



Published by  
Priv.-Doz. Dipl.-Ing. Dr. techn. Nicole Dörr  
Univ.-Prof. Dr.-Ing. Carsten Gachot  
Dr.-Ing. Max Marian  
Dr.-Ing. Katharina Völkel



# 24th International Colloquium Tribology

**Industrial and Automotive Lubrication  
Conference Proceedings 2024**

**24<sup>th</sup> International Colloquium Tribology**  
Industrial and Automotive Lubrication  
23<sup>rd</sup> to 25<sup>th</sup> January 2024  
Technische Akademie Esslingen



## **Published by**

Priv.-Doz. Dipl.-Ing. Dr. techn. Nicole Dörr

Univ.-Prof. Dr.-Ing. Carsten Gachot

Dr.-Ing. Max Marian

Dr.-Ing. Katharina Völkel

# **24<sup>th</sup> International Colloquium Tribology – Industrial and Automotive Lubrication**

Conference documents 2024

## **Bibliografische Information der Deutschen Nationalbibliothek**

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.dnb.de> abrufbar.

The German National Library lists this publication in the German National Bibliography. Detailed bibliographic data are available in the Internet at <http://dnb.dnb.de>

The work including all its parts is protected by copyright. Any use outside the narrow limits of copyright law without the consent of the publisher is inadmissible and punishable. This applies in particular to reproductions, translations, microfilming and storage and processing in electronic systems.

The present work was created with great care. However, errors cannot be completely ruled out. Neither the publisher nor the authors or publishers therefore accept any liability for the correctness, topicality and completeness of the work and its electronic components.

Das Werk einschließlich aller seiner Teile ist urheberrechtlich geschützt. Jede Verwertung außerhalb der engen Grenzen des Urheberrechtsgesetzes ist ohne Zustimmung des Verlages unzulässig und strafbar. Das gilt insbesondere für Vervielfältigungen, Übersetzungen, Mikroverfilmungen und die Einspeicherung und Verarbeitung in elektronischen Systemen.

Das vorliegende Werk wurde mit großer Sorgfalt erstellt. Fehler können dennoch nicht völlig ausgeschlossen werden. Weder Verlag noch Autoren oder Herausgeber übernehmen deshalb eine Haftung für die Fehlerfreiheit, Aktualität und Vollständigkeit des Werkes und seiner elektronischen Bestandteile.

© 2024. Alle Rechte vorbehalten.

expert verlag  
Ein Unternehmen der  
Narr Francke Attempto Verlag GmbH + Co. KG  
Dischingerweg 5 · D-72070 Tübingen  
E-Mail: [info@verlag.expert](mailto:info@verlag.expert)  
Internet: [www.expertverlag.de](http://www.expertverlag.de)

Technische Akademie Esslingen e. V.  
An der Akademie 5 · D-73760 Ostfildern  
E-Mail: [maschinenbau@tae.de](mailto:maschinenbau@tae.de)  
Internet: [www.tae.de](http://www.tae.de)

Printed in Germany

ISBN 978-3-381-11831-1 (Print)  
ISBN 978-3-381-11832-8 (ePDF)

# 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 **24<sup>th</sup> 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



# Table of contents

---

<b>P</b>	<b>Plenary Lectures</b>	
<b>P.1</b>	<b>Sustainability in Winter Sports – The Tribological Perspective</b> Matthias Scherge	<b>23</b>
<b>P.2</b>	<b>Minimizing CO<sub>2</sub> Emissions and Maximize ROI: Implementing Known Tribology and Design for Zero Principles for a Carbon Neutral Industry</b> Roland Larsson, Victoria Van Camp	<b>25</b>
<b>P.3</b>	<b>Dynamic Properties of Lubricants for Electric Vehicles</b> Yan Chen, Hong Liang	<b>27</b>
<b>P.4</b>	<b>E-Fuels and Tribology</b> Lars Hummel	<b>*</b>
<b>P.5</b>	<b>Supporting Mobility Transition – Alternative Energy Carriers in Tribology</b> Marcella Frauscher, Adam Agocs, Charlotte Besser, Michael Adler, Hannes Hick	<b>29</b>
<b>P.6</b>	<b>Towards Superefficiency</b> Thomas Lohner, Constantin Paschold, Karsten Stahl	<b>31</b>
<b>P.7</b>	<b>The Data Science Frontier in Tribology</b> Nick Garabedian, Iliia Bagov, Malte Flachmann, Nuoyao Ye, Miłosz Meller, Floriane Bresser, Christian Greiner	<b>33</b>
<b>1</b>	<b>New Trends in Lubricants and Additives</b>	
<b>1.1</b>	<b>EV-Lubricants and Additives</b>	
<b>1.1.1</b>	<b>Lubricants Technology for Improving the Protection Performance of Reduction Gears in Transaxles for Electric Vehicles</b> D. Takekawa, H. Tatsumi, K. Matsubara, K. Narita	<b>37</b>
<b>1.1.2</b>	<b>Next-Generation Anti-Wear for EV Lubricants</b> Christelle Chretien	<b>39</b>
<b>1.1.3</b>	<b>Impact of Lubricating Oils on the Performance for Liquid-Cooled Motor and Battery Thermal Control System Applied to Electric Transaxles</b> K. Narita, Y. Nakahara, K. Matsubara	<b>41</b>
<b>1.2</b>	<b>Organic Friction modifiers</b>	
<b>1.2.1</b>	<b>Novel Organic Friction Modifiers with Extended Performance Durability</b> Pieter Struelens, Marion Kerbrat, Micky Lee	<b>43</b>
<b>1.2.2</b>	<b>Effect of Organic Friction Modifiers on Friction and Wear of HDDEO Formulations</b> Gareth Moody, Alexei Kurchan, Sydne Tison	<b>45</b>
<b>1.2.3</b>	<b>Performance Enhancement of Molybdenum-Based Friction Modifiers</b> David Boudreau Sr, Brian Casey	<b>47</b>



<b>1.3</b>	<b>Nanoparticle-based Friction Additives</b>	
<b>1.3.1</b>	<b>Lubricity-improving Additives Based on the Synergy of Nanoparticles and Protic Ionic Liquid</b> Raimondas Kreivaitis, Milda Gumbytė, Artūras Kupčinskas, Jolanta Treinytė	<b>49</b>
<b>1.3.2</b>	<b>Looking for the Perfect Friction Match in the 2D World</b> Prof. Dr. Carsten Gachot	<b>*</b>
<b>1.3.3</b>	<b>In-Operando Formation of Transition Metal Dichalcogenides – Instant Lubrication by Simple Sprinkling of Se Nano-Powder onto Sliding Contact Interfaces</b> Philipp G. Grützmacher, Maria Clelia Righi, Ali Erdemir, Carsten Gachot	<b>51</b>
<b>1.4</b>	<b>Biobased Lubricants, Greases and Additives</b>	
<b>1.4.1</b>	<b>SAPS-free Bio-based Additives for Lubrication in Next-generation Vehicles</b> Xin He, Christelle Chretien	<b>53</b>
<b>1.4.2</b>	<b>Biobased Ionic Liquid for Conductive Lubricants</b> Pieter Struelens, Yen Yee Chong, Micky Lee	<b>55</b>
<b>1.4.3</b>	<b>Introducing a New High-Performance Water-Based Rust Preventive Additive for Formulations Demanding Superior Metal Parts Protection in Severe Corrosion Conditions</b> Clifford Pratt	<b>57</b>
<b>1.5</b>	<b>Base Oils</b>	
<b>1.5.1</b>	<b>Production of High VI Base Oils from Full Conversion Hydrocracker Residue with Solvent Refining</b> Dimitrios Karonis, Panorea Kaframani	<b>59</b>
<b>1.5.2</b>	<b>Base Oil Solvency and High Temperature Deposit Formation in Gas Engine Oils – a Model Study –</b> Thomas Norrby, Marcella Frauscher, Christoph Schneidhofer, Frans Nowotny-Farkas	<b>61</b>
<b>1.5.3</b>	<b>An investigation of Using Ultra-low Viscous Naphthenic Oil in Lubes and Greases</b> Jinxia Li, Mehdi Fathi-Najafi, Thomas Norrby	<b>63</b>
<b>1.6</b>	<b>Lubricants and Additives for Cutting and Drawing</b>	
<b>1.6.1</b>	<b>Tunable Viscosity of PAG and its Application in Sheet Metal Forming</b> Dominic Linsler, Korhan Celikbilek, Stefan Reinicke, Bernd Aha	<b>65</b>
<b>1.6.2</b>	<b>Surfactant Systems with Improved Lubricity for Water Miscible Cooling Lubricants</b> Ludger Bösing, Arjan Gelissen	<b>67</b>
<b>1.6.3</b>	<b>Formulating Next Generation Multi-Metal Wire Drawing Fluids with Multifunctional Amino Alcohols</b> Denis Buffiere, Kathleen Havelka, Amelie Bretonnet	<b>69</b>

<b>1.7</b>	<b>Anti-Oxidation and Anti-Wear Technology</b>	
<b>1.7.1</b>	<b>Antioxidative Action and Tribological Performance of CuDTP as a Potential Additive for Hydraulic Fluids</b> N. Ayame, K. Yagishita, T. Oshio	<b>71</b>
<b>1.7.2</b>	<b>Boundary Lubricant Additive Responses on Steel, Aluminum and Copper Using Twist Compression Tests (TCT) for Multi- metal Lubricant Formulation</b> Ted G. McClure, Alexes Morgan	<b>73</b>
<b>1.7.3</b>	<b>Effect of Phosphonium Ionic Liquid as Lubricant Additive in Gear Oil against White Etching Areas Formation in Bearing Steel</b> Linto Davis, P. Ramkumar	<b>75</b>
<b>2</b>	<b>Coatings, Surface Interactions and Underlying Mechanisms</b>	
<b>2.1</b>	<b>Coatings</b>	
<b>2.1.1</b>	<b>Combination of DLC Coatings and Dedicated Lubricants in order to Achieve Supralow Friction in Highly Loaded Sliding Contacts</b> Johnny Dufils, Etienne Macron, Christophe Héau	<b>79</b>
<b>2.1.2</b>	<b>Numerical and Experimental Analysis of the Tribological Performance of a DLC-Coated Piston Ring-Cylinder Liner Contact</b> Thomas Lubrecht, Nans Biboulet, Antonius A. Lubrecht, Johnny Dufils	<b>81</b>
<b>2.1.3</b>	<b>The Running-In of a DLC-Metal-Tribosystem – A Study on Multiple Scales</b> Matthias Scherge, Joachim Faller	<b>83</b>
<b>2.1.4</b>	<b>Influence of Particles on DLC Coated Journal Bearings</b> Alexander Hofer, Manuel Zellhofer, Thomas Wopelka, Andreas Kübler, Andreas Nevosad, Martin Jech	<b>85</b>
<b>2.1.5</b>	<b>Assessment of Different Coatings on the Friction and Wear Behavior of Differential Shafts for Electric Vehicles</b> Etienne Macron, Johnny Dufils, Christophe Heau	<b>87</b>
<b>2.1.6</b>	<b>Atomistic Insights into the Behavior of Solid Lubricants Under Tribological Load</b> Andreas Klemenz, Michael Moseler	<b>89</b>
<b>2.2</b>	<b>Surface Modification</b>	
<b>2.2.1</b>	<b>Modification of Surface Properties on Various Mg-Based Alloys for Tribological Applications via Plasma Electrolytic Oxidation Process</b> Ashutosh Tiwari, Jörg Zerrer, Anna Buling	<b>91</b>
<b>2.2.2</b>	<b>Mechanical Adhesion with Micropatterned Surfaces</b> Marco Bruno, Luigi Portaluri, Luciana Algieri, Stanislav Gorb, Massimo De Vittorio, Michele Scaraggi	<b>93</b>
<b>2.2.3</b>	<b>Unveiling Extreme Lightweight Potential by PEO Refinement of Innovative Al Alloys</b> Anutsek Sharma, Jörg Zerrer, Genki Funamoto, Anna Buling	<b>95</b>

<b>2.3</b>	<b>Surface Interactions</b>	
<b>2.3.1</b>	<b>The Effects of the Lubricant Properties and Surface Finish Characteristics on the Tribology of High-Speed Gears for EV Transmissions</b>	<b>97</b>
	Boris Zhmud, Morteza Najjari, Boris Brodmann	
<b>2.3.2</b>	<b>Effects of Calcium Detergents on Micro-Pitting of Gear Metals</b>	<b>99</b>
	Akira Tada, Dirk Spaltmann, Kazuo Tagawa, Valentin L. Popov	
<b>2.3.3</b>	<b>Friction Reducing Effect of Lubricants Applied to Organic Fibres</b>	<b>101</b>
	Igor Velkavrh, Nicole Dörr	
<b>2.3.4</b>	<b>Lubricant Inerting – a New Era in Lubrication Technology</b>	<b>103</b>
	Jie Zhang, Janet Wong, Hugh Spikes	
<b>2.3.5</b>	<b>Tribological Behaviour of Polymer Compounds containing Microencapsulated Lubricants</b>	<b>105</b>
	Susanne Beyer-Faiss, Regina Wannemacher, Thomas Witt, Moritz Grünewald	
<b>2.3.6</b>	<b>Early Stages of Tribo-Oxidation in Single Crystalline Copper</b>	<b>107</b>
	Ines L. Kisch, Julia S. Rau, Vahid Tavakkoli, Lisa T. Belkacemi, Baptiste Gault, Christian Greiner	
<b>2.3.7</b>	<b>Effect of Atmospheric Composition on the Friction and Wear of Cobalt-Based Alloys at Elevated Temperatures</b>	<b>109</b>
	Tobias König, Philipp Daum, Dominik Kürten, Andreas Kailer, Martin Dienwiebel	
<b>2.3.8</b>	<b>Thermal-Elasto-Plastic Hydrodynamic Contact Between Rough Surfaces</b>	<b>111</b>
	M. J. Montenegro Cortez, P. Correia Romio, C. M. da Costa Gomes Fernandes, P. M. Teixeira Marques, S. Portron, J. H. O. Seabra	
<b>2.3.9</b>	<b>Micropitting in Rolling-Sliding Contacts: Mechanisms and Prevention</b>	<b>*</b>
	Dr. Amir Kadiric	
<b>3</b>	<b>Machine Elements and their Application in Tribology</b>	
<b>3.1</b>	<b>Efficiency and NVH of engines and power trains</b>	
<b>3.3.1</b>	<b>Simulation-Based Evaluation of Drive Cycle Fuel Efficiency Gains in Gasoline Engines through Engine Oil Viscosity Reduction</b>	<b>115</b>
	X. Simón-Montero, J. Blanco-Rodríguez, J. Porteiro, M. Cortada-Garcia, S. Maroto	
<b>3.3.2</b>	<b>A Study on the Effect of Surface Tension on the Drag Torque of Wet Clutches</b>	<b>117</b>
	Nikolaos Rogkas, Vasilios Spitas	
<b>3.3.3</b>	<b>Influence of the Steel Disk on the NVH Behavior of Industrial Wet Disk Clutches</b>	<b>119</b>
	Patrick Strobl, Katharina Voelkel, Thomas Schneider, Karsten Stahl	

<b>3.2</b>	<b>Gears and transmission systems</b>	
<b>3.2.1</b>	<b>Stick-Slip in Hydraulic Cylinders: New Test Methods &amp; Simulation as a Tool for Selecting Coating Solutions for Piston Rods to Avoid Critical Operating Conditions</b> Giuseppe Tidona, Jürgen Molter	<b>121</b>
<b>3.2.2</b>	<b>Wear Optimization of Roller Chain Drives with Triboactive Transfer Coatings</b> Martin Rank, Manuel Oehler, Oliver Koch	<b>123</b>
<b>3.2.3</b>	<b>Investigation of Polymer Solid Lubricated Steel-Bronze Contacts for Worm Gears Applications</b> Konstantinos Pagkalis, Manuel Oehler, Thomas Schmidt, Michaela Gedan-Smolka, Stefan Emrich, Michael Kopnarski, Oliver Koch	<b>125</b>
<b>3.3</b>	<b>Bearings</b>	
<b>3.3.1</b>	<b>Power Loss in High-Speed Angular Contact Ball Bearings</b> Lúcia B. S. Pereira, Justino A. O. Cruz, Pedro M. T. Marques, Stephane Portron, Jorge H. O. Seabra, Carlos M. C. G. Fernandes	<b>127</b>
<b>3.3.2</b>	<b>Effect of Slip on Piezo-Viscous-Polar Lubricated Multirecessed Hybrid Journal Bearing</b> Vishal Singh, Arvind K. Rajput	<b>129</b>
<b>3.3.3</b>	<b>Film Formation Evolution in Grease-Lubricated Rolling Contacts</b> Shuo Zhang, Georg Jacobs, Benjamin Klinghart, Florian König	<b>131</b>
<b>3.4</b>	<b>Condition Monitoring and Damage Mechanisms</b>	
<b>3.4.1</b>	<b>Enhancing Reliability and Service Life Predictions through Friction Monitoring and Sensor-Embedded Smart Contacts</b> Michael Gless, Anette Schwarz	<b>133</b>
<b>3.4.2</b>	<b>The Effect of Electrical Currents and Lubricant Formulation on Rolling Contact Fatigue</b> Dr. Monica Ratoi	<b>*</b>
<b>3.4.3</b>	<b>Optimisation of EV Transmission Efficiency Using a Tribological Model</b> Dr. Amir Kadiric	<b>*</b>
<b>3.5</b>	<b>Seals and Lubricants for increased Sustainability</b>	
<b>3.5.1</b>	<b>Analysis of Biodegradable Lubricants for Radial Shaft Seals Under Critical Conditions</b> Stefanie Haupt, Dr. Florian Johannes Heiligtag, Maria Frackowiak, Tanja Püler, Danijela Grad, Dirk Fabry	<b>135</b>
<b>3.5.2</b>	<b>Implementing the use of Water Based Environmentally Acceptable Lubricants in the Ship Industry</b> N. Espallargas, E. Valaker, H. Khanmohammadi	<b>137</b>
<b>3.5.3</b>	<b>Enhancing Machining Efficiency and Sustainability of Ti-6Al-4V through MQL with Polymeric Ester Based Metalworking Fluids: A Comparative Study with Conventional Cutting Fluids</b> Ramazan Hakkı Namlu, Kübra Kavut, Hanife Gülen Tom	<b>139</b>

<b>4</b>	<b>Computational Methods and Digital Transformation in Tribology</b>	
<b>4.1</b>	<b>Contact Mechanics</b>	
<b>4.1.1</b>	<b>Simulation of the Local CoF Development in Dynamically Loaded Contact Surfaces (Fretting)</b> Silvano Oehme, Alexander Hasse	<b>143</b>
<b>4.1.2</b>	<b>Static and Dynamic Friction of Elastomers in Dry Conditions</b> Fabian Kaiser, Daniele Savio, Felix Meier, Michele Scaraggi	<b>145</b>
<b>4.1.3</b>	<b>Identification of the Dominant Wear Mechanism in Dry Contacts by Numerical Modeling</b> F. Koehn	<b>147</b>
<b>4.2</b>	<b>Hydro/Elastohydrodynamics</b>	
<b>4.2.1</b>	<b>EHL Simulation for the Design Workflow of Contacts with Limited Lubricant Availability</b> Pastor Cesar, Solovyev Sergey	<b>149</b>
<b>4.2.1</b>	<b>A Novel Mortar Multiphysics Computational Method for Thermal Elastohydrodynamic Lubrication</b> Volker Gravemeier	<b>151</b>
<b>4.2.3</b>	<b>A Full-Scale Numerical Model for the Prediction of EHD Friction in Circular Contacts Lubricated with Pure Glycerol</b> Dr. Deepak Prajapati	<b>*</b>
<b>4.2.4</b>	<b>Development of a Digital Twin through Simulation of PVD/PACVD Coatings</b> Vincent Hoffmann, Emanuel Tack, Nick Bierwisch	<b>153</b>
<b>4.2.5</b>	<b>Lubrication Mechanism Analysis of Textures in Journal Bearings Using CFD Simulations</b> Yujun Wang, Georg Jacobs, Florian König, Weiyin Zou, Benjamin Klinghart	<b>155</b>
<b>4.2.6</b>	<b>Investigation of Wear Protection and Friction Losses in Ultralow Viscosity Lubricant Formulations: A Combined FEM-CFD Simulation</b> Javier Blanco-Rodríguez, Jacobo Porteiro and Marti Cortada-Garcia, Silvia Fernández	<b>157</b>
<b>4.3</b>	<b>Machine Learning</b>	
<b>4.3.1</b>	<b>Towards the Prediction of Lubricated Contacts by Machine Learning</b> Max Marian	<b>159</b>
<b>4.3.2</b>	<b>Detection of Critical Operation in Porous Journal Bearings Using Machine Learning</b> Josef Prost, Guido Boidi, Georg Vorlaufer, Markus Varga	<b>161</b>
<b>4.3.3</b>	<b>A Machine Learning approach to Tribological Performance Prediction of New Lubricant Formulations</b> Wahyu Wijanarko, Nuria Espallargas	<b>163</b>

<b>4.4</b>	<b>Molecular Dynamics</b>	
<b>4.4.1</b>	<b>Per Aspera ad Astra</b> L. B. Kruse, K. Falk, M. Moseler, D. Markert, R. Klein, J. Rausch, R. Luther	<b>165</b>
<b>4.4.2</b>	<b>Computational Modeling of Tribological Systems: Insights into Grinding Processes, Materials Tribology and Tribofilm Formation through Molecular Dynamics</b> Stefan J. Eder, Philipp G. Grützmaker, Manel Rodríguez Ripoll, Andreas Nevosad, Karen Mohammadtabar, Ashlie Martini, Nicole Dörr, Daniele Dini, Carsten Gachot	<b>167</b>
<b>4.4.3</b>	<b>Tribochemical Reactions in the Degradation Process of Iron Nitride with Reactive Molecular Dynamics Simulation</b> Mizuho Yokoi, Masayuki Kawaura, Shogo Fukushima, Yuta Asano, Yusuke Ootani, Nobuki Ozawa, Momoji Kubo	<b>169</b>
<b>4.4.4</b>	<b>Towards a Continuum Description of Lubrication in Highly Pressurized Nanometer-wide Constrictions: the Importance of Accurate Slip Laws</b> Andrea Codrignani, Stefan Peeters, Hannes Holey, Franziska Stief, Daniele Savio, Lars Pastewka, Gianpietro Moras, Kerstin Falk, Michael Moseler	<b>171</b>
<b>4.4.5</b>	<b>Tribochemical Properties of Glycerol as a Green Lubricant on Ferrous Substrates: Atomic-scale Study by Reactive Molecular Dynamics Simulation</b> Vahid Fadaei Naeini, J. Andreas Larsson, Roland Larsson	<b>173</b>
<b>4.4.6</b>	<b>Effect of Polar Additives on the Slip and Bulk Shear of Hydrocarbon Oils</b> Seyedmajid Mehrnia, Maximilian Kuhr, Peter F. Pelz	<b>175</b>
<b>4.5</b>	<b>Multiscale + Multiphysics</b>	
<b>4.5.1</b>	<b>Role of Coating Thickness on Static Leakages, Contact Area and Electrical Resistance: A Theoretical and Experimental Study for Randomly Rough Interactions</b> Prof. Dr. Michele Scaraggi	<b>*</b>
<b>4.5.2</b>	<b>Numerical and Experimental Analyses of the Multiscale Effects in the Tribological System Rotary Shaft Seals</b> Jeremias Grün, Marco Gohs, Simon Feldmeth, Frank Bauer	<b>177</b>
<b>4.5.3</b>	<b>Simulative and Experimental Characterization of the Tribo-Electrical Contact of Roller Bearings</b> Stefan Paulus, Simon Graf, Oliver Koch, Stefan Götz	<b>179</b>
<b>5</b>	<b>Test and Measurement Methodologies</b>	
<b>5.1</b>	<b>Greases</b>	
<b>5.1.1</b>	<b>Comparison of Different Standard Test Methods for Evaluating Greases for Rolling Bearings under Vibration Load or at Small Oscillation Angles</b> Markus Grebe, Henrik Buse, Alexander Widmann	<b>183</b>
<b>5.1.2</b>	<b>Panta Rei: Everything Flows</b> René Westbroek, Ben Habgood, Daniel Williams	<b>185</b>
<b>5.1.3</b>	<b>Enhancing Understanding of Grease-Retention and Lubrication-Mechanisms of Oscillating Sliding Contacts with Long Stroke Lengths</b> Andreas Keller, Markus Grebe	<b>187</b>

<b>5.2</b>	<b>Tribometry</b>	
<b>5.2.1</b>	<b>Correlation of MTM Striebeck Curves with Efficiency Data for Predictive Analysis of Coaxial EV Gearbox Performance</b> Dmitriy Shakhvorostov, Mirjam Bäse	<b>189</b>
<b>5.2.2</b>	<b>LIF Signal Calibration for Bench Simulating Experiments and Engine Oil Film Thickness Investigations</b> Polychronis S. Dellis	<b>191</b>
<b>5.2.3</b>	<b>Digital Twin Parametrization of a Roller Bearing based on Ultrasonic Film Thickness Measurement</b> Fabio Tatzgern, Boris Gigov, Michal Kracalik, Georg Vorlaufer, Markus Varga	<b>193</b>
<b>5.3</b>	<b>EV Fluid Testing</b>	
<b>5.3.1</b>	<b>Oil Aging on a Test Rig to Introduce Sustainable Lubricants in Electric Vehicle Transmissions</b> Timo Koenig, Marco Kohnle, Luca Cadau, Lukas Steidle, Didem Cansu Gueney, Katharina Weber, Joachim Albrecht, Markus Kley	<b>195</b>
<b>5.3.1</b>	<b>Copper Wire Resistance Corrosion Test for Assessing Potential Fluids as E-Thermal Fluids in BEVs Immersion Cooling Applications</b> Bernardo Tormos, Vicente Bermúdez, Jorge Alvis-Sanchez, Leonardo Farfan-Cabrera	<b>197</b>
<b>5.3.1</b>	<b>Shear Stability and Thermal Performance Analysis of Engine Oils for Electric Vehicles</b> Victor Nino, Fabio Alemanno, Deepak Halenahally Veeregowda	<b>199</b>
<b>5.4</b>	<b>Metalworking</b>	
<b>5.4.1</b>	<b>Go Greener by In-situ Characterization of Lubricants for Cold Rolling – Droplet Size Distribution and Physical Separation/Emulsion stability</b> Arnold Uhl, Stefan Kuchler, Sylvain Gressier, Titus Sobisch	<b>201</b>
<b>5.4.2</b>	<b>Investigation of Functional Lubricity of Water-Based MWFs by an Innovative Tool</b> Ameneh Schneider, Felix Zak	<b>203</b>
<b>5.4.3</b>	<b>Tribological Testing for the Assessment of Friction and Metal Transfer in Sliding Contacts between Cemented Carbide and Aluminum during Metal Forming</b> N. Cinca, M. Olsson, M. G. Gee	<b>205</b>
<b>5.5</b>	<b>Metrology in Tribology</b>	
<b>5.5.1</b>	<b>Analysis of Tribo-Films in Industrial Applications</b> Joerg W. H. Franke, Janine Fritz, Daniel Merk	<b>207</b>
<b>5.5.2</b>	<b>Detection of Wear in Modern Naval Engines</b> Theodora Tyrovola, Fanourios Zannikos	<b>209</b>
<b>5.5.3</b>	<b>Unveiling the Butterfly Effect in Tribology: The Impact of Surface Profile</b> Yulong Li, Nikolay Garabedian, Johannes Schneider, Christian Greiner	<b>211</b>
<b>5.5.4</b>	<b>Soft and Highly Sensitive Contact Pressure Sensors Based on Randomly Rough Surfaces</b> Luciana Algieri, Luigi Portaluri, Marco Bruno, Massimo De Vittorio, Michele Scaraggi	<b>213</b>
<b>5.5.5</b>	<b>The Importance of Inocula for Biodegradation Testing of Lubricants</b> Dr. Peter Lohmann	<b>215</b>
<b>5.5.6</b>	<b>Active, Real-Time Friction Control with ElectroAdhesion: Application to Soft Contacts for Augmented Tactile Perception</b> Luigi Portaluri, Luciana Algieri, Massimo De Vittorio, Michele Scaraggi	<b>217</b>

<b>5.6</b>	<b>Lubricant Analysis</b>	
<b>5.6.1</b>	<b>Limit Values for the Evaluation of Lubricant Analyses</b> Stefan Mitterer	<b>219</b>
<b>5.6.2</b>	<b>The European Tribology Centre</b> Franz Pirker, Alberto Alberdi, Xavier Borrás	<b>221</b>
<b>5.6.3</b>	<b>Tribological Investigations under Varying Pressure Atmosphere</b> Felix S. M. Zak, Ameneh Schneider, Gregor Patzer	<b>223</b>
<b>5.7</b>	<b>Test Methodologies</b>	
<b>5.7.1</b>	<b>Efficiency Improvements of In-Situ Hydrogen Permeation Measurements in Lubricated Bearing Steel Contacts Using the Modified Devanathan-Stachurski Cell (MDSC) Method</b> Edward Vernon-Stroud, Ajay Pratap Singh Lodhi, Frederick Pessu, Ivan Delic, Nicole Dörr, Markus Varga, Josef Brenner, Ardian Morina	<b>225</b>
<b>5.7.1</b>	<b>Parallel Wear Testing – an Update</b> Lais Lopes, Dirk Drees, Pedro Baião, Emmanouil Georgiou	<b>227</b>
<b>5.7.1</b>	<b>Building Tribology Application Testing to Determine Wear and Characterization of Polymer-based Composites</b> Michael Katzer, David Rich, Diarmaid Williams	<b>229</b>
<b>6</b>	<b>Sustainability and Resource Efficiency</b>	
<b>6.1</b>	<b>Sustainability</b>	
<b>6.1.1</b>	<b>How Oil Care Can Reduce Oil and Maintenance Costs</b> Steffen D. Nyman	<b>233</b>
<b>6.1.2</b>	<b>Using Molecular Modelling to Anticipate Future Toxicity Classifications of Anti-oxidants and Identify Safer Structures</b> Siegfried Lucazeau, Grégoire Hervé, Florence Séverac	<b>235</b>
<b>6.1.3</b>	<b>Viscosity Index Improvers with an Environmental Acceptable design and an Improved Performance</b> Gerard Cañellas	<b>*</b>
<b>6.2</b>	<b>Applications</b>	
<b>6.2.1</b>	<b>Oxidation Effects on the Rheology and Tribology of Sustainable Lubricants for Electromechanical Drive Systems</b> Didem Cansu Güney, Joachim Albrecht, Katharina Weber	<b>237</b>
<b>6.2.2</b>	<b>Bio-Lubricants as Metal-Working Fluids: More than an Environmental-Friendly Choice</b> Marco Bellini, Simone Pota	<b>239</b>
<b>6.2.3</b>	<b>Potential and Performance of Pure Water Lubrication in Gearboxes</b> Andreas Nevosad, Stefan Krenn, Michael Adler, Dominik Cofalka, Siegfried Lais, Uwe Gaiser	<b>241</b>



<b>6.3</b>	<b>Baseoils</b>	
<b>6.3.1</b>	<b>A Life Cycle Assessment (LCA) to Analyze the Green House Gas (GHG) Emissions for Estolides Produced from Castor Oil</b> Dr. Matthew Kriech	*
<b>6.3.2</b>	<b>Sustainability Assessment of Polyol Esters – A Comparative LCA Analysis of a Bio-Based vs. Fossil-Based Product</b> Verena Koch, Denise Haas	<b>243</b>
<b>6.3.3</b>	<b>How can Esters Improve the Sustainability of Both Intrinsic and Extrinsic Factors?</b> Gareth Moody, Gemma Stephenson	<b>245</b>
<b>6.4</b>	<b>Additives</b>	
<b>6.4.1</b>	<b>Moving towards Sustainable Lubrication – Challenges and Findings for Lube Components from Biobased Sources</b> Marcella Frauscher, Jessica Pichler, Rosa-Maria Nothnagel, Adam Slabon	<b>247</b>
<b>6.4.2</b>	<b>New Technologies of Antiwear and Antioxidant Additives Used for Designing Nonhazardous Turbine Oils and Sustainable High-Performance Lubricants Including Greases</b> Grégoire Hervé, Florence Severac	<b>249</b>
<b>6.4.3</b>	<b>The Effects of Applying the Tribological Compound TZ NIOD</b> Philipp Harrer, Dmitrii Svetov, Patrick Eisner, Maximilian Lackner, Erich Markl	<b>251</b>
<b>6.5</b>	<b>Recycling/Waste</b>	
<b>6.5.1</b>	<b>Innovative Lubricant Components with Lower Greenhouse Gas Emissions</b> Dr. Sabrina Stark, Edith Tuzyna, Rene Koschabek	<b>253</b>
<b>6.5.2</b>	<b>High Quality Sustainable Base Oils from Plastic Waste and Biomass</b> Matias de Tezanos, Boris Zhmud	<b>255</b>
<b>6.5.3</b>	<b>Hybrid Lubricating Grease Formulations: A Sustainable Approach for Utilizing Renewable Resources within a Circular Economy Model</b> George S. Dodos, Mehdi Fathi-Najafi, Christina Dima, Nora Kaframani, Andreas Dodos	<b>257</b>
<b>7</b>	<b>Young Tribologists/Various Tribology</b>	
<b>7.1</b>	<b>Young Tribologists</b>	
<b>7.1.1</b>	<b>Amorphous Carbon Coatings for Total Knee Arthroplasty – a Knee Simulator Evaluation</b> Benedict Rothhammer, Kevin Neusser, Marcel Bartz, Sandro Wartzack	<b>261</b>
<b>7.1.2</b>	<b>On the Relation between Friction and Surface Topography – Models and Challenges</b> Charlotte Spies, Arshia Fatemi	<b>263</b>
<b>7.1.3</b>	<b>Modeling of Shape Deviations for the Development of Predictive Models of TEHD Contacts</b> Klara Feile, Marcel Bartz, Sandro Wartzack	<b>265</b>

<b>7.2</b>	<b>Various Tribology</b>	
<b>7.2.1</b>	<b>Estimation of Remaining Useful Life of Greases after Thermo-Oxidative Ageing by Application of New Method DIN 51830-2</b> Markus Matzke, Gerd Dornhöfer	<b>267</b>
<b>7.2.2</b>	<b>Correct Lubricant Selection for Metal Forming</b> Dr. Richard Baker, Dr. Dirk Drees	<b>269</b>
<b>7.2.3</b>	<b>Measurable Sustainability enhancemer</b> Richard Wurzbach	<b>*</b>

---

## Appendix

<b>Scientific-Technical Board</b>	<b>275</b>
<b>Index of Authors</b>	<b>277</b>

\* not available at the time of publication



weiterbilden  
weiterkommen

TAE

# Maschinenbau, Produktion und Fahrzeugtechnik

Bis zu  
**70 %**  
Zuschuss  
möglich

Besuchen Sie unsere Seminare, Lehrgänge und Fachtagungen.

Maschinenbau und Feinwerktechnik

Fahrzeugtechnik

Elemente, Maschinen und Anlagen

Entwicklung und Konstruktion

Werkstoffe und Betriebsstoffe

Qualität, Mess- und Prüftechnik

Fertigungs- und Produktionstechnik

Verfahrens- und Oberflächen-  
technik, Korrosion

Instandhaltung

Betriebliche Organisation

Arbeitssicherheit, Umwelt-  
und Strahlenschutz



EUROPÄISCHE UNION



Chancen fördern  
EUROPÄISCHER SOZIALFONDS  
IN BADEN-WÜRTTEMBERG

Ein Großteil unserer Seminare wird unterstützt durch das Ministerium für Wirtschaft, Arbeit und Wohnungsbau Baden-Württemberg aus Mitteln des Europäischen Sozialfonds. Profitieren Sie von der ESF-Fachkursförderung und sichern Sie sich bis zu 70 % Zuschuss auf Ihre Teilnahmegebühr. Alle Infos zur Förderfähigkeit unter [www.tae.de/foerdermoeglichkeiten](http://www.tae.de/foerdermoeglichkeiten)

Weitere Informationen und Anmeldung unter [www.tae.de/go/maschbau](http://www.tae.de/go/maschbau)

FOCUS

TOP

AN-BIETER  
WEITERBILDUNG

2024

FOCUS-BUCHUNG.SIC  
DU WISSENST DU  
FACTS & FIELD





## **Plenary Lectures**



# Sustainability in Winter Sports – The Tribological Perspective

Matthias Scherge<sup>1</sup>

<sup>1</sup> Fraunhofer/KIT MikroTribologie Centrum, Rintheimer Querallee 2b, 76131 Karlsruhe

## 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.

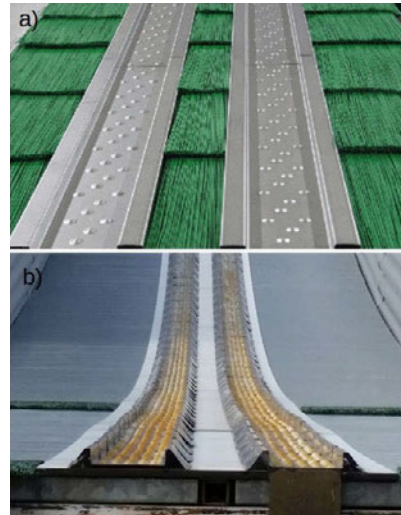


Fig. 1: Different kinds of inruns of a ski jump.

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.

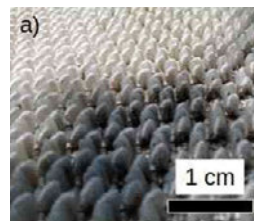


Fig. 2: A modern type of mats.

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.



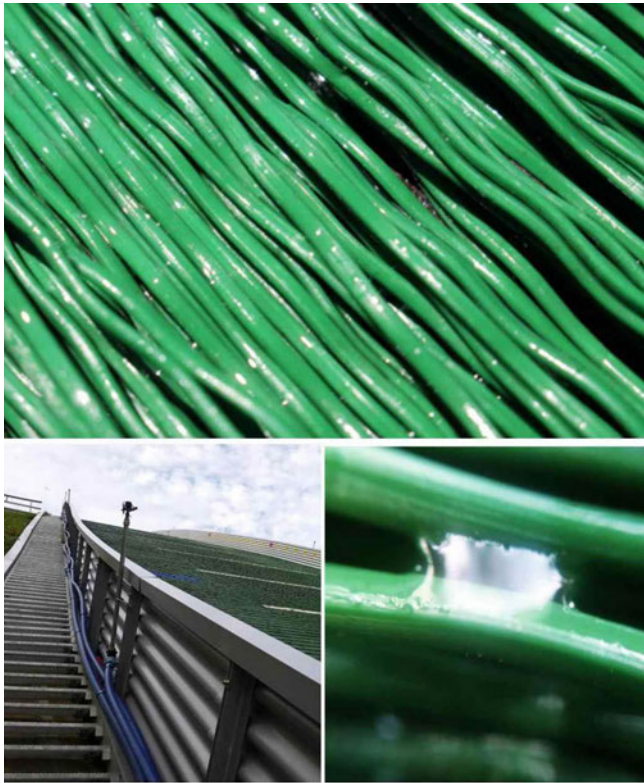


Fig. 3: Mats and watering system for lubrication.

### 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<sub>2</sub> Emissions and Maximize ROI: Implementing Known Tribology and Design for Zero Principles for a Carbon Neutral Industry

Roland Larsson<sup>1</sup> and Victoria Van Camp<sup>1</sup>

<sup>1</sup> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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.

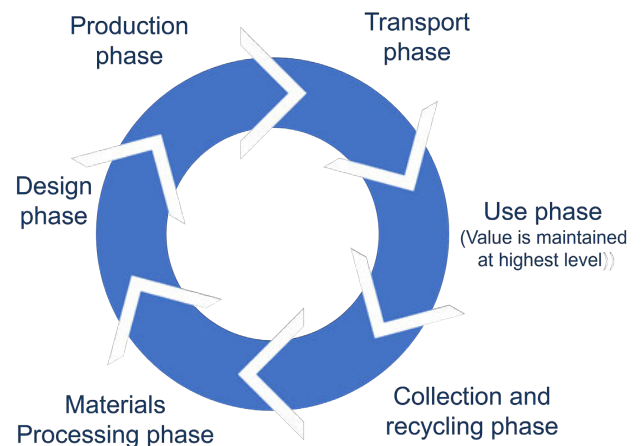
It is often argued that a ‘circular economy’ is the solution to achieving CO<sub>2</sub> neutrality, as it involves keeping existing resources in a closed loop within the atmosphere. While the reuse of materials and parts must increase, extending the technical lifespan of machinery well beyond current 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 CO<sub>2</sub> 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.

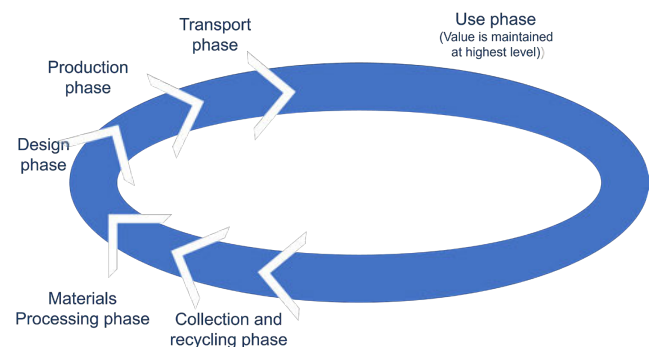
One approach to implementing a circular economy is to transform the business model in a way that benefits all involved parties by ensuring the long, trouble-free service life of machinery. This can be achieved through methods like leasing contracts or delivering the functionality as a service, often 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 CO<sub>2</sub> 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.

#### References

- [1] McKinsey Global Institute summary report (2022). The net-zero transition. What it would cost, what it could bring. <https://www.mckinsey.com/capabilities/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring>.
- [2] Heid, B., Linder, M., Patel, M. (2022). Delivering the climate technologies needed for net zero. McKinsey&Co, McKinsey Sustainability <https://www.mckinsey.com/capabilities/sustainability/our-insights/delivering-the-climate-technologies-needed-for-net-zero>
- [3] S. Jacobson, U. Wiklund, J. Hardell, R. Larsson, "Tribology and the case for an Elliptical economy", 24th International Conference on Wear of Materials, 2023, 16-20 April, Banff, Alberta, Canada.
- [4] Holmberg, K., Erdemir, A. (2017). Influence of tribology on global energy consumption, costs and emissions. *Friction* 5(3), pp. 263-284
- [5] Holmberg, K., Siilasto, R., Laitinen, T., Andersson, P., Jäsberg, A. (2013). Global energy consumption due to friction in paper machines. *Tribology International* 62, pp. 58-77.
- [6] Woydt, M. (2022) Material efficiency through wear protection – the contribution of tribology for reducing CO<sub>2</sub> emissions. *Wear* 488-489.
- [7] Almagor, D., Lavid, D., Nowitz, A., Vesely, E. (2019). Maintenance 4.0 Implementation handbook. Reliabilityweb.com.
- [8] Moleda, M., Malysiak-Mrozek, B., Ding, W., Sunderam, V., Mrozek, D. (2023) From corrective to predictive maintenance – a review of maintenance approaches for the power industry. *Sensors* 2023, 23, 5970.
- [9] Cota, E., Garnbratt, A., Jansson, M., Lindh, C., Månsson, K., Sandgren, J. (2022). Livscykelanalys, miljö-kommunikation och beslutsprocesser, Utvärdering av SR Energys vindkraftsparker ur ett hållbarhetsperspektiv. Candidate thesis in Industrial Economy, TEKX04-22-06, Chalmers University of Technology, Sweden.
- [10] Razdan, P., Garret, P. (2019). Life cycle assessment of electricity production from an onshore V150-4.2 MW wind plant. Vestas Wind Systems A/S <https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/reports-and-ratings/lcas/LCAV10020MW181215.pdf.coredownload.inline.pdf>
- [11] Ulrich, K. (1995). The role of product architecture in the manufacturing firm. *Research Policy* vol 24, issue 3, May pp. 419-440.

# Dynamic Properties of Lubricants for Electric Vehicles

## EV fluids

Yan Chen <sup>1</sup> and Hong Liang <sup>1,2,\*</sup>

<sup>1</sup> Department of Materials Science & Engineering, Texas A&M University, College Station, TX 77843, USA

<sup>2</sup> J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123, USA

\* Corresponding author: hliang@tamu.edu

### 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 mechanical 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 successfully examine the electrical conductivity against the oil film thickness. The thickness and electrical resistance can be calculated from impedance. We integrate an electrochemical potential state with a disc-on-disc tribometer. It allowed us to measure the capacitor and resistor parallel. If we assume that capacitance is fully contributed from the oil film. It thus has a dielectric constant of 2.1 [9]. The our equation is like the following:

$$R = \frac{1}{\text{Re}\left(\frac{1}{Z}\right)} \quad (1) \text{ and}$$

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

where  $R$  is the resistance,  $Z$  is the impedance subtract the impedance of the shorted measuring system  $Z = Z_{\text{measured}} - Z_{\text{shorted}}$ .  $A$  is the nominal area of contact,  $\epsilon \epsilon_r$  is the dielectric constant,  $\omega$  is the angular frequency of the applied voltage. Then  $\text{Re}$  and  $\text{Im}$  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 results 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 discussion as well as thermal conductivities will be provided during presentation.