific questions to be answered in the conclusion, as well as the hypotheses related to this work.

#### 9. Knowledge of existing literature

##### Excellent

The state-of-the art section of the manuscript is a very substantial section, covering especially elastohydrodynamic lubrication (EHL) regime and subregimes such as isoviscous-elastic, piezoviscous-elastic (etc.) and transition regions, since such soft contact often operates in-between distinct regimes. A focus is made on soft elastohydrodynamic lubrication regime (i.e. using soft materials), and the (few works relating the) main characteristics of lubricant film thickness in this situation, including semi-analytical film thickness prediction models. Though the very disparate knowledge in the literature concerning soft -EHL (often not consistent), the author succeeded perfectly in giving a clear and exhaustive view of the literature.

#### 10. Choice of methods and technical soundness

##### Very good

The author proposes a well-established optical interferometry technique to measure film thickness in EHL ball-on-disc contacts. The novelty of the approach, which also explains why few experimental works have been done yet, is the difficulty to find transparent (and optically ideal) polymer materials through which film thickness can be measured. Different ball-on-disc configurations were tested included BK-7 or sapphire disc on polymer ball (either polyamide, PEEK, polyacetal) or (the other way around) PMMA disc on steel ball. Unfortunately, the polishing of polymer balls was not efficient enough to guaranty a small enough roughness, and only the PMMA disc on steel ball configuration was studied. With this choice, the author was able to conduct a very sound and high-quality experimental campaign, discussed in the three published papers.

#### 11. Quality, originality and significance of the results

##### Very good

The results shown in the manuscript and through the published papers are significant, as exposed earlier, since few works of that kind exist in the literature. The measured film thickness, with high precision, was compared with existing models of the literature. Interesting discussions arised concerning the influence of temperature, load and entrainment velocity on film thickness and a deep understanding was proposed concerning the involved mechanisms, concerning either the piezoviscous response of the lubricant or the viscoelastic constitutive polymer material behaviour. Unexpected results were sometimes found, compared to existing literature and the author always proposed a temptative explanation based on sound physical basis.

## 12. Quality of attached papers

### Very good

Linked to the manuscript are three published papers in international, high-quality, peer-reviewed journals. They are the basis on which the results section of the manuscript is made of. They are very well written, very clear and original. The findings are very sound. The author explores a new lubrication framework and discussed the relevance of the existing models from the literature. He even proposes to integrate the viscoelastic response of PMMA into existing (H&D) EHL film thickness models, and achieve with this attempt a very good agreement at high temperature. However, the lubrication regime by itself is not well predicted yet, showing that this topic would probably give scientific challenges for several decades to come.

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

### Very good

This manuscript represents a very good piece of work. The experimental strategy is very relevant, and the author managed to find acceptable enough surface conditions with new (polymer) materials to be able to measure film thickness with optical interferometry technique. The principal strengths of this work are a very deep understanding of the state-of-the-art and very good experimental skills. The new results represent a very useful basis to be able to challenge mostly numerical results from the literature on this (relatively little explored) soft-EHL topic. Main weaknesses are linked to the limitations of the available experimental possibilities. Other polymers than PMMA should be consider in the future to be able to take some height on these results.

## 14. Questions and comments

While reading the manuscript, some questions arise. In some configurations, film thickness results are in good agreement with hard-EHL usual prediction formulae. This is surprising since polymer surfaces are considered above glass transition temperature where the viscoelastic behaviour should be dominant. Also, the fact that no absolute minimal film thickness was found at the exit part of the contact (but always at the side lobes) contradicts the literature. With two different fluids (TOTM and SQL), the central film thickness is either greater or smaller than the prediction from semi-analytical models from the litterature. But the range of entrainment velocities is also very different, meaning that the loading cycle of the polymer surface is different and so is the viscoelastic response. It is mentioned that the slide-to-roll ratio (SRR) has almost no effect on film thickness, except at pure sliding, where the film thickness expectedly decreases. But the thermal effects that may be the cause of this result could be investigated deeper. For example, do we expect a difference between PMMA disc at rest or steel ball at rest (i.e.  $SRR = +2$  or  $-2$ ) ? Heat transfers in the solid at rest would be probably very different between these two situations.

## 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



20/03/2024

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](mailto:Klara.Javorcekova@vut.cz)