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24th International Colloquium Tribology

Industrial and Automotive Lubrication

Conference Proceedings 2024

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Industrial and Automotive Lubrication
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Technische Akademie Esslingen

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Preface

Challenging times demand swift and effective solutions to problems. Since the last 5 years, we have been confronted with several serious global challenges. On the one hand, there are geopolitical „flashpoints“ where science unfortunately offers limited guidance, as the ball is mainly in the political arena. On the other hand, the pressing issue of climate change repeatedly reminds us of our vulnerability.

In addition, questions regarding sustainable energy supply, resource conservation and the urgent need to take completely new pathways in transport and production to combat global warming are paramount. Buzzwords like e-mobility, hydrogen, circular economy, and digital transformation, while initially rather having been empty words, need to be filled with life, realized by courageous political decisions enabling significant implementation of novel technologies. The multifaceted nature of these issues demands interdisciplinary solutions. Tribology, as the science of friction, wear, and lubrication, is uniquely positioned to address these challenges due to its interdisciplinary nature.

As already once noted by the gifted Galileo Galilei, “in matters of science, the authority of thousands is not worth the humble argumentation of a single person”. This underscores the significance of conferences that bring together scientists with diverse perspectives from all over the world. It‘s through these interactions that innovative ideas can develop and mature, potentially providing solutions to critical contemporary questions.

The **24th International Tribology Colloquium** of the TAE in Ostfildern offers an ideal communication platform for representatives from industry and science to come together and discuss approaches to solutions for current tribological issues. The conference covers a wide range of tribological topics to advance solutions to challenges as outlined above. Accordingly, 5 main topics were defined that illustrate the main fields of current research in tribology:

- New trends in lubricants and additives
- Coatings, surface interactions and underlying mechanisms
- Machine elements and their application in tribology
- Computational methods and digital transformation in tribology
- Test and measurement methodologies

The conference will be rounded off by excellent plenary and keynote talks on topics of mobility, data handling and efficiency enhancement of machine elements. Last but not least, we invite our “Young Tribologists” to the curtain with 2 dedicated sessions to report on ongoing research work in tribology in their early careers.

We are looking forward to a pro-active exchange and stimulating discussions and hope that curiosity will drive us all to advance the field of tribology in its entirety. Together, we can address the multifaceted challenges presented by global crises and create a brighter future.

Yours sincerely,
Nicole Dörr, Katharina Völkel, Max Marian & Carsten Gachot
Steering Committee

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* not available at the time of publication

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Plenary Lectures

Sustainability in Winter Sports – The Tribological Perspective

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1. Introduction

This contribution highlights the topic of sustainability in winter sports with a focus on tribology, i.e. processes related to friction, lubrication and wear. It will be shown what measures have been taken in skiing and skating to conserve energy and resources. Since snow and ice have unique properties related to gliding, it is assessed how these properties are changed by substitute products. Furthermore, it is explained how the tribological mechanisms change, for example, when switching from the runner – ice system to a runner – polymer system.

2. Example I: Ski Jumping

Ski jumps are operated in winter as well as in summer. Therefore, there are various friction partners with which the skis make contact, such as e.g. snow, ice, porcelain, various plastic mats and grass. All the above-mentioned materials result in a wide range of friction coefficients.

In the inrun of a ski jump as well as in the landing hill, the friction in the direction of travel must be significantly lower than perpendicular to it. Inside the inrun, this is taken into account in that movement perpendicular to the direction of travel is not possible due to side restraints. In the landing hill, this requirement is implemented by the structure of the mats, which provide a certain degree of resistance when the skis are edging.

Naturally, different inrun tracks exist for winter and summer operation. In winter one finds tracks made of snow or ice, while in the rest of the year tracks made of metal or metal with sliding bodies are used. To reduce friction, these tracks are rinsed with water. To further reduce friction, the tracks are given hemispherical, partially flattened knobs. Plastic (POM), ceramic or porcelain are used as material. In some cases, embossing is also used to structure the metal track in such a way that nubs are formed, see Fig. 1.

While in the inrun the lowest friction is required, in the landing hill there is the demand for a safe landing, which requires a certain friction value for lateral guidance. Since the 70's, mainly green mats consisting of a multitude of individual threads have proven their worth, see Fig. 1a. Like the inrun, the mats must also be watered to reduce friction. When magnified it can be shown, how the mats retain water. The used plastic is hydrophilic and wets very well. If this were not the case, the water would run through the mat into the ground and the water demand of the hill would be very high.

Friction measurements with a portable tribometer proved the clear difference between dry and lubricated friction.

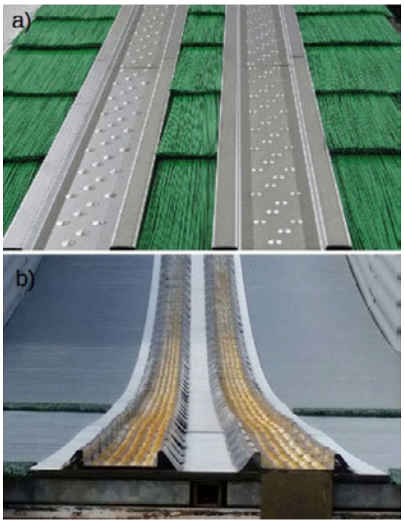


Fig. 1: Different kinds of inruns of a ski jump.

The type of mat presented in Fig. 2 was installed on a small hill at Steinbach-Hallenberg in 2018. Due to the combination of plastic fiber and loop shape, smaller friction was achieved with these mats than on their green predecessor. Due to the fiber bundles, the mats hold significantly more water. This reduces the water consumption of the system.

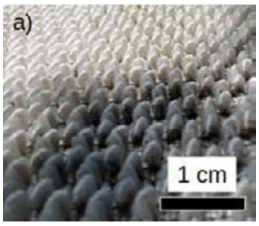


Fig. 2: A modern type of mats.

As with the inrun, the tribological mechanism can be found in the hydrodynamics. The water stored in the fiber composite of the mats serves as a lubricant. Since contact between the ski and the mat is very rapid during landing, there is not enough time for the water to be forced out of contact and a lubricating effect is created, see Fig. 3.

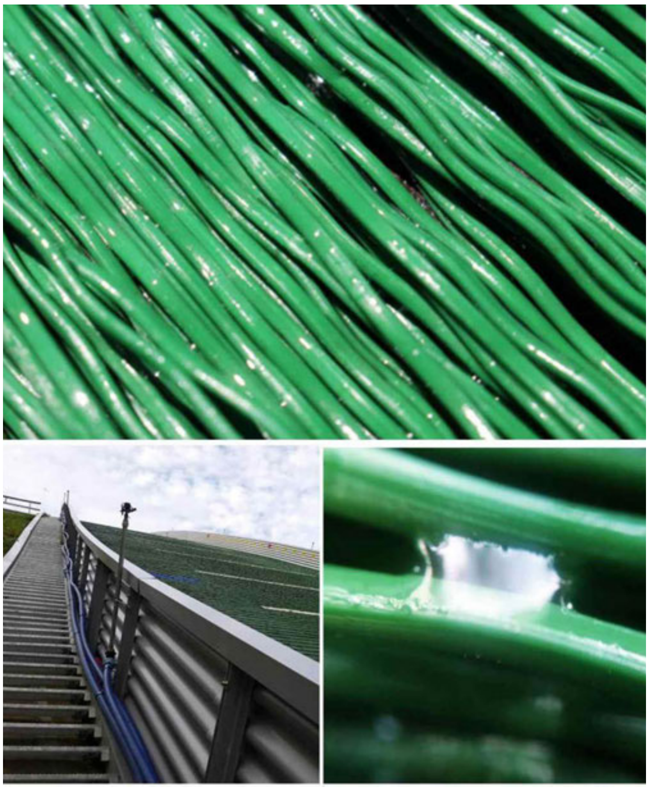


Fig. 3: Mats and watering system for lubrication.

3. Example II: Ice-Skating and Bobsledding

Skating on artificial ice usually refers to activities such as ice skating and ice hockey. Artificial ice in the form of polymer sheets is often used in ice halls, ice rinks or ice parks to provide year-round ice activities. Artificial ice offers the advantage of being less sensitive to temperature fluctuations and does not require any energy for cooling.

The ice substitute, like most ski bases, is made of ultra-high molecular weight polyethylene filled to the limit with oils. The oil diffuses to the surface, where it forms a very thin lubricating film that is imperceptible by hand but efficiently separates the friction partners. A few nanometers are sufficient for this. With additional contact pressure, the oil is pressed out of the sintered granules and improves lubrication. As a result, freshly ground runners glide better because the contact pressure is higher. However, the fact that the coefficient of friction is higher than against ice, can also be read indirectly from the wear. According to users, the skates become dull about twice as fast as against ice.

If you compare the friction mechanisms, you will notice that when the skate and ice come into contact, the friction power causes the ice to melt near the surface and forms the lubricating water film. This water cannot be formed by pressure alone. In the case of skate-polymer contact, however, the contact pressure plays the decisive role, because it conveys the lubricant from the interior of the polymer to the surface.

For the sport of bobsleigh, it was shown that with polymer sliding surfaces, that do not need to be cooled or watered, training and competition are possible as well.

Fig. 4: Bobsled track.

As an example, a completely new and innovative push-off training track was developed and already put into use, see Fig. 4. This training track can be set up at any location and does not require a specially cooled building. This achieves several advantages at once. Besides saving cooling power, there is no need for ammonia as the chemical basis of cooling. Since the track can be set up anywhere, realistic training is possible even for smaller clubs that cannot afford to train in a “cold store” and the transportation costs. If the track is used in a social environment, e.g. at city festivals, many new possibilities for recruiting new talent open up.

The sliding mechanism is the same as described for skating. Since the bobsleigh runners have considerably more contact surface with the polymer, a higher mass is required to build up the necessary pressure. The total mass of the mono bobsleigh shown above is 248 kg. Thus, the necessary pressure can be built up and low friction can be ensured.

4. Summary

Sustainability in winter sports is of great importance to protect the environment in which we enjoy these activities. By conserving resources, protecting nature and promoting responsible behavior among winter sports enthusiasts, we can ensure that future generations will be able to experience the same fascination and enjoyment of winter sports. In addition, mobile facilities can ensure that more people find their way to this sport. By promoting sustainable tourism, we can also support local communities while maintaining the economic benefits of winter sports. Combining fun and responsibility is the key to a sustainable future in winter sports.

Minimizing CO_2 Emissions and Maximize ROI: Implementing Known Tribology and Design for Zero Principles for a Carbon Neutral Industry

Roland Larsson[1] **and Victoria Van Camp**[1]

[1] Division of Machine Elements, Luleå University of Technology

1. Introduction

The world is undergoing a significant transformation in the economy and industry to achieve Net Zero CO2 emissions by 2050 [1,2]. Tribology will play a crucial role in this transformation. Machinery, including steel plants, wind turbines, vehicles, and e-motors, will require upgrades and retrofits, with new designs targeting neutral or negative CO2 emissions while minimizing the use of scarce materials. The primary challenge lies not in discovering new technologies (although this is also necessary) but in implementing the technology and knowledge we already possess and doing so quickly.

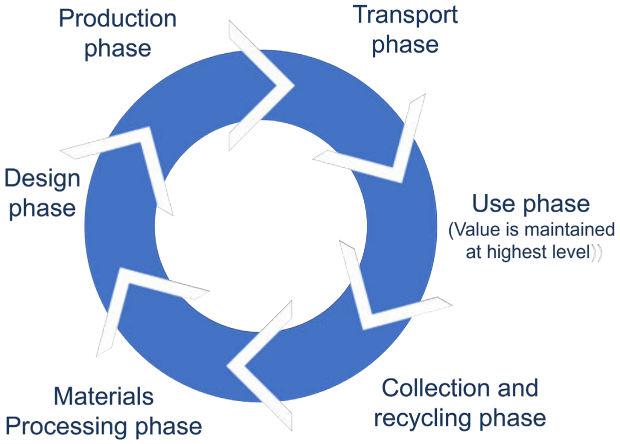
It is often argued that a 'circular economy' is the solution to achieving CO2 neutrality, as it involves keeping existing resources in a closed loop within the atmosphere. While the reuse of materials and parts must increase, extending the technical lifespan of machinery well beyond current warranty periods offers a shortcut to improving the financial return on existing assets and justifying new investments. This can be achieved through innovative design, employing 'Design for Zero' principles, and through strategic maintenance and upgrades of existing equipment.

Here, we explain why 'circularity' for industrial machinery is not sufficient and why extending the useful life of equipment to its technical limits is crucial for both minimizing CO2 emissions and improving return on investment (ROI).

2. Circular economy

A circular economy is an economic system designed to minimize waste and maximize resource efficiency. Its goal is to depart from the traditional linear "take-make-dispose" model by promoting continuous product use, refurbishment, upgrading and recycling/reuse. In a circular economy, products are intentionally designed for durability, repairability, and recyclability, while resource use and waste are minimized both through the original design as well as through responsible consumption and production practices. This approach contributes to conserving natural resources, reducing environmental impacts, and establishing a more sustainable and resilient economic system.

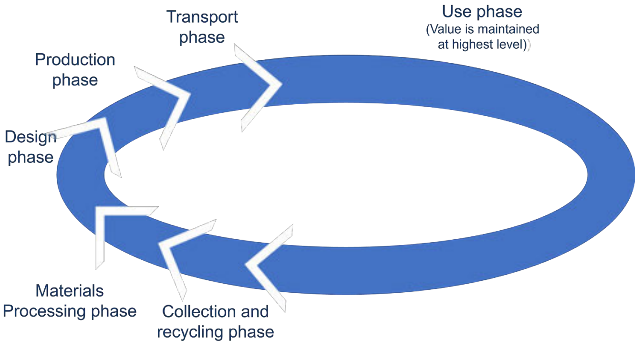
One approach to implementing a circular economy is to transform the business model in a way that benefits all involved parties by ensuring the long, trouble-free service life of machinery. This can be achieved through methods like leasing contracts or delivering the functionality as a service, often referred to as Product-Service Systems (PSS).



3. Elliptical economy

However, Product-Service Systems (PSS) were not initially conceived with the goal of achieving Net Zero emissions but were primarily driven by economic factors, such as cost reduction and increased profitability. Done right, PSS also adds value for customers and gives continuous opportunity for customer feedback and improvements. PSS gained prominence as businesses recognized its potential to align with sustainability objectives and enhance resource efficiency, although the primary motivations may differ among companies.

By integrating sustainability considerations into PSS, it becomes evident that profitability is directly linked to extending the machinery's operational lifespan as much as possible. This extended use-phase significantly contributes to the growth of a well-functioning circular economy, which can be likened to an ellipse rather than a circle [3].



4. The role of tribology

The role of tribology in prolonging the use-phase is obvious. Previous research by Holmberg et al. [4,5] and Woydt [6] have demonstrated that the service life of machinery can be significantly enhanced when wear resistance is given top priority during the design process. Traditional linear business models have not actively promoted this concept, but in an elliptical economy business model, there are compelling reasons to leverage existing knowledge in surface enhancement for promoting longevity.

Proper maintenance of existing assets has always been important in industry and power plants, mainly driven by high costs for unexpected downtime [7,8]. With connected machinery and machine learning (AI), maintenance practices and the ability to take proactive actions to prolong machine technical life is here to stay. In addition, the sustainability effects of predictive maintenance and data analytics are substantial, with their help, expected life of modern wind turbines are now of the order 30-35 years compared with previous 15-20 years. This substantially reduces lifetime CO2 emissions per produced kWh [9, 10].

Significant changes are required during the design phase in an elliptical economy, with concepts like modularization [11] becoming crucial. Building machinery in modular segments of varying characteristics provides design flexibility and improves maintainability and future (in the design phase yet unknown) upgrades. For instance, surfaces vulnerable to wear can be placed within easily replaceable modules, while parts of the load-bearing structure that remain durable over time can be housed in separate modules. Functionality that may require upgrades to new, as-yet-uninvented technologies can be incorporated into a different module.

The climate impact of most mechanical components is largely determined by energy consumption during the use phase, with frictional losses being particularly prominent in components like rolling bearings. Thus, it is imperative to prioritize low-friction solutions when designing machinery for the elliptical economy. Also, maintenance practices such as maintaining shaft alignment and replace worn parts, including seals, before they impact friction losses has substantial impact on energy consumption.

5. Conclusions

In the field of tribology, we already possess technologies that can be effectively used to significantly reduce wear rates and frictional losses. The reason these methods have not been consistently applied is twofold: economic viability and a lack of awareness among engineers. A product's life cycle cost encompasses all phases within a circular (or linear) economy. Typically, these costs are distributed among various stakeholders, with each value chain contributor primarily focusing on their own profitability. When all participants in the cycle – the life cycle value chain –collectively share the total cost, it becomes more economically advantageous to extend the use-phase and employ more costly methods to minimize wear and friction. Moreover, the global shift towards sustainability will inevitably result in higher resource utilization costs and increased emissions fees, further making the adoption of tribological solutions at a higher cost feasible. As a result, the value of tribological solutions will rise, emphasizing the need for even more effective solutions. Finally, the tribologists themselves must prioritize sustainability, using fossil-free and renewable materials in their work.

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Dynamic Properties of Lubricants for Electric Vehicles

EV fluids

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1. Summary & Introduction

Evolving needs in lubricants requires better understanding and testing. In this presentation, the requirements in lubricants for electric, hybrid, and internal combustion engine (ICE) vehicles will be compared to identify key performance characteristics. Further discussion will be focused on our recent research. Our recent study has revealed that certain fundamental properties of lubricants alter under working and electrified conditions. Specifically, we investigated the properties of working lubricants, their electrical and thermal properties. In establishing relationship between electrical conductivity and a fluid oil film thickness, results indicated the non-ohmic behaviour of a lubricating film in the hydrodynamic regime. In probing thermal performance, we found out that thermal properties of lubricants depended on the shear that are not constant as being widely accepted. These findings are beneficial to design effective EV lubricants.

2. Working Fluids

A lubricant becomes a working fluid when a mechan-ical system, such as a vehicle, is in operation. To satisfy the working conditions of an electric vehicle, new challenges arose over the electrical and thermal properties of the fluid. The current understanding about the properties of lubricants has been on the fluidic viscosity, [1-3] film formation, [4-6] and the frictional respond to shear [7, 8]. For the application to EVs, electrical and thermal conductivities are important.

3. Dynamic Properties of Working Fluids

In this research, we constructed a system to success-fully examine the electrical conductivity against the oil film thickness. The thickness and electrical re-sistance can be calculated from impedance. We in-tegreate an electrochemical potential state with a disc-on-disc tribomeer. It allowed us to meaure the capacitor and resitor parallel. If we assume that ca-pacitance is fully contributed from the oil film. It thus has a dielectric constant of 2.1 [9]. The our eq-uition is like the following:

$$R = \frac{1}{Re\left(\frac{1}{Z}\right)} \qquad (1)$$

and

$$t = A\frac{\epsilon\epsilon_r}{Im\left(\frac{1}{Z}\right)/\omega} \qquad (2)$$

where R is the resistance, Z is the impedance sub-tract the impedance of the shorted measuring system $Z = Z_{measured} - Z_{shorted}$. A is the nominal area of contact, $\varepsilon\varepsilon_r$ is the dielectric constant, ω is the angular frequency of the applied voltage. Then *Re* and *Im* take the real and imaginary part of a complex number, respectively.

Our data showed that, interestingly, there was a non-ohmic behavior of the fluid in the hydrodynamic regime.

Further experiments were conducted, and it showed that the properties of fluids are affected by a few factors. The study on thermal performance of a mineral oil and polyalphaolefin (PAO) was also carried out. Data gathered showed that the thermal properties of fluids are affected by the shear stress that has not been widely understood.

4. Conclusion

Fluids' behave differently when under a share force than static. In this work, we experimentally studied the non-ohmic behavior of working fluids in they are in the hydrodynamic regime. We electrically measured the oil film thickness against its temperature. Our restuls showed that the „dynamic" thermal conductivity of a mineral oil was 0.25mW/K and that of a Poly-alpha-olefin (PAO) oil was 0.2mW/K, when the speed/load of the tribometer was set at 100cm/Ns. These data indicated that commercial lubricants for conventional vehicles could be improved in order for them to be adapted to electric vehicles. Detailed discusison as well as thermal conductivities will be provded during presention.