Overview

Please check the errata in your registration bag to verify course times. Some times might change slightly.

WEDNESDAY, MAY 21, 2014

Registration (7 am – 6 pm) – East Registration
Speakers Breakfast (7 – 8 am) – Americas B
Commercial Exhibits and Student Posters (9:30 am – Noon) – Americas A/B

Education Courses (8 am – 5 pm)
• Advanced Lubrication 301 – Americas A
• Basic Lubrication 102: Basic Applications – Republic B
• Gears 101 – Fundamentals of Gears – Republic C
• MWF 130: Metal Treating, Cleaning & Protecting Fluids – Republic A
• Synthetic Lubricants 204: Fluid Formulation & Applications – Republic D

Technical Sessions (8 am – Noon)
5A Lubrication Fundamentals V – Experimental – Nutcracker 1
5B Materials Tribology II – Nutcracker 2
5C Tribotesting II – Nutcracker 3
5E Non-Ferrous Metals I – Fantasia C/D
5F NanoTribology V – Fantasia E/F
5G Condition Monitoring III – Fantasia E/F
5H Engine & Drivetrain II – Fantasia K/L
5I Wear I – Fantasia M/N
5J Rolling Element Bearings in Wind Turbine Applications: Joint Session I – Fantasia P/Q
5K Commercial Marketing Forum V – Americas B

Technical Sessions (1:30 – 6 pm)
6A Lubrication Fundamentals VI: Modeling – Nutcracker 1
6B Material Tribology III – Nutcracker 2
6C Surface Engineering I – Nutcracker 3
6F Nanoscale Phenomena in Materials Tribology: Material Tribology/Nanotribology Joint Session – Fantasia E/F
6G Engine & Drivetrain III – Fantasia K/L
6H Wear II – Fantasia M/N
6J Rolling Element Bearings in Wind Turbine Applications: Joint Session II – Fantasia P/Q
6K Fluid Film Bearings I – Americas B

Beverage Breaks are scheduled at 10 am and 3 pm daily.
### SESSION 5F
**Nanotribology V**

- Phase Diagrams for the Characterisation of the Rheology of Confined Fluids: A Molecular Viewpoint, D. Dim, p. 108
- Study of the Tribological Properties and Effects of Water on Carbon-Based Materials Using Molecular Dynamics Simulations, M. Fallet, p. 108
- A Model for Capillary Flow Between Rough Surfaces, A. Rostami, p. 108
- A Local Region Molecular Dynamics Simulation Method for Nanoscale Sliding Contacts, A. Tong, p. 109

### SESSION 5G
**Condition Monitoring III**

- Magnetic Head and Disk Coated with Ultrathin DLC: Molecular Dynamics Modeling on the Contact of Contacts, J. Burbank, p. 122
- Diamond-like Carbon and Tungsten, Nanoscale Sliding Friction Phenomena at the Interface of, A. Bhattacharyya, p. 122
- Adhesion Between Carbon-based Materials Upon Prevalent Duty Cycles, and Climate Conditions in Southeast Asia, I. Tracy, p. 122
- Fuel Efficiency Gains Considering Local Fleet Usage, Regional Lubricant Formulation Opportunities for, D. Sander, p. 122

### SESSION 5H
**Engine & Drivetrain II**

- Friction Characteristics of Polyethylene Glycol Based Engine Oil Formulations, A. Gangapadhyay, p. 109
- Tribological Characteristics of GTL Based Engine Oils, H. Gao, p. 110
- A Prototype Low-Viscosity Engine Oil Using an Ionic Liquid as Anti-Wear Additive, M. Viola, p. 110
- Analysis of Shear-Thinning on Engine Friction Using Mineral and PAO Base Oils, M. Plumley, p. 110

### SESSION 5I
**Wear I**

- Combination of Wear Damage Analysis and Numerical Simulations for Optimizing the Hot Shearing Process of Rolled Steel, M. Rodriguez Ripoll, p. 112
- A Stress-Based Damage Mechanics Model to Simulate Fretting Wear of Hertzian Line Contact in Partial Slip, A. Ghosh, p. 112
- Difference in Preventative Mechanism for Fretting Wear between Oil and Grease Lubrication, T. Maruyama, p. 112
- Effect of Microstructure on the Tribological Performance of Al-Si Alloys, Q. Xue, p. 112

### SESSION 6F
**Tribology/Nanotribology**

- A Molecular Dynamics Investigation of the Adhesion Between Carbon-based Materials Upon Repetitive Contact, J. Harrison, p. 121
- Simulation of Tribio-Initiated Chemistry in Immuno-Hydrocarbon Systems, J. Schall, p. 121
- Advances in Nanomechanical Characterization Methods of Surfaces with Atomic Force Microscopy, D. Yablon, p. 121

### SESSION 6G
**Engine & Drivetrain III**

- Regional Lubricant Formulation Opportunities for Fuel Efficiency Gains Considering Local Fleet Usage, Prevalent Duty Cycles, and Climate Conditions in Southeast Asia, I. Tracy, p. 122
- Towards a Reliable Friction Prediction in Automotive Journal Bearings, D. Sander, p. 122
- Predicting Wear due to Sliding-Electrical Contact of Materials, Q. Wang, p. 124

### SESSION 6H
**Wear II**

- Characterizing Fretting Fatigue Frictional Behavior Using Digital Image Correlation (DIC) Technique, R. Hogun Zehms, p. 112
- A Microstructural Damage Model for Coatings under Fretting Wear and Fatigue, B. Jalalahmadi, p. 113
- Wear of Multi-Component Surfaces 65 Million Years Ago: Applications of Tribology to Dinosaur Dentition, B. Krick, p. 113

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# Metalworking Additives

## Our Specialty

### Lubricity Additives
- Oil Soluble, EP agents, Polylol and **Polymeric esters**
- **Self emulsifying esters** fit for machining **aluminum**, **magnesium**, **titanium** and other alloys
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- Self - Emulsifying
- Water soluble (Synthetic)

### Surfactants
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## Our Pledge
- **Win / Win Long Term Sustainable Relationship**

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### LUBRICATION FUNDAMENTALS V: EHD LUBRICATION – EXPERIMENTAL

**Session Chair:** K. Mistry, The Timken Company, Canton, OH  
**Session Vice Chair:** B. Miller, Chevron Oronite Company LLC, Richmond, CA

#### 8 – 8:30 am  
**An Experimental Investigation into the Influence of Roughness on Friction and Film Thickness in Elasto-Hydrodynamic Contacts**

*J. Guegan, H. Spikes, A. Kadiról, C. SKF-UTC, Tribology Group, Imperial College London, London, United Kingdom, T. Reddyhoff, Tribology Group, Imperial College London, London, United Kingdom, A. Gabelli, G. Morales-Espejel, SKF Engineering and Research Centre, Nieuwegein, Netherlands*

Most studies of friction and lubrication in elasto-hydrodynamic (EHD) contacts consider very smooth surfaces. However, real engineering components, such as rolling bearings, possess rough surfaces and this profoundly influences the EHD film friction. The roughness of machined surfaces covers a wide spectrum of wavelengths and heights. In this paper, a custom duo-chromatic optical interferometry technique is described and used to measure EHD film thickness in a sliding-rolling contact of a rough ball on smooth glass disc. The study is focused on roughness consisting of parallel ridges oriented along the rolling sliding direction, with varying heights and wavelengths. EHD friction is measured in parallel and in real time, so that it is possible to correlate the two measurements directly. Results are presented to show that at certain contact conditions, this particular type of roughness generates significantly thinner films and higher friction than the equivalent smooth contacts.

#### 8:30 – 9 am  
**Film Thickness of a Lubricant in Optical EHL of Rolling Point Contact**

*G. Gyimah, P. Huang, Q. Zuo, Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, China*

This paper is devoted to study the behavior of film thickness of a lubricant in EHL of rolling point contact. PTFE and MoS2 at varied quantities were added to purified oil for this study. The effect of load and speed on film thickness in EHL point contact in pure rolling was determined experimentally. The practical range of dimensional speed and load were used in Hamrock and Dowson Equation in obtaining film thickness data and were compared with experimental values. The obtained data were statistically examined by a multiple linear regression analysis. The influence of the speed and load were studied. Using data points within each range in statistical regressive analysis, a multiple linear regression analysis was obtained. The film thickness results obtained practically indicated a reasonable agreement with the film thickness predicted by the multiple linear regression and Hamrock and Dowson model.

#### 9 – 9:30 am  
**Lubricant Behaviour Under Side Slip Conditions in EHL Contacts**

*M. Omasta, I. Krupka, M. Hartl, Brno University of Technology, Brno, Czech Republic*

During last decades it was found experimentally that in EHL contacts, film thickness distribution and traction are influenced by many phenomena. Most of them are associated with thermal behaviour of contact, rheology of lubricant and other shear-induced effects. However, it is still difficult to distinguish these different effects. Under high sliding conditions, most of these phenomena are much more noticeable. When studying such conditions, the vast majority of authors assume sliding in the same direction as entrainment speed. However, when we assume sliding in different direction, e.g. perpendicular to entrainment – called “side slip”; we can distinguish different effects much more easily. This study brings experimental results based on different entrainment and sliding direction that can provide an evidence of some aspects. These are connected mainly with mechanical and thermal properties of contacting bodies and complex rheology of lubricant.

#### 9:30 – 10 am  
**The Effect of Surface Slip on Elastohydrodynamic Lubrication**

*J. Wong, A. Ponjavic, Mechanical Engineering, Imperial College London, London, United Kingdom*

This presentation explores how boundary slip affects friction, film thickness and lubricant rheology in an in elastohydrodynamic (EHD) contact. Polybutene (PB) is used as the model lubricant. A glass sphere and a glass flat modified with an oleophobic coating are used as rubbing surfaces. The effect of surface slip on the local rheology of lubricant in an EHD contact is investigated by obtaining local through-thickness velocity profiles with photobleached fluorescent imaging. The amount of slip on modified glass flats is quantified and is dependent on normal pressure. A critical normal stress exists below which no or little slip is identified. Above the critical pressure, large amount of slip is observed and the velocity profile of the EHD lubricant resembles plug flow. When slip occurs, a large reduction in lubricant film thickness and the friction are recorded. The magnitude of the reduction in film thickness and friction cannot be fully accounted for by existing EHD theories.

#### 10 – 10:30 am – Break

#### 10:30 – 11 am  
**Influence of Polymer Shear Thinning on Friction in Hydrodynamic Contacts**

*N. Marx, H. Spikes, Mechanical Engineering, Imperial College London, London, United Kingdom, R. Taylor, Shell Research Ltd, Chester, United Kingdom*

Viscosity modifier polymers are added to almost all engine lubricants to reduce the viscosity-temperature dependence of their blends. It has long been known that viscosity modifier solutions can undergo both temporary and permanent shear thinning in high shear rate contacts and it is now recognised that temporary shear thinning can make a valuable contribution to fuel economy by reducing hydrodynamic friction. This presentation describes an experimental study of the impact of polymer solution shear thinning on hydrodynamic film thickness and friction. The shear thinning behaviour of several polymer solutions is measured using conventional and high shear rate viscometer and compared with film thickness and friction measurements from a low pressure, sliding lubricated contact. This enables quantification of the influence of polymer shear thinning on friction in hydrodynamic conditions.
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11 – 11:30 am
Cost-Effective Formulating with Sulfurized Additives
L.V. Marmerstein, J. Vence, The Elco Corporation, Cleveland, OH
Different sulfurized chemistries are widely used in industry to provide antiwear, extreme pressure protection and enhance the lubricity of finished lubricants. There are a wide variety of sulfurized products – of different viscosity, sulfur content, corrosion properties, etc.
This presentation discusses chemistry of sulfurized materials; how substrates, sulfur content and manufacturing parameters affect properties and performance of additives. The performance of different sulfurized chemistries is evaluated using various 4 Ball test methods and a disc-on-disc test method. Performance results of grease formulations that utilize different sulfurized chemistries at different concentration are presented. There is no “one solution for all”, but knowledge of the properties and characteristics of sulfur chemicals will allow a formulator to choose the best performing and most cost-effective additive.

11:30 am – Noon
Elastohydrodynamic (EHD) Lubrication Behavior at High Speeds: Comparison of Numerical and Experimental Analysis
H. Liang, D. Guo, J. Luo, Mechanical Engineering, Tsinghua University, Beijing, China, T. Reddyhoff, H. Spikes, Mechanical Engineering, Imperial College London, London, United Kingdom
This paper describes a study of elastohydrodynamic (EHD) lubrication behavior at high speeds (up to 20 m/s). Central film thickness values, obtained from optical interferometry measurements, were compared with numerical predictions. The comparison indicated that numerical solutions considering thermal effects were in good agreement with the experimental measurements while both the values were considerably thinner than those predicted by the Hamrock-Dowson equation at high speeds. The reduction in film thickness is mainly caused by shear heating effects. Film thickness and pressure profiles were numerically calculated considering thermal effects under the same conditions. The numerical results were used to determine the influence of slide-roll ratio and operating temperature on film thickness profiles and the experimental data were used to amend a set of unified parameters for the thermal corrections for different types of oil at high speeds.

8:30 – 9 am
The Effects of High Temperature on the Wear and Transfer of Alumina-PTFE Nanocomposites
H. Khare, J. Ye, D. Burris, Mechanical Engineering, University of Delaware, Newark, DE
Polytetrafluoroethylene (PTFE) is a solid lubricant which exhibits low friction and inert behavior but suffers from high wear rates in dry sliding. Orders of magnitude improvements in wear rates can however be achieved with the trace loadings of nanosized filler materials, such as alpha-alumina to the matrix. Sliding-induced transfer and tribofilms play a crucial role in promoting low wear of alumina-PTFE nanocomposites and have been shown to consist of oxidized or defluorinated polymer. Recent studies have also demonstrated the inability of adherent transfer films to form in the absence of moisture. In the present study, high temperature wear rates of alpha-alumina filled PTFE nanocomposites are measured in environments with varying oxygen and water to identify competitions between thermally-driven oxidation and desorption. Results of transfer film evolution in terms of optical morphology and chemical composition are also presented.

9 – 9:30 am
Morphological and Compositional Evolution of Ultra-low Wearing Polytetrafluoroethylene (PTFE) and Alumina Nanocomposite Transfer Films
J. Uruena, A. Pitenis, K. Harris, W. Sawyer, Mechanical and Aerospace, University of Florida, Gainesville, FL
Polytetrafluoroethylene (PTFE) is a solid lubricant known for its low friction coefficient and high wear rate (~7x10^-4 mm^3/(Nm)). When filled with very low volume percent of alumina nanofiller its wear rate decreased over three orders of magnitude. The development of a thin, uniform and well-adhered transfer film during sliding is partially responsible for this decrease in wear rate by creating a low shear interface and forming a protective layer between the PTFE alumina sample and metal counterparts. In this work, a transfer film was generated by sliding up to one million reversals over a gradually decreasing stroke length. Wear and friction experiments were performed on a microtribometer to determine the robustness of the transfer film. Interferometry and profilometry were used to measure the roughness, height and wear of the film. Microscopy and spectroscopy were used to investigate the morphological and compositional properties of the transfer film over sliding distance.

9:30 – 10 am
A Quantitative Metric of Transfer Film Assessment
J. Ye, H. Khare, D. Burris, Mechanical Engineering, University of Delaware, Newark, DE
The wear resistance of polymeric tribomaterials is often attributed to qualitative properties like the ‘quality’ or ‘uniformity’ of the transfer films they deposit. Despite the overwhelming evidence that wear is related to transfer film properties, the community has not yet identified a quantifiable property of a transfer film that generally correlates to the wear resistance of the system. Our prior interrupted studies of transfer film morphology for a well-studied low-wear alumina PTFE nanocomposite showed strong correlation between the characteristic dimension of uncovered areas within transfer film (Lf) and the wear rate, and propose to use Lf as a quantitative means of evaluating transfer film quality. First, we present a robust statistical method of evaluating Lf using optical images of the transfer film. Second, we examine the relationship between wear rate and Lf for several polymer systems.
10 – 10:30 am – Break

10:30 – 11 am

TEM and Precession Electron Diffraction Studies to Determine Wear-Induced Structures in Tribological Coatings and Engineered Surfaces

T. Scharf, H. Mohseni, J. Mogonye, P. Nandwana, R. Banerjee, Materials Science and Engineering, University of North Texas, Denton, TX

Since electron backscatter diffraction cannot resolve orientation and texture of tribologically-induced near surface ultrafine grain (<50 nm) structures, precession electron diffraction was used in the TEM to investigate these phenomena in worn tribological coatings. Laser deposited coatings were studied including graphite in a TiC/Ni matrix and in situ nitrided Ti alloys (Ti-6Al-4V and Ti-35Nb-7Zr-5Ta, TNZT). In the case of the graphite/TiC/Ni composite, low friction (μ = 0.1) was observed with the presence of amorphous carbon (a-C) on the surface with texture evolution in α Ti elongated grains; while higher friction was due to the absence of α-C. For the Ti-alloys, nitrided Ti-6Al-4V exhibited brittle fracture (shear bands) while the nitrided TNZT exhibited plastic deformation (nanocrystalline grain refinement). Precession-orientation imaging phase maps were used to determine the orientation and percentage of α and β Ti in nitrided TNZT responsible for improved friction and wear.

11 – 11:30 am

Tribology and Deformation Behavior of Cold Sprayed Al-Al2O3 Composites as Influenced by Particle Morphology

J. Shockley, R. Chromik, Department of Mining and Materials Engineering, McGill University, Montreal, QC, Canada, S. Descartes, Laboratoire de Mécanique des CONTACTS et des Structures, Institut National des Sciences Appliquées de Lyon, Lyon, France, P. Vo, E. Irissou, J. Legoux, National Research Council Canada, Boucherville, QC, Canada

Particulate-reinforced aluminum matrix composite (Al-MMC) materials benefit from improved wear resistance due to the presence of hard secondary phases such as SiC or Al2O3. The improved tribology of Al-MMC materials is often linked to development of deformed layers at the sliding interface, commonly called mechanically mixed layers (MML), the formation of which is enhanced by the presence of hard particles. The most common particle morphology is blocky and angular. However, spherical morphologies are increasingly available due to advancements in processing techniques, and the influence of reinforcement morphology on the tribology of Al-MMC materials remains relatively unexplored. In this study, Al-Al2O3 composites with spherical and angular Al2O3 particles were consolidated using the cold spray process, then subjected to sliding wear tests against an Al2O3 sphere. The influence of particle morphology on deformation behavior, friction, wear rates, and MML formation will be discussed.

11:30 am – Noon

Effect of Lubrication Mode on Wear Behavior of Porous Plasma Electrolytic Oxidation Coatings

H. Eiliat, Mechanical, Automotive and Materials Engineering, University of Windsor, Windsor, ON, Canada

Plasma electrolytic oxidation treatment creates a porous ceramic-based thin layer with high resistance to wear and corrosion. Based on treatment parameters such as current density, electrolyte composition or current polarity, created coatings can demonstrate different wear behavior. A good indicator of the coating behavior is coating topography and its roughness. This study is focused on understanding the relation between average roughness and skewness of the coatings and their ability of oil retention. Pores on the outside layer of the coating can act as oil reservoirs and can minimize the wear effect on both the substrate and the counter surface. This study is done under a range of lubrication modes: dry condition, oil deprivation and well lubricated condition. Wear tracks of the coatings are studied using SEM and AFM techniques.

Session 5C • Nutcracker 3

TRIBOTESTING II

Session Chair: A. Segall, Pennsylvania State University, University Park, PA

Session Vice Chair: N. Gitis, CAMR, Campbell, CA

8 – 8:30 am

Design and Functionality of a High Frequency Coating Impact Fatigue Tester

B. Nation, N. Argibay, M. Dugger, Sandia National Laboratories, Albuquerque, NM

An impact fatigue tester for evaluating the mechanical properties of commercial and research coatings has been developed. The tester has been designed to measure the impact load versus time, and the energy absorbed during impact at sampling rates over 50 kHz to enable resolution of millisecond events. In-situ measurement of impact crater depth enables high-speed life testing of coatings, and real time display of impactor energy loss allows the evolution of coating response to be monitored throughout testing. The repeatability of the impact site during high-cycle impact testing will be discussed. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

8:30 – 9 am

Thermal Limit of Tribocorrosion Surface Films from Fully Formulated Lubricants

M. Lorenzo-Martin, O. Ajayi, R. Erck, G. Fenske, Argonne National Laboratory, Argonne, IL

In contacts lubricated with formulated lubricants, the formation of tribochemical or boundary films is critical to friction and wear performance. Lubricants are often designed or formulated to operate at some optimal temperature range. Due to a variety of reasons, the contact temperature may exceed the optimal temperature, hence establishment of the thermal limits for tribochemical films is important. This paper presents the study of thermal limit for four different lubricants; engine and gear oils using a reciprocating steel-on-steel line contact. Tests were conducted using a continually varying temperature increase until failure occurs as indicated by irreversible friction increase. Failure mechanism in the tribofilm were analyzed by different level of microscopy and surface analysis.

9 – 9:30 am

Tribocorrosion Behavior of Metallic Materials in Chloride Media

S. Kuiry, S. Shaffer, Bruker Nano Surfaces, Campbell, CA

Tribocorrosion is an emerging research frontier that has relevance in chemical, marine, mining, aerospace, automotive, and biomedical areas of applications. Metallic materials are subjected to wear in aggressive chemical environments. Under such simultaneous actions of mechanical wear and electrochemical corrosion, the extent of materials degradation is enhanced due to the synergistic effect of wear and corrosion. It is important to evaluate the tribocorrosion behavior of materials to understand the performance of engineering component and to develop advanced materials that are suitable for such applications. This presentation deals with tribocorrosion behavior of metallic materials in chloride media.
9:30 – 10 am  
**Strubeck Curve Generation Using Four Different Tribotest Geometries**  
S. Shaffer, S. Papanicolaou, Bruker Nano Surfaces, Campbell, CA

Since its original publication at the turn of the 20th Century, Strubeck curves have been a useful tool for illustrating the different lubrication regimes, namely thick film (hydrodynamic), thin film (mixed) and “starved” (boundary). For a contact geometry with a converging gap, we can relate the physical parameters of load, velocity and viscosity to the lubricant behavior in the different regimes. This presentation shows the effect of contact geometry and test mode on the Strubeck curve for different lubricant types and viscosities, by using a circular point contact, line contact, area contact, and even a non-conformal contact. The resulting levels of boundary friction and hydrodynamic friction are found to be, in most cases, independent of test geometry. However, the position of the “shoulder” and “knee” in the curve delineating the mixed lubrication regime, is found, not surprisingly, to be strongly affected by test geometry.

10:30 – 11 am  
**Capturing Ball Interactions from a Spiral Orbital Tribometer**  
I. Shareef, M. Gilles, IMET, Bradley University, Peoria, IL, S. Pepper, NASA Glenn Research Center, Cleveland, OH

Bearings have played an important role in enhancing the standard of living since their advent and more significantly since the coinage of the word Tribology by Peter Jost in 1967. Ever since that time bearing research has attracted significant attention. This led to the introduction of several bearing test machines including NASA-GRC Spiral Orbital Tribometer (SOT). SOT is capable of capturing two parameters: normal load applied to the ball and radial load to return the ball to its original orbit. This research deals with the redesign of the SOT that is capable of measuring friction force and normal force between: a) the ball and plate, and b) the ball and guide rod. In essence the new design measures seven parameters that enable accurate measurement of tribological interactions of the ball with the guide rod, and top/bottom plates. The proposed design enhances the work done earlier and is capable of changing material properties of either ball or race, and changing lubricant properties.

11 – 11:30 am  
**The Effect of Nanoparticles Used as Lubricant Additives on Friction and Wear Under Different Contact Configurations and Conditions**  
N. Demas, R. Erck, M. Lorenzo-Martin, O. Ajayi, G. Fenske, Argonne National Laboratory, Argonne, IL

Researchers have shown that the addition of nanoparticles to lubricants can reduce friction and wear. In this work, the effect of various oxides and carbon-based additives on friction and wear was studied under laboratory test conditions using a reciprocating test rig and two test configurations (a ball-on-flat, and ring-on-liner) at speeds up to 5 Hz. Tests were performed over a range of temperatures up to 150°C using different oils. It was found that the addition of most nanoparticles reduced the coefficient of friction of basestock oil. However, a positive effect was not observed when nanoparticles were added to fully-formulated oil. In often cases, the formation of a non-conductive boundary film separating the sliding surfaces was evident. Examination of the rubbed surfaces showed the pronounced formation of a thick tribofilm in some cases, while mild polishing on the surface was also observed.

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The system combines equipment from several leading equipment manufacturers with some innovative technology and sophisticated software that was developed by Wearcheck for use in their oil analysis laboratory. The system has a high degree of flexibility and can be customized to a large extent to suit local laboratory processing requirements.
9:30 – 10 am
Formulation Challenges Encountered with Using Today’s Base Oil Offerings in Metalworking Fluids
J. Cepec, Allegheny Petroleum, Wilmerding, PA
The available base oil offerings from refineries are constantly changing, as environmental regulations, customer requirements, market dynamics, crude supplies, or other factors impact refining markets and customers. Metalworking fluid formulators are challenged to keep up to date with these changes to protect their product line and product performance. Formulation choices must be made with the future of the market in mind. This paper will describe the current market conditions for base oils and how anticipated changes will impact metalworking fluid formulators. Changes in both naphthenic and paraffinic base oils will be discussed and the advantages and disadvantages of each, including the predicted decline of Group I base oils and the increased market presence of the more highly refined, but solubility challenged, Group II and Group III fluids.

10 – 10:30 am – Break

10:30 – 11 am
Chatter Phenomenon in Hot Rolling of Aluminum
P. Deneuville, Constellium CRV, Voreppe, France
Chatter is a natural phenomenon of self-excited vibrations linked to the elastic structure of the mill associated with the roll stacks. The whole mechanical structure of a rolling mill does not offer a good damping. The unexpected and sometimes uncontrolled vibrations cause on the strip surface various defects that are not always removed by the next and final passes. Some theoretical guidelines exist touching the way to modify the physical structure to avoid vibrations. But it is also recognised that the coolant and the state of the oil film inside the roll bite are of great importance to help putting the phenomenon under control. This paper discusses all the aspects of the chatter on a hotmill. It presents the method of measurements, the results on the strips and elaborates a discussion on the influence of the lubricant and on the way to address the problem.

11 – 11:30 am
Surface Defects Induced on Aluminum Alloy Surfaces by Hot Rolling: A Laboratory Simulation Examination
M. Shafiei, J. Hunter, Surface Science Group, Novelis Global Research & Technology Center, Kennesaw, GA, O. Gali, Q. Zhao, R. Riahi, Mechanical, Automotive and Materials Engineering, University of Windsor, Windsor, ON, Canada
A hot rolling tribo-simulator was developed to study surface defects induced on surfaces of aluminum alloys by deformation during hot rolling. The simulator comprises of a work roll and a stage that holds a rectangular work piece. The configuration allows for variation of rolling parameters such as roll surface conditions, temperature, applied force, lubrication and forward slip to examine their effects on the work piece. Aluminum surfaces deformed with a rough roll displayed formation of shingles and grooves after the first pass, while surfaces deformed with a smooth roll showed no evidence of such defects. Cross-sectional analysis of transverse cracks formed after 9 and 17 passes revealed a magnesium-rich near surface microstructure, along with crack propagation into the subsurface region. The crack depth and structure varied with number of passes and forward slip.

11:30 am – Noon – Non-Ferrous Business Meeting

Session 5F • Fantasia E/F

NANOTRIBOLOGY V

Session Chair: C. Korach, Univernessity of Mount Union, Alliance, OH
Session Vice Chair: H. Khare, Department of Mechanical Engineering, University of Delaware, Newark, DE

8 – 8:30 am
Phase Diagrams for the Characterisation of the Rheology of Confined Fluids: A Molecular Viewpoint
D. Dini, D. Heyes, C. Gattinoni, Mechanical Engineering, Imperial College London, London, United Kingdom
This article reviews the recent progress made by the authors in the modelling the behaviour of confined fluids using non-equilibrium molecular dynamics simulations (NEMD). Phase diagrams are sketched in the pressure-velocity space; liquid-like, plug-flow, central localisation and asymmetric melting are identified to be the possible states representing the complex fluid behaviour. These states are associated to different regimes in terms of loading conditions and relative sliding speeds.

8:30 – 9 am
Study of the Tribological Properties and Effects of Water on Carbon-Based Materials Using Molecular Dynamics Simulations
M. Fallet, J. Harrison, K. Ryan, P. Mikulski, US Naval Academy, Annapolis, MD, M. Knippenberg, High Point University, High Point, NC
Tribological studies of C-based materials have come to the forefront of experimental and computational chemistry with applications for microfluidic devices and tip-based nano-manufacturing. The negative effects of humidity on friction and adhesion of some carbonaceous materials underscore the need to understand underlying mechanisms. Because, it is difficult to elucidate atomic-scale behavior via experimental methods, molecular dynamics simulations have been used to examine this behavior. Sliding simulations of non-hydrogenated, and hydrogenated, ultrananocrystalline diamond (UNCD) surfaces in the presence of water using the QAIReBO potential [1] have been performed. This reactive potential can model charge in C, H, and O systems. Hybridization changes, as well as charge distribution results will be presented to better understand the impact of water on wear in these systems.

9 – 9:30 am
A Model for Capillary Flow Between Rough Surfaces
A. Rostami, J. Streator, Georgia Institute of Technology, Atlanta, GA
Many micro and nano scale devices are influenced by the presence of liquid at the interface between contacting surfaces. Such liquid may induce large and undesired adhesive or “stiction” forces. In some cases, liquid may find its way into the interface of two rough surfaces that are already in contact. It is of interest to model the manner in which the interface proceeds to a new equilibrium configuration upon introduction of the liquid. Such a process involves interactions among viscosity, elasticity and capillarity. To simulate such effects, a multi-scale contact model is employed to account for surface deformation, a mixed-lubrication model is applied to analyze liquid flow and the Young-Laplace equation is implemented at the boundary of the wetted region to provide the capillary pressure. Calculations are performed to reveal the roles of liquid viscosity, liquid surface tension, surface roughness and elastic modulus on the generation of adhesive forces.
9:30 – 10 am
A Local Region Molecular Dynamics Simulation Method for Nanoscale Sliding Contacts
R. Tong, G. Liu, T. Liu, Northwestern Polytechnical University, Xi’an, China

Efficiency and precision are two main problems in molecular dynamics simulations, which always conflict with each other. How to enhance the efficiency and keep or even enhance the precision at the same time is concerned by each corresponding researcher. A local region molecular dynamics (LRMD) simulation method which can meet these two factors concurrently in nanoscale sliding contacts is developed in this paper. A criterion called displacement contribution is presented, which is used to estimate local region in the MD model. By using the local region, nanoscale sliding contact between a rigid cylindrical tip and an elastic substrate is investigated. The friction forces and contact force distributions in contact region of LRMD simulations agree well with the results from full MD simulations, which testify the effectiveness of LRMD simulation method. For different models and different indentation depths, the results are also compared to verify the validity of LRMD simulation method.

10 – 10:30 am – Break

Session 5G • Fantasia E/F

CONDITION MONITORING III
Session Chair: G. Livingstone, Fluitec, Jersey City, NJ
Session Vice Chair: R. Butler, Chemtool Incorporated, Crystal Lake, IL

10:30 – 11 am
Rotor/Stator Rubbing Contact in an Overhung Rotodynamic System
P. Varney, I. Green, Georgia Institute of Technology, Atlanta, GA

Rotordynamic systems and their associated triboelements are susceptible to a variety of faults, such as rubbing contact between the rotor and stator. Clearances in fluid film elements such as seals and bearings are decreased in an effort to increase efficiency; such reductions heighten susceptibility to rotor/stator contact. An analytic model is presented incorporating rubbing contact into an overhung rotordynamic system to simulate dynamic contact between the rotor and a mechanical face seal. The rubbing contact is modeled via a tangential Coulomb friction force and an associated stiffness reaction generated by deformation at the rotor/stator interface. The rotor’s dynamic angular response is presented, emphasizing higher harmonic oscillations and the appearance of forward and backward whirl. Aspects of the results pertaining to simultaneous multiple fault detection and diagnosis are discussed, specifically with regard to concurrently detecting a transverse fatigue crack.

11 – 11:30 am
Mechanical Fault Detection on Motor-Gear Driving System Using Motor Current Signal Spectrum Analysis
M. Rgeai, M. Elhaj, A. Elshanti, The College of Electronic Technology, Tripoli, Libya

Due to the complexity of the interaction between the electrical and mechanical processes in the motor-gear driving system, a mathematical model is introduced to describe these processes and to simulate numerically the system under normal and abnormal conditions. Moreover, this paper investigates the application of MCSA to the detection of mechanical faults in a helical gearbox driven by 11Kw induction motor. The driving system includes the effects of gear eccentricity and gear local faults. Both, simulated and experimental current spectrum show identical results in detecting faults in the gearbox. The spectrum is dominated by the 50Hz component and sidebands that correlate with the shaft rotational frequencies (RF) around the (GMF). The difference can be observed between faulty and healthy spectra. The work in this paper then confirms the abilities of motor current signal for fault detection of downstream machines.

11:30 am – Noon
Onsite Industrial Fluid Analysis: Status and Challenges
P. Henning, Spectro, Inc., Chelmsford, MA

With ever-increasing frequency, onsite fluid analysis is utilized to provide real-time determination of the health of the fluid and associated critical assets. In this paper we discuss current state-of-the-art tools and approaches to such analysis, including at-line and on-line modalities. We examine the cost savings impact such methodologies have had on end-users in various industries. Finally, we discuss challenges that remain in making sure that the technology keeps pace with rapidly evolving practices across industries, after significant recent advances in this regard have enabled more widespread adaptation of onsite fluid analysis protocols than ever before.

Noon – 12:30 pm – Condition Monitoring Business Meeting

Session 5H • Fantasia K/L

ENGINE & DRIVETRAIN II
Session Chair: P. Lee, Southwest Research Institute, San Antonio, TX
Session Vice Chair: K. Sinha, Chevron Oronite Co. LLC, Bellaire, TX

8 – 8:30 am
Friction Characteristics of Polyalkylene Glycol Based Engine Oil Formulations
A. Gangopadhyay, D. McWatt, L. Elie, J. Cuthbert, E. Hock, Dow Chemical, Midland, MI, K. Sinha, Chevron Oronite Co. LLC, Bellaire, TX

Mineral and polyalpha olefin base stocks have been used traditionally for the formulation of engine oils and developments on base stock and additive package served the automotive industry over the years successfully with incremental improvement in fuel economy. Recently, polyalkylene glycol (PAG) has gained attention as a base stock for engine oil formulation. PAG lubricants have the potential to deliver significantly higher fuel economy improvement than mineral oils. In the present investigation, several engine oils were formulated by varying PAG lubricant chemistry. The friction performance of these lubricants was evaluated using a motored valvetrain rig, single cylinder piston ring friction rig, and in an engine as a function of speed and temperature. The results showed significant friction reduction compared to GF-5 engine oils. The differentiation between different PAG lubricants was more prominent at lower temperature than at higher temperature.
8:30 – 9 am  
Tribological Characteristics of GTL Based Engine Oils  
H. Gao, J. Cheng, B. Papke, R. Dixon, Shell Global Solutions, Inc., Houston, TX  
The tribological performances of GTL based engine oils were tested and compared against other synthetic engine oils. The unique molecular structures of GTL base oils impart superior performances of formulated engine oils such as high viscosity index and excellent cold temperature properties. MTM traction and EHD film thickness were tested over a wide range of temperatures from cold start to high temperature durability. The friction and wear of GTL based engine oils were tested under high contact stress, high speed and high temperature. Meanwhile, the tribofilm formation was measured using MTM/SLIM to look at the film formation and thickness for superior wear protection.

9 – 9:30 am  
A Prototype Low-Viscosity Engine Oil Using an Ionic Liquid as Anti-Wear Additive  
ORNL-GM-Lubrizol has successfully developed a prototype formulated engine oil using an oil-soluble, phosphonium-phosphate ionic liquid (IL) at 1 wt.% treat rate as the anti-wear additive. The prototype oil has low kinematic viscosities, 25.5 and 5.4 cSt at 40 and 100°C, respectively, and a low HTHS (high-temperature, high-shear) viscosity of 1.9 cP at 150°C. Tribological bench tests of the IL-additized oil showed 20-33% lower friction in mixed and EHD lubrication and 40-90% lower wear in boundary lubrication compared with commercial Mobil 1 and Mobil Clean 5W-30 engine oils. High-temperature, high load (HTHL) full-size engine tests have confirmed the excellent anti-wear performance for the IL-additized engine oil benchmarked against the Mobil 1 5W-30 oil. Sequence VID engine dynamometer tests are being conducted to determine the improved fuel economy for this IL-additized, low-viscosity engine oil. The effects of the IL additive on three-way catalysts are under investigation as well.

9:30 – 10 am  
Analysis of Shear-thinning on Engine Friction Using Mineral and PAO Base Oils  
M. Plumley, V. Wong, MIT, Cambridge, MA  
The impact of viscosity shear rate dependence on diesel engine friction was investigated through experiment and modeling analysis using recently formulated oils with identical additive and kinematic viscosity temperature relationships, yet different shear thinning characteristics. The lubricants include a 15W40 developed with group II and III base stock, and an SAE40 developed from polyalphaolefins (PAO). Temporary shear thinning impact on piston and ring friction and wear were investigated using the modified Reynolds equation, while valvetrain friction was investigated using commercial modeling software. Motored and fired engine tests were conducted with a test engine outfitted with a camshaft torque sensor. Shear thinning reduces viscosity over most of an engine cycle, thereby reducing friction while low shear rates near top and bottom dead center provide some wear benefit.

10 – 10:30 am – Break

10:30 – 11 am  
Optimizing Base Oil Viscosity for Power Cylinder Friction Response Temperature Dependency  
M. Plumley, V. Wong, MIT, Cambridge, MA  
Lubricant viscosity, and therefore instantaneous local friction, along the engine cylinder liner varies by an order of magnitude due to temperature variation. There is tremendous potential for fuel economy improvement by optimizing local viscosity variations. Friction and wear in the power-cylinder system are analyzed to quantify opportunities for improving mechanical efficiency through lubricant formulation tailored specifically to temperature distributions along the cylinder liner. Methods for estimating friction and tradeoffs are discussed and applied to a typical 11.0 L diesel engine power cylinder. Models incorporating the modified Reynolds equation are used to calculate friction under the top ring and piston skirt. Viscosity temperature profiles are proposed to highlight how base oil temperature characteristics may be tailored to optimize friction and wear response for a given application and engine operating condition.

11 – 11:30 am  
Engine Lubricant Viscosity Optimization for Valvetrain and Power Cylinder Systems  
T. Martins, V. Wong, M. Plumley, MIT, Cambridge, MA  
A study was conducted to optimize the viscosity of engine lubricants on a per engine subsystem basis. Using a fired diesel engine with two separate lubrication circuits, a variety of research oils were tested within the valvetrain system and power cylinder system in order to identify the combination of lubricants that minimize engine friction. An inline rotating torquemeter at the flywheel, individual cylinder pressure transducers and a custom made camshaft pulley torquesensor allowed friction work to be measured and characterized in both the engine valvetrain and power cylinder regions with various experimental lubricants. Two viscosity classifications were identified as optimal for each respective system particular to this engine and an overall decrease in friction was demonstrated. This study also discusses the potential gains achieved by implementing an engine with segregated lubricant circuits.

11:30 am – Noon  
Time-Temperature-Pressure Superposition in Polymer Thickened Engine Oils  
F. Qureshi, S. Bair, The Lubrizol Corporation, Wickliffe, OH  
In order to minimize the temperature impact on viscosity, engine oils contain certain polymers known as viscosity modifiers and may suffer from shear thinning. Shear-dependent viscosities have been measured over a range of temperature and pressure for seven engine oils. Elevated pressure measurements were performed with a pressurized thin-film Couette viscometer and ambient pressure measurements were done with a commercially available ultra-shear viscometer (USV). These measurements were fitted to a generalized Newtonian model with the effective shear modulus specified by an empirical power-law shifting rule. Like the Tannas Co. TBS viscometer, the USV viscometer provides shear-dependent viscosity measurements, which can be essential for the most accurate TTPS shifting. Viscosities measured at high viscous power in the ambient pressure viscometer, however, tend to be influenced by thermal softening and at high stress by shear cavitation.
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WEAR I

Session Chair: Z. Li, Northwestern University, Evanston, IL
Session Vice Chair: J. Bomidi, Baker Hughes Incorporated, The Woodlands, TX

8 – 8:30 am
Combination of Wear Damage Analyses and Numerical Simulations for Optimizing the Hot Shearing Process of Rolled Steel

The production of rolled steel requires the removal of metal sheet edges for dimensional control. These edges are removed by shearing blades, which operate at high temperature and suffer from severe wear. Shearing blades need frequent repair and cause elevated maintenance costs. In order to increase the lifetime of shearing blades, a wear damage analysis was performed on field samples. The location and severity of different wear mechanisms, such as severe plastic deformation, thermal fatigue and oxidation were evaluated and correlated with the results of thermo-mechanical finite element simulations. A relationship was found between the stress and temperature distributions predicted by the simulations and the shearing blade areas most affected by wear. Based on this result, a parametric study was performed in order to evaluate the most relevant parameters affecting wear. The optimization of the process allows reducing tool wear without compromising the quality of finished sheet metal.

8:30 – 9 am
A Stress Based Damage Mechanics Model to Simulate Fretting Wear of Hertzian Line Contact in Partial Slip
A. Ghosh, F. Sadeghi, Mechanical Engineering, Purdue University, West Lafayette, IN, B. Leonard, Engineered Custom Lubricants, Aurora, IL

In this investigation, a new model for dry fretting wear of similar materials in Hertzian contact is proposed. The wear law which is dependent on material properties, applied load and sliding distance is proposed for similar materials under dry fretting wear conditions. Based on this law, a stress based damage mechanics equation for wear is formulated and a finite element model is developed to determine wear rates and wear coefficients. To simulate fretting wear, fatigue crack initiation and propagation along the grain boundaries, which are simulated using voronoi tessellation, and grain removal technique is developed. The results of the simulation are compared with the Archard wear law and the calculated wear coefficients are of the same order as suggested in the literature. Wear volume measurements for partial slip regime in fretting wear are obtained using the model and the effects of coefficient of friction, hardness and Young’s modulus on fretting wear is studied.

9 – 9:30 am
Difference in Preventive Mechanism for Fretting Wear between Oil and Grease Lubrication
T. Maruyama, T. Saitou, A. Yokouchi, NSK Ltd, Fujiwara, Japan

Rolling bearings sometimes suffer from the fretting wear as a result of an oscillatory motion. The fretting wear on a bearing surface could cause a reduction of bearing performance, such as an excessively noise, an increase of torque, and the flaking. This study investigated the difference in preventive mechanism for the fretting wear between the oil and grease lubrication by using thrust bearings. The fretting wear was reduced when the high viscosity oil was used in the oil lubrication. In the case of the grease lubrication, the frequency influenced the relationship between the fretting wear and the viscosity. Specifically, the fretting wear was reduced when the high viscosity oil was used at the low frequency. On the other hand, the fretting wear was also reduced when the low viscosity oil was used at the high frequency.

9:30 – 10 am
Effect of Microstructure on the Tribological Performance of Al-Si Alloys
Q. Zou, L. Ren, Mechanical Engineering, Oakland University, Rochester, MI, Q. Wang, GM Powertrain, Pontiac, MI

Aluminum-silicon alloys have been widely used in automotive industry due to their lightweight property, low expansion, low density and high resistance to corrosion. However, the effect of the microstructure of the Al-Si alloys on the tribological performance has not been well studied. In this research, as-cast 6101 aluminum alloy was used as the base material. The alloy was preheated to 545 °C and then went through various aging treatment with different aging time. The hardness vs. aging time curve was then obtained. Two aging time durations which produced equivalent hardness, but different Al-Si microstructures were chosen as the heat treatment for the samples. After the heat treatment, friction and wear tests were performed by using UMT-3 tribometer. Wear tracks were measured by using WYKO 3D Surface Profiler, and wear volume was calculated accordingly. The results indicated that the microstructure of the Al-Si alloys had a significant influence on their tribological behavior.

10 – 10:30 am – Break

10:30 – 11 am
Characterizing Fretting Fatigue Frictional Behavior Using Digital Image Correlation (DIC) Technique
R. Hojjati Talemi, M. Abdel Wahab, P. De Baets, Mechanical Construction and Production, Ghent University, Ghent, Belgium

Fretting fatigue is one of the challenging engineering failure issues which depends not only on fatigue properties of material, but also on tribological properties of connected parts. Fretting fatigue crack initiation process can be caused by formation of macro-cracks at contact interface. The stress states at contact counterparts are used to estimate crack initiation lifetime [1]. However, the stress gradient is highly sensitive to frictional properties of connected parts. In this study the frictional properties of connected parts are monitored by means of DIC technique. DIC technique was used to monitor the displacement field which was calculated based on the best correlation between the image of a deformed surface and a reference image of the undeformed surface. Fretting fatigue test was carried out under partial slip regime for coupon scale and Double Bolted Lap Joints (DBLJ) tests. DIC technique was used to measure coefficient of friction under partial slip regime.
A Microstructural Damage Model for Coatings under Fretting Wear and Fatigue

B. Jalalahmadi, Sentient Corporation, Buffalo, NY, N. Bolander, Sentient Corporation, Idaho Falls, ID

In this work, a microstructural damage model is developed which is able to simulate a coating layer on top of a RVE and predict the fretting lives of coated specimens. The coating layer has a mush finer granular structure compared to the base material. The main inputs for the model are coating layer thickness, coating grain size, and coating material properties (mechanical properties and damage parameters). In order to validate the model, the fretting fatigue and wear tests are performed on different types of coatings and on uncoated specimens as well. Then, the model is used to predict the fretting lives of the coated and uncoated specimens. Model results show an improvement in fretting fatigue lives of coated specimens compared to the uncoated specimens, which were in agreement with test rig results.

Wear of Multi-Component Surfaces 65 Million Years Ago: Applications of Tribology to Dinosaur Dentition

B. Krick, Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA, K. Rowe, W. Sawyer, Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL, G. Erickson, Biological Science, Florida State University, Tallahassee, FL

Hadrosaurids were large herbivores with sophisticated dentition that allowed them to liberate nutrients from tough plants; until recently, this dentition was a mystery to paleontologists. Wear rates, preserved in the 65 million year old fossil, were measured for each of six dental tissues. Measured wear rates were used to simulate the hadrosaurid tooth chewing surfaces with an iterative model coupling evolution of worn surface profile and local contact pressure, resulting in a surface profile that closely resembles a naturally worn hadrosaurid dental battery. The model revealed how the arrangement of tissues of different wear rates evolves during wear to form complex dental features in teeth of dinosaurs, ten of millions of years before mammals evolved analogous features. Additionally, the model is compared to a laboratory wear experiment of a two-component polymer sample. Differences between the measured and predicted surface profiles were within the sample’s surface roughness (3um).

Session 5J • Fantasia P/Q

BEARING CHALLENGES IN WIND TURBINES: ROLLING ELEMENT BEARINGS/WIND TURBINE JOINT SESSION I

Session Chair: V. Bakolas, Schaeffler Technologies, Schweinfurt, Germany
Session Vice Chair: W. Anderson, Afton Chemical, Richmond, VA

8 – 8:30 am
Effect of Magnesium Hydrosilicate on Rolling Element Bearings

P. Rudenko, Q. Chang, Washington State University, Cofax, WA, A. Erdemir, Argonne National Laboratory, Argonne, IL

There is a continuous search of better performing components to lubricating greases. Magnesium hydrosilicated demonstrated formation of the thick tribofilms with self-optimizing properties. Our previous research demonstrated peculiar mechanism of a complex structured tribofilm formation in sliding contact that leads to superlubricity under results that are typically attributable to boundary lubrication. The important role of dopants and powder structure have been demonstrated before. In this follow-on work, we share results of our research aimed at fatigue longevity improvement in industrial rolling element bearings with film forming solid powders of Magnesium Hydrosilicates. The best application of such work can be found in wind bearings where film forming lubricant can be applied after manufacturer warranty expires or when condition monitoring system gave early warning of wear or micropitting.

8:30 – 9 am
Simulation of Microstructural Alterations Around Inclusions using Damage Mechanics

S. Mobasher Moghaddam, Mechanical Engineering, Purdue University, West Lafayette, IN

Wind turbine bearings commonly encounter premature failure within 2-5 years from installation while they are designed to last for 20 years. Microstructural alterations around inclusions which are known as “butterfly-wings” are associated with these failures. In this work damage mechanics is used to model these microstructural alterations. It was found that mean stress due to surface traction has a significant effect on butterfly formation. A new damage evolution law which accounts for the effect of mean stresses was introduced to capture the microstructural changes. The proposed damage evolution law matches the observed butterfly orientation, shape, and size successfully. The simulation predicts the regions for embryonic crack locations and debonding at inclusion/matrix interface in corroboration with experimental observations. The model is exercised to obtain S-N results for butterfly formation at different Hertzian load levels. The results match the experimental data closely.

9 – 9:30 am
Premature White Etching Crack Bearing Failures in Wind Gearboxes

K. Stadler, J. Baum, SKF GmbH, Schweinfurt, Germany

Bearings in large industrial gearboxes sometimes fail, resulting in a failure mode known as white etching cracks (WEC) or sometimes called white structure flaking (WSF). The occurrence of premature failures is heavily discussed within the wind industry and independently investigated by wind turbine manufacturers, gearbox manufacturers, bearing suppliers as well as universities and independent institutes. Unfortunately, a consistent theory does not exist today. In this paper, influencing factors that can lead to WEC networks will be discussed. This is on the one hand done by reflecting bearing related aspects including chemical effects and material properties. On the other hand, application conditions are considered with special focus on wind turbine specifics. From this work it is clear that a generalized simple root cause is counterproductive; pinpointing the need to carefully evaluate each WEC case in the light of the corresponding application.

9:30 – 10 am
Understanding White Etching Cracks in Rolling Element Bearings: Reproduction and Influential Tribocatalytic Drivers

A. Ruelan, F. Viller, J. Cavorot, LaMCoS-INSa Lyon, Université de Lyon, Villeurbanne Cedex, France, X. Kleber, MATEIS – INSa Lyon, Université de Lyon, Villeurbanne, France, C. Burnet, D. Girodin, NTT-SNR Research Center, Annecy, France

Among tribological failures in wind turbine rolling element bearings, an unusual and premature rolling/sliding contact fatigue mode has been defined as White Etching Cracks (WEC) being wide subsurface 3D branching crack networks bordered by nano-grained ferritic white etching microstructure. As WEC occurrences present no common denominator and are delicate to reproduce and observe, no consensus on the formation mechanisms has been verified yet. Analysis of a standard bearing test rig reproducing WEC repeatedly, without artificial hydrogen charging, suggest that WEC initiate through incipient axial surface microcracks and propagate by hydrogen enhanced cracking.

11 – 11:30 am
A Microstructural Damage Model for Coatings under Fretting Wear and Fatigue

B. Jalalahmadi, Sentient Corporation, Buffalo, NY, N. Bolander, Sentient Corporation, Idaho Falls, ID

In this work, a microstructural damage model is developed which is able to simulate a coating layer on top of a RVE and predict the fretting lives of coated specimens. The coating layer has a mush finer granular structure compared to the base material. The main inputs for the model are coating layer thickness, coating grain size, and coating material properties (mechanical properties and damage parameters). In order to validate the model, the fretting fatigue and wear tests are performed on different types of coatings and on uncoated specimens as well. Then, the model is used to predict the fretting lives of the coated and uncoated specimens. Model results show an improvement in fretting fatigue lives of coated specimens compared to the uncoated specimens, which were in agreement with test rig results.

11:30 am – Noon
Wear of Multi-Component Surfaces 65 Million Years Ago: Applications of Tribology to Dinosaur Dentition

B. Krick, Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA, K. Rowe, W. Sawyer, Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL, G. Erickson, Biological Science, Florida State University, Tallahassee, FL

Hadrosaurids were large herbivores with sophisticated dentition that allowed them to liberate nutrients from tough plants; until recently, this dentition was a mystery to paleontologists. Wear rates, preserved in the 65 million year old fossil, were measured for each of six dental tissues. Measured wear rates were used to simulate the hadrosaurid tooth chewing surfaces with an iterative model coupling evolution of worn surface profile and local contact pressure, resulting in a surface profile that closely resembles a naturally worn hadrosaurid dental battery. The model revealed how the arrangement of tissues of different wear rates evolves during wear to form complex dental features in teeth of dinosaurs, tens of millions of years before mammals evolved analogous features. Additionally, the model is compared to a laboratory wear experiment of a two-component polymer sample. Differences between the measured and predicted surface profiles were within the sample’s surface roughness (3um).
due to lubricant decomposition. Initiation and propagation require a subtle equilibrium between contact kinematics and stresses, material parameters and lubrication aspects as additives and water ingress. Contact conditions are transposed on a twin disc machine to simulate WEC and qualify the influence of different drivers.

10 – 10:30 am – Break

10:30 – 11 am

**About the Contribution of Lubricants in White Etching Cracks Bearing Failures**

**W. Holweger, Central Research, Herzogenaurach, Germany**

Bearings suffer worldwide from White Etching Crack failures. Such failures may cause severe destruction of the materials surfaces, hence reduction of plant availability. Root cause is discussed intensely in between bearing manufacturers, customers and scientists. Apart from details in everyone’s explanation, there is a common agreement that lubricants play an essential role. The paper describes in detail the nature of the lubricant assisted failures and how the contribution of the lubricant supports the sub-surface destruction of the bearing material, that finally causes the White Etching Cracks. First numerical simulation results show the initiation and propagation of the failure in the microstructure.

11 – 11:30 am

**Residual Stress Evolution and Acoustic Emission During Lubrication Assisted White Etching Crack (WEC) Formation**

**S. Barteldes, F. Walther, Department of Materials Test Engineering, TU Dortmund University, Dortmund, Germany, W. Holweger, Schaeffler AG, Herzogenaurach, Germany**

White Etching Cracks dominate bearing failures in special industrial applications, for example wind energy plants. Failures may suddenly emerge by the spalling of the raceway of the infected bearing. Test rig results prove that white etching crack formation strongly depends on the presence of special lubricants. Condition monitoring by use of the Barkhausen noise signal emission during the white etching crack formation process shows this process to be completely different to those from rolling contact fatigue phenomena. While, in the case of rolling contact fatigue processes, coercive forces and residual stress are strictly in correlation to each other; the white etching crack process leads to a descent on the coercive force and constant residual stress with no correlation. Online acoustic emission measurements show pronounced signals caused by subsurface cracks in the beginning of the failure. Signals received from the subsurface failure are detected hours before raceway spalling.

11:30 am – Noon

**Investigations to Confirm Subsurface Initiation at Non-Metallic Inclusions as One Mechanism for White Etching Crack (WEC) Formation Under Non-Hydrogen Charged Conditions**

**M. Evans, A. Richardson, L. Wang, R. Wood, National Centre for Advanced Tribology at Southampton (nCATS), University of Southampton, Southampton, United Kingdom, W. Anderson, Industrial Additives, Afton Chemical Corporation, Richmond, VA**

White etching cracks (WECs) cause premature wind turbine gearbox bearing failures. The initiation mechanisms of WECs are contested; hence extensive work previously conducted by the authors aimed to elucidate this. It was confirmed that WECs form by subsurface crack initiation at inclusions under hydrogen charged conditions. Initial evidence was also found for a subsurface mechanism occurring under non-hydrogen charged conditions; therefore this study conducts further work to verify this. RCF testing was conducted on 100Cr6 steel cylindrical roller thrust bearings on a FAG-FE8 test rig. A serial sectioning process was used to map WECs in their entirety that formed in the rollers under non-hydrogen charged conditions for the first time. The results confirm that one mechanism of WEC initiation is subsurface as numerous inclusion-WEC interactions were found and some WECs were contained entirely within the subsurface. Small sized inclusions (~2 – 15 μm) predominated as crack initiators.

**Society of Tribologists and Lubrication Engineers**

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Solazyme, Inc has developed a breakthrough Renewable Tailored Oils technology that addresses and overcomes the traditional shortcomings associated with other vegetable and mineral-based metalworking base oils, providing both high performance and sustainability benefits to its users. In this presentation, we will showcase High Oleic Algal Oil and assist the audience in exploring many non-traditional applications for the improved technology. The necessity for non-mineral oil-based metalworking fluids has driven advancements in sustainable alternatives other than the typical seed oils, that have corrected many of those traditional limitations associated with past seed oil type metalworking fluids. These advancements have further demonstrated enhanced performances with respect to the cutting force, surface finish of work piece, tool wear and the reduction of product carry-off.

**Session 6A • Nutcracker 1**

**LUBRICATION FUNDAMENTALS VI: MODELING**

**Session Chair:** I. Kudish, Kettering University, Flint, MI  
**Session Vice Chair:** P. Shiller, The University of Akron, Akron, OH

**1:30 – 2 pm**  
**Molecular Dynamics Simulation of High Pressure Rheology of Lubricant Mixtures**  
P. Liu, H. Yu, Q. Wang, Center for Surface Engineering and Tribology, Northwestern University, Evanston, IL; N. Ren, F. Lockwood, Ashland Inc., Lexington, KY

Rheological properties of lubricant are determined by the molecular structures of the base oil and additives; they vary with temperature, pressure and shear rate. However, it is difficult to experimentally obtain the viscosity values at a high shear rate and high pressure. Moreover, lubricants are usually mixtures of a number of molecules; it is not easy to distinguish influences of each component in the mixture. This paper reports a molecular dynamics simulation approach for acquiring the rheological properties of lubricant mixtures. The relaxation time is calculated to estimate the critical shear rate for the beginning of shear thinning behavior. The non-equilibrium molecular dynamics (NEMD) approach is used to model the planar Couette flows of the lubricant. Simulations are focused on the shear-rate dependent viscosity and pressure-viscosity coefficient (the alpha value). Time-temperature superpositioning is used to calculate the high pressure viscosity when necessary.

**2 – 2:30 pm**  
**Predicting Pressure-Viscosity Coefficients Using Molecular Dynamics Simulations**  
U. Ramasamy, A. Martini, University of California-Merced, Merced, CA

The effect of pressure on fluid viscosity, quantified by the pressure-viscosity coefficient (PVC), is an important characteristic that dictates lubricant performance in highly loaded contacts. The objective of this project is to develop computational tools using Molecular Dynamics (MD) simulations that correlate fluid molecular structure to viscous properties. Here, PVC is obtained indirectly using empirical equations that relate it to material properties that are easily accessible from MD. Specifically, we use an expression based on Doollittle Free-Volume Theory that relates compressibility to PVC, where compressibility is estimated from MD simulations of nanoscale volumes of fluid. The cumulative errors associated with the empirical model and MD simulations are quantified using Error Propagation Theory. Ultimately, we anticipate that this approach will provide a fundamental understanding of the effect of chemical structure and lubricant composition on PVC.

**2:30 – 3 pm**  
**Ultra-Accelerated Quantum Chemical Molecular Dynamics Simulation of Overbased Detergent Interaction with Brass Synchronizer Surface**  

The ultra-accelerated quantum chemical molecular dynamics (UA-QCMD) simulator has been developed and applied to various industrially relevant tribological systems. In the present study it was applied to model the interaction of overbased sulfonate detergents with manual transmission synchronizer rings (brass) and cones (steel). Overbased detergents are used in manual transmission fluids to control friction and minimize wear in brass and molybdenum synchronizers. Using a computational method based on UA-QCMD, it was found that the interaction of oxygen in calcium carbonate with Cu and Zn in brass is stronger than that with Fe in steel. This is consistent with the experimental observation that thick calcium oxide/carbonate deposits are formed on the surface of brass synchronizers and not on the steel cones. In addition, the UA-QCMD calculations show that the detergent micelle is heated under shear, which may explain the conversion of calcium carbonate to oxide.

**3 – 3:30 pm – Break**

**3:30 – 4 pm**  
**Modeling the Elastohydrodynamic Lubrication of Multi-layered Materials**  
Z. Wang, State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, China; C. Yu, Q. Wang, Mechanical Engineering, Northwestern University, Evanston, IL

A novel model is developed for solving Elastohydrodynamic lubrication of multi-layered materials (ML-EHL). Since the film thickness equation needs the term of the deformation caused by pressure, the key problem for the ML-EHL is to develop a method for rapid calculation of the surface deformations, or displacements, caused by pressure. The elastic displacement and stresses can be calculated by employing the DC-FFT method with influence coefficients where the influence coefficients in the frequency domain relating pressure to surface displacements or stresses are derived by using the Papkovich-Neuber potentials. This model can be extended to the functionally graded material (FGM), which is the FGM-EHL model, where the FGM is described using the multi-layered system with constant material properties in each layer. The effects of multi-layered materials and functionally graded materials on film thickness and pressure distribution are further investigated through parametric studies.

**4 – 4:30 pm**  
**Lubricant Film Thickness Behavior in Counterformal Contacts Considering the Effect of Plastic Deformation**  
T. He, D. Zhu, J. Wang, School of Aeronautics & Astronautics, Sichuan University, Chengdu, China

EHL is a common mode of fluid film lubrication found in many machine elements. Upon many years of research, its lubricant film formation mechanism has been well understood, and some curve-fitting formulae have been widely used. However, engineering materials are usually not ideally elastic, and plastic deformation often occur in many cases, possibly influencing the lubrication characteristics considerably. Therefore, the lubricant film thickness behavior in reality may not exactly follow the conventional EHL theory. In the present study, the plasto-elastohydrodynamic lubrication (PEHL) simulations are conducted for different materials properties in a wide range of
operating conditions, and obtained film thickness results are compared with those from the EHL formulae by Hamrock and Dowson that do not consider the effect of plastic deformation. Based on this the lubricant film thickness prediction method taking into account the plastic deformation is discussed.

4:30 – 5 pm
A Theoretical Analysis of the Elastohydrodynamic Lubrication in Elliptical Contacts with an Arbitrary Entrainment
W. Pu, D. Zhu, J. Wang, Sichuan University, Chengdu, China
Numerical simulations of the EHL have been conducted by many researchers, in which the entraining velocity is usually parallel to one of the axes of Hertzian contact ellipse. However, in some engineering applications, such as spiral bevel and hypoid gears, entraining velocity vector may have an oblique angle that could possibly influence the lubrication characteristics significantly. In the present study the recently developed mixed EHL model is modified to include the effect of arbitrary entraining velocity angle, then the model is validated by comparing its results with available experimental data and previous numerical analyses found in literature. Based on this, computer simulations are conducted in a wide range of operating conditions covering the entire lubrication spectrum from thick-film and ultra-thin film lubrication all the way down to mixed and boundary lubrication. In addition, film thickness prediction method is also discussed in this paper.

5 – 5:30 pm
Revision of the Fundamental Assumptions in EHL and Lubricant Friction Modeling in Heavily Loaded Line Contacts
I. Kudish, Mathematics, Kettering University, Flint, MI
Most modeling results of friction in EHL contacts significantly overestimate the frictional stress. The fundamental assumption affecting friction in lubricated contacts is based on treating surface velocities as constant values along the solid surfaces, i.e. the effect of frictional stresses on surface velocities is completely ignored. In heavily loaded lubricated contacts frictional stresses reach relatively high values and cause significant tangential displacements in contact solids. That makes the surface velocities of the solids to vary from one point to another which significantly mitigates the growth of frictional stresses. This paper studies the influence of elastic tangential displacements on friction. The proper problem formulation for calculating friction in heavily loaded line EHL contacts is proposed, a stable numerical method for calculating friction and other lubrication parameters is developed and realized. A detailed analysis of numerical results is provided.

5:30 – 6 pm
hp Non-Conforming Least Square Spectral Element Method for Solving EHL Line Contact Problem Using Parrellel Computers
P. Singh, P. Sinha, Mathematics & Statistics, IIT Kanpur, Kanpur, India
New Computational algorithms have been developed for solving Elastohydrodynamic Lubrication (EHL) problem of infinite line contact which is based on hp non conforming least square spectral Element method(hp-LSSEM) using parrellel computers. The Reynolds, elasticity and force balance equation are solved simultaneously. A systematic approach have been developed and investigated using parrellel computers. PCGM Solver is used for solving Reynolds equation. Film thickness equation is solved using singular quadrature technique. H2 norm preconditioner have been used to enhanced the performance iteration steps. The numerical procedure is stable and accurate enough to capture pressure spike Comparison of the results have been done to validate the methods. Roughness effect also investigated using present method. Idea have been extended for two-dimensional point contact case also which author will discuss in their upcoming papers.
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3:30 – 4 pm
Tribological Performance of VN-Cu and MoN-Cu Coatings at High Temperature
G. Ramirez, T. Burgo, O. Eryilmaz, A. Erdemir, Tribology Section, Argonne National Laboratory, Argonne, IL

VN-Cu and MoCu-N nano-composite coatings were prepared using a reactive magnetron sputtering technique. The films were grown on 440C stainless steel flat and ball samples for tribological tests and Si wafer samples are coated for other coating characterization studies. The tribological tests were conducted using a high temperature ball on disk system in open air environment. The tests were sampled at room temperature, 350°C and 650°C. The results show that the coefficient of friction has a strong dependence on test temperature. For both VN-Cu and MoN-Cu coatings, COF decreased with increasing temperature and the lowest COF (i.e., 0.4) was attained at 650°C due to the formation of the lubricious metallic oxides on sliding surfaces. The wear resistance of coatings also improved with increasing temperature. The nature of lubricious oxides was studied using Raman and x-ray photoelectron spectroscopy techniques and correlated with the friction and wear performance of coated surfaces.

4 – 4:30 pm
Tribological Behavior of VN-Cu Coatings in Lubricated Conditions
G. Ramirez, O. Eryilmaz, A. Erdemir, Tribology Section, Argonne National Laboratory, Argonne, IL

VN-Cu composite coatings were prepared by using a reactive magnetron sputtering technique. A HIPIMS power supply is used to sputter Vanadium and for metal ion etching purposes to improve the adhesion of the composite coatings. XRD and XPS techniques were used to characterize the coatings before and after tribological testing; also nanoindentation technique is used to determine the mechanical properties of the coatings. Using fully formulated engine oil and pure poly-alpha olefin oil, a series of tribological tests were run with a ball-on-disk and high-frequency reciprocating test machines under boundary lubricated test conditions and at temperatures up to 100°C. Test results revealed much reduced friction coefficients for the VN-Cu coated substrates and the amount of wear on both the substrate and ball side was hard to measure as opposed to very significant wear on uncoated surfaces. XPS is used to elucidate the friction and wear mechanisms of VN-Cu surfaces.

4:30 – 5 pm
Load Dependence of Silver Tantalate as a High-Temperature Solid Lubricant
H. Gao, UC Merced, Merced, CA, S. Aouadi, T. Scharf, University of North Texas, Denton, TX, A. Martini, UC Merced, Merced, CA

Silver tantalate (AgTaO3) is a promising candidate as a solid lubricant for high-temperature applications. In this study, molecular dynamics simulation, together with experiments, are used to investigate the load-dependent properties of AgTaO3. Both experiments and simulations of sliding contact of AgTaO3 predict that friction increases with normal load and decreases with temperature. To understand these trends, we characterize the evolution of the composition of the tribofilm during sliding at different normal loads. The results indicate that Ag atoms are easily displaced from the contact and aggregate outside the wear track, and that this silver redistribution is more significant at higher loads. Further, the findings suggest possible sliding mechanisms for AgTaO3, in which the both the segregation of silver and tribofilm density play important roles. This study enables us to understand the tribological mechanisms of AgTaO3, both at the sliding interface and inside of the tribofilm.

5 – 5:30 pm
Evaluation and Investigation of Tungsten Disulfide Aimed at Utilization as Space Solid Lubricant
A. Takahashi, K. Hashimoto, Teikyo University, Tochigi-ken, Japan

To be used in harsh environments, spacecraft may also cause a different problem with the ground. In order to prevent the problem, many of the sliding portion of the spacecraft are subjected to lubrication processing. Lubricant for the solid lubricant space suitable for low pressure environment and temperature are utilized, Gold (Au) and Molybdenum disulfide (MoS2) is the mainstream among others. In order to simulate deployment friction, experiments were conducted with a pin-on-disk of reciprocating tribometer in the vacuum chamber. Evaluation of solid lubricant is Tungsten disulfide (WS2). Because lubricating properties of Tungsten disulfide known similar to Molybdenum disulfide, so it expected to be put to practical use in space applications. It was found that the Tungsten disulfide lubricant coating is high performance at friction of coefficient. Tungsten disulfide substrates have been analyzed using SEM-EDS after friction test.

5:30 – 6 pm
Wear Resistance of Gold Platings in Electrical Contacts Under Low-amplitude Reciprocation
E. Terrell, Mechanical Engineering, Columbia University, New York, NY

In electrical contacts, thin films of nickel and gold or silver are traditionally plated on top of the copper baseplate to provide corrosion resistance and wear protection. Most recently, the rising cost of noble metals has driven the industry towards thinner plating layers, which gives rise to questions regarding how interfacial contact and wear is affected by plating thickness. This study uses a combination of finite element analysis and ex-situ wear measurement to determine the effect of gold plating thickness on wear performance under linear reciprocating sliding contact. Correlations between predicted and measured results lead to insight into the stress state within the multilayered system under contact conditions as well as a wear map for gold platings that can be used to inform future connector designs.
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2. Tribology: Micro & Nano Scales (Dr. Ashlie Martini, University of California Merced)
3. Tribology: Macro scales (Dr. Daejong Kim, University of Texas at Arlington)
4. Tribology: Medical Applications (Dr. David Burris, University of Delaware)
5. Tribology: Natural Processes (Dr. David Burris, University of Delaware)
6. Tribology: Energy Economy & Sustainability (Dr. Aaron Greco, Argonne National Laboratory)
7. Tribology: Tribology in Manufacturing Processes (Dr. Daniel Nelias, INSA – LaMCoS)

Questions?
Visit [www.stle.org](http://www.stle.org) for program updates, online registration (opens June 1) and hotel reservations. Or contact Merle Hedland at mhedland@stle.org.
It has long been recognized that creating regular arrays of features on lubricated bearing surfaces can alter their friction and wear characteristics. The tribology literature describes how the sizes, spacings, shapes, orientation, load bearing area, and depth of micro-scale features can affect sliding friction. Lubricated friction tests were conducted on brass, bronze, and titanium alloy surfaces using three different textures and methods of creating them: (a) arrays of hardness impressions, (b) captive ball arrays, and (c) compression texturing of complex patterns using hard wire meshes. A method to simultaneously texture and form curved surfaces for use as bearing inserts was developed. Friction tests of textured copper alloy surfaces against AISI 8620 steel were conducted using a programmable load bearing test system in drip-fed 15W40 and 0W30 diesel engine oils to determine whether texturing could offset the frictional effects of using lower viscosity oils.

**2 – 2:30 pm**

**Microstructured Surfaces in Highly Loaded Contacts – Differences Due to Sliding Effects**

M. Weschta, S. Tremmel, S. Wartzack, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany, M. Pausch, Schaeffler Technologies AG & Co. KG, Schweinfurt, Germany

In the scope of this presentation the impact of microstructures in highly loaded contacts – where elastohydrodynamic lubrication theory applies – on improving lubricant film formation and effects of friction reduction will be analyzed. Examples used here are ball bearings, in condition of pure rolling, and the cam-tappet contact, a system with a higher proportion of sliding. For such contacts the effects of microstructures are subject of current basic research. Due to high pressures in the contact region, elastic deformation of contacting bodies plays an important role. Microstructures influence this deformation, resulting in a local change of the lubricating film geometry. It will be shown numerically and experimentally that for elliptical contacts in condition of pure rolling no positive effects can be expected. In contrast the cam-tappet contact shows friction reduction effects on a test rig and a local increase in fluid film thickness can be observed simulating the cam tip contact.
Material tribology and nanotribology research has made significant progress in understanding the mechanical properties of materials at the nanoscale. This includes the study of contact forces, adhesion, and wear mechanisms. Recent advancements in atomic force microscopy (AFM) and molecular dynamics (MD) simulations have allowed researchers to explore these phenomena at unprecedented levels of detail.

**Tribological Properties of Biomimetic Multi-scale Patterned Surfaces**

E. Yoon, S. Piao, D. Pham, I. Cho, Center for BioMicrosystems, Korea Institute of Science and Technology, Seoul, Korea, K. Jhang, Dept. of Mechanical Eng., Hanyang University, Seoul, Korea

This study presents an investigation of hydrophobicity and nanoscale tribological properties of multi-scale patterns which mimic the morphology of the Lotus leaves. Micro, nano, and hierarchical patterns of Si-wafer were fabricated by conventional MEMS fabrication procedure and those of poly(methyl methacrylate) (PMMA) were fabricated on Si wafers using a two-steps capillary force lithography technique, in which nano-scale patterns were created on micro-scale patterns to form the multi-scale structures. Static water contact angle (WCA) of the patterned surfaces was examined by a water contact angle analyzer. Adhesion and friction forces of all materials were examined by an atomic force microscope (AFM). Results showed that the patterning increases WCA of the Si and PMMA flat surface. For tribological properties, the hierarchical patterns showed the lowest values of these forces compared to the rest of tested materials, presumably due to their lowest real contact area.

**Simulation of Tribo-Initiated Chemistry in Iron-Hydrocarbon Systems**

J. Schall, Mechanical Engineering, Oakland University, Rochester, MI

Tribosystems containing both iron and hydrocarbon-based lubricants are ubiquitous and an understanding of the chemistry that takes place in such systems is essential. In this study, the triboinitiated chemistry of alkanes and poly-alpha-olefins (PAO) molecules and iron surfaces was investigated using molecular dynamics simulation and a REAX-FF interatomic potential function for Fe, O, C and H (Zou, JOM, 64, 2012, 1426). Chemistry in both straight and branched alkanes and PAOs of various molecular weights on iron surfaces were investigated. The alpha carbon in PAO molecules was observed to form a bond bridging between adjacent Fe atoms on surface. In straight-chain alkanes, no surface chemical reactivity was observed. Chemical reactivity in branched alkanes and PAOs was observed particularly in systems containing quaternary carbon atoms. In this presentation the effect of these chemical differences will be discussed in regards to the friction behavior and tribofilm formation.

**Advances in Nanomechanical Characterization Methods of Surfaces with Atomic Force Microscopy**

D. Yablon, SurfaceChar, Sharon, MA

Recent advances in hardware and software have enabled new capabilities with atomic force microscopy for mechanical based characterization of materials. Two such novel methods are described here. The first is multifrequency AFM, where the cantilever is simultaneously oscillated at multiple eigenmodes, thereby improving the ability of the AFM to discriminate and differentiate multi-component materials. The second is the dynamic contact method of contact resonance, where tip and contact are oscillated together at small amplitudes. Contact resonance can be used to investigate the mechanical properties such as Young's modulus, loss modulus and loss tangent, to be measured. Measurements with AFM contact resonance compare favorably with macroscopic mechanical measurements. The benefits of multifrequency AFM and contact resonance are demonstrated on a variety of organic polymer systems.

**A Molecular Dynamics Investigation of the Adhesion Between Carbon-based Materials Upon Repetitive Contact**

J. Harrison, K. Ryan, P. Keating, United States Naval Academy, Annapolis, MD, V. Vahdat, Y. Jiang, K. Turner, R. Carpick, Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA, J. Schall, Mechanical Engineering, Oakland University, Rochester, MI

Atomic-scale wear hinders the performance of nanoscale probes used in atomic force microscopy (AFM) experiments. This wear cannot be fully understood on the atomic level using experimental methods or continuum-based models. Molecular dynamics (MD) simulations allow behavior at the nanoscale to be modeled by resolving the positions, velocities, and forces of all atoms in the system. Recently, we have used MD simulations to model amplitude modulation (AM) AFM, which involves repeated contacts between the tip and surface. An amorphous carbon and hydrogen (a-C:H) tip with a radius of curvature of 15 nm, larger than those modeled in previous simulations, was used to contact an ultrananocrystalline diamond (UNCD) surface. Tip and surface material, tip shapes, and tip sizes were chosen to closely mimic those used in comparable experiments. The wear processes, including adhesive forces, material transfer, and changes to material hybridization are examined following multiple contacts.

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4 – 4:30 pm
Effect of Alloy Carbides on Hardening Behavior of M-50 NIL Bearing Steel Due to RCF
A. Bhattacharyya, G. Subhash, N. Arakere, University of Florida, Gainesville, FL

Rolling contact fatigue (RCF) in bearing steels is associated with complex localized mechanical and microstructural changes, as a function of contact cycles. RCF produces significant work hardening in the localized subsurface micro- plastic zone due to cyclic strain accumulation via ratcheting. In this study we study the effect of alloy carbides on ratcheting behavior in bearing steels subjected to RCF. The carbides induce stress concentration and unsymmetric shear stress cycles which promote ratcheting. Nano-indentation is used to measure and map the highly localized changes in microhardness adjacent to the carbide particles. The hardness of the matrix material adjacent to the carbides is found to be significantly greater compared to the regions further away from the carbides. The presence of carbides and triaxial cyclic fatigue stress due to RCF is the key driver for high material work hardening, far in excess of that observed in conventional high cycle fatigue.

4:30 – 5 pm
Nanoscale Sliding Friction Phenomena at the Interface of Diamond-like Carbon and Tungsten
P. Stoyanov, P. Romero, M. Dienwinkel, M. Moseler, KIT-IWM

Macroscopic tribometry is linked with classical atomistic simulations in order to improve our understanding of the nanoscale interfacial processes during sliding of a-C:H against a metal (W) in dry and lubricated conditions. Wear and roughness measurements are performed on-line, which are then correlated to the frictional resistance. Ex situ analysis is also performed of the near-surface region using XPS, AES, and TEM. In order to elucidate the atomistic level processes which contribute to the microstructural evolution in the experiments, classical molecular dynamics are performed employing a bond order potential for the Tungsten-Carbon-Hydrogen system. Experiments show that dry sliding of DLC against W results in higher frictional resistance and significantly more material transfer compared to lubricated conditions. Similarly, the molecular dynamics simulations exhibit higher average shear stresses and clear material transfer for dry conditions compared to simulations with a lubricant.

5 – 5:30 pm
Reactive Boundary Layers in Metallic Rolling Contacts
J. Burbank, C. Scholz, M. Woydt, BAM (Federal Institute for Materials Research and Testing), Berlin, Germany

The running-in phase of mechanical systems is critical from a tribological standpoint, because microcracks, a cause of material failure, can appear during this phase of heightened friction and wear. The goal of this current work is to transfer the running-in phase into the finishing process through the preconditioning of novel, high toughness steel bearings in comparison to conventionally used steels. This has been achieved through the generation of tribo-reactive protective films, as well as through cold work hardening of the steel surface substrates. The presence of reactive tribofilms was determined via SEM-EDX with Element-Mapping, whereas the effects of cold work hardening on the samples was observed through measurement of localized hardness and residual stresses. Both tribofilm-protected samples and cold work hardened samples were subjected to long term slip-rolling testing (10,000,000 cycles, approx. 18 days) to determine any changes in friction behaviour or wear performance.

5:30 – 6 pm
Molecular Dynamics Modeling on the Contact of Magnetic Head and Disk Coated with Ultrathin DLC Film
L. Li, Q. Liu, Z. Hou, W. Song, G. Zhang, Harbin Institute of Technology, Harbin, China, A. Ovacharenko, Western Digital Corporation, San Jose, CA

Diamond-like carbon (DLC) films have been used as protective coating on disk and sliders of magnetic head in hard disk drives (HDD) for years. With the increasing of storage density, the thickness of carbon films has decreased to atomic scale. The contact and nanotribological properties of the ultrathin DLC film on the disks and head should be understood in order to improve the reliability of HDD. In this work, a molecular dynamics (MD) model is developed to investigate the nanotribological properties of the head and disk. The head is simplified as two parts, the DLC films and the substrate. The disk is defined as three parts, the DLC films, the magnetic recording layer and the substrate. The effect of the density and the sp3/sp2 ratio of the DLC film are investigated. The effect of contact conditions, normal load and sliding velocity are determined.

ENGINE & DRIVETRAIN III

Session Chair: D. Uy, Ford Motor Co., Dearborn, MI
Session Vice Chair: S. Watson, Imperial Oil Ltd., Sarnia, ON, Canada

1:30 – 2 pm
Regional Lubricant Formulation Opportunities for Fuel Efficiency Gains Considering Local Fleet Usage, Prevalent Duty Cycles, and Climate Conditions in Southeast Asia
I. Tracy, V. Wong, Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA

The climate and nature of automobile use in Southeast Asia present unique opportunities for tailoring lubricants to yield significantly enhanced regional diesel engine efficiency. Lubricants play key roles in reducing piston assembly friction, which accounts for 40 – 50% of total engine mechanical friction losses. Our related studies indicate that a 30% reduction in piston assembly friction can be achieved by controlling the variation of viscosity in situ along the cylinder liner. A strategy for controlling lubricant viscosity index and overall piston-cylinder liner friction involves optimizing additives to a lubricant base oil for a given engine operating in a particular environment. This presentation demonstrates that by optimizing lubricant composition in a light-duty diesel engine operating in Southeast Asia, where environmental and engine operating conditions are relatively favorable, brake thermal efficiency can be improved by 3% with no appreciable increase in ring pack wear.

2 – 2:30 pm
Towards a Reliable Friction Prediction in Automotive Journal Bearings
D. Sander, H. Allmaier, H. Priebsch, F. Reich, NVH & Friction, Virtual Vehicle Research Center, Graz, Austria

Frictional losses in automotive journal bearings count for up to 44% of overall mechanical losses in internal combustion engines [Holmberg 2012]. To improve the efficiency under growing mechanical and thermal loads in modern engines, reliable simulation methods are essential to minimize friction and at the same time to avoid bearing failure. Low-viscosity engine oil is one measure to reduce the losses in journal bearings. Oil viscosity is the key parameter to describe
lubricated contacts and is extremely sensitive to temperature and pressure. Nowadays, multi-grade engine oils are commonly used in passenger cars. Such oils behave highly non-newtonian. This presentation will describe a systematic method to enhance viscosity models in bearing simulation and to improve the precision of elastohydrodynamic simulation in automotive applications. The developed method is based on extensive validation with a journal bearing test-rig.

2:30 – 3 pm
A Comprehensive Mixed-Lubrication Regime Modelling of Rigid Line Contacts
D. Zachariadis, F. Profito, Mechanical Engineering (Laboratory of Surface Phenomena), University of São Paulo, São Paulo, Brazil

A comprehensive mathematical modelling conceived to predict the tribological characteristics of rigid line contacts under mixed-lubrication conditions is presented. The hydrodynamic pressures are calculated from the averaged Reynolds equation (Patir and Cheng's approach), and the lubricant cavitation is predicted adopting the mass-conserving p− model. Viscosity-pressure-temperature-shear-thinning corrections are also taken into account for the lubricant rheology. The asperity contact pressures are computed employing the Greenwood-Tripp model with contact parameters calculated from actual topographies. A computational program has been developed for the simulation of the proposed modelling, and comparisons with experimental results from reciprocating piston-ring tests exhibited excellent agreement. Simulation results aimed to investigate the influence of honing angles on lubrication and the significance of using a mass-conserving cavitation model in textured contacts are also discussed.

3 – 3:30 pm – Break

3:30 – 4 pm
Methodology to Study Engine Components’ Friction of a Fired/motored Engine: Results for Piston and Valvetrain Assemblies and Bearings
M. Moneer, P. Lee, E. Liu, J. White, Southwest Research Institute, San Antonio, TX

Demand for improved fuel efficient spark/compression ignition engines have driven the automotive sector to reduce viscosities and new additive solutions. As the percentage fuel economy improvements become increasingly smaller, improved accuracy in measuring these frictional improvements becomes increasingly important. Although much is achieved through bench testing, results do not always directly translate to the results obtained in engines. SwRI has built a single cylinder fired engine test stand to measure total, piston assembly and valvetrain friction, from which bearing friction is calculated. This presentation will discuss the methodology behind the work and efforts to refine accuracy exemplified through recorded data.

4 – 4:30 pm
Developing a Screener Test for the Cummins ISB Camshaft and Tappet Interface
G. Hansen, P. Lee, Southwest Research Institute, San Antonio, TX

The Cummins ISB test evaluates a lubricant’s ability to prevent valve train wear; specifically in the region of the camshaft and solid tappet lifter interface. Southwest Research Institute endeavored to build a bench test that simulated the ISB test conditions while using actual ISB valve train components. The purpose of this bench test was to use it as a low cost screener for experimental heavy duty oils prior to evaluation in the actual engine.

In addition to standard speed and temperature measurements, a novel measurement system was developed to monitor the RPM of the tappet. The data collected from the bench test on oils that have operated in the full ISB test showed good correlation on the standard wear measurements and also provided insight into what effects the oil has on tappet RPM and how that correlates to increased or decreased wear. This presentation will highlight the development of the bench test and some of the more significant results.

4:30 – 5 pm
Correlating Material Loss Between Radioactive Isotope Tracers and Pre/Post Test Metrology Metrics in the Current PC-10 Category Mack T-12 Test
C. Wileman, Southwest Research Institute, San Antonio, TX

Studying material removal using radioactive isotope labels within powertrain components is an established technology. How well does the radioactive material measurement correlate to Start-of-Test vs. End-of-Test metrology in a full length ASTM Mack T-12 test, that is currently employed in the PC-10 heavy duty category? This study demonstrates the necessary practices for achieving the best possible correlation between the two metrics. Agreement between the metrics allows for instantaneous dimensional characterization of the labeled part in a running engine or operating powertrain component. This study depicts the performance of two oil formulations evaluated, simultaneously, as prescribed by the ASTM procedure and by Radioactive Tracer Technology during two complete 300-hr tests.

5 – 5:30 pm
Predicted Crankshaft Main Bearing Oil Film Thickness Under Hull Deflection and Journal Misalignment in a Large Ship Engine
K. Hoag, Southwest Research Institute, San Antonio, TX

Oil film thickness at each main bearing was predicted for a V-16 ship diesel engine. Analysis began with a simple crankshaft bending versus stiffness model coupled with plain bearing hydrodynamic simulation of the nine main bearings. Variables including engine speed and load, lubricant temperature, engine firing order, and crankshaft torsionals were assessed. The simple, crankshaft bending stiffness model was then replaced with a detailed crankshaft finite element model. Comparative predictions between the models were assessed, and the more detailed approach to crankshaft deflection was used to assess the effects of hull deflection in rough seas, and main bearing journal misalignment.

5:30 – 6 pm
An XPS Study on the Composition of Zinc Dialkyl Dithiophosphate Tribofilms and Their Effect on Camshaft Lobe Wear
E. Liu, S. Kouame, Southwest Research Institute, San Antonio, TX

Zinc dialkyl dithiophosphate (ZDDP) derived tribofilms were analyzed with X-ray photoelectron spectroscopy to determine the relationship between tribofilm chemical composition and wear severity. Samples were generated on cam lobes from engine tests conducted at different oil temperatures, and wear depths were measured with a surface profilometer. Tribofilm specimens were analyzed by XPS to assess changes in film chemistry as a function of wear severity. Tribofilms present on all camshaft lobes were found to contain polyphosphate glass of various lengths. Long-chain polyphosphate were observed on low wear tracks, while short-chain polyphosphates were found on severe wear tracks. Variations in polyphosphate length are also apparent at various wear depths along a low wear track. The presence of long-chain polyphosphates on low wear tracks was indicative of their superior antiwear properties to those of short-chain polyphosphates.

6 – 6:30 pm – Engine & Drive Train Business Meeting
Session 6H  •  Fantasia M/N

WEAR II

Session Chair: Y. Zhou, Texas A&M, College Station, TX
Session Vice Chair: A. Ghosh, Purdue University, West Lafayette, IN

1:30 – 2 pm
Running-In Effects on the Performance of Polycrystalline Diamond Thrust Bearings
Polycrystalline diamond (PCD) thrust bearings demonstrate running-in behavior through friction reduction and achieving steady state over time. This frictional transition period greatly affects the overall performance of the bearings, especially the load capacity. Laboratory tests were performed to measure the PCD thrust bearings’ load capacity; it was compared between bearings undergoing a running-in period and bearings without the running-in process. The bearings going through the running-in process, until reaching a steady state friction, showed a significant increment in load capacity when compared to bearings without a running-in process.

2 – 2:30 pm
A New Mechanism for Diamond Wear
H. Xiao, H. Liang, C. Lin, Texas A&M University, College Station, TX
Diamond has been used as a high performance material in industry that involves drilling and machine. We investigate tribochemical wear mechanisms of a diamond-silicon carbide composite using a pin-on-disk configuration in both aqueous and dry environments. The worn surface and wear debris after tribological experiments were characterized. Phase transformation from diamond carbon (sp3) to amorphous carbon (sp2) in friction was confirmed by Raman spectroscopy. In addition, the Raman peak of wear debris identified a shift from crystalline Si (521 cm-1) to the mixture of amorphous silicon and silicon oxide at 510 cm-1. Interestingly, the surface roughness of the diamond particles was found to be greatly reduced due to wear. The smoothening of the surface asperities was due to polishing effect of silicon oxide as abrasives promoting removal of weaker sp2 bonded carbon. We propose a polishing-wear mechanism of diamond. The research is important for design new diamond-containing tools.

2:30 – 3 pm
Predicting Wear due to Sliding-Electrical Contact of Materials
Q. Wang, W. Chen, H. Miwa, T. Nanbu, Y. Uehara, Northwestern University, Evanston, IL, D. Zhu, Advanced Materials Laboratory, Nissan Research Center, Kanagawa, Japan
This joint research aims to study the contact and wear behaviors of several materials in sliding electrical contacts. Pin-on-disk electrical contact experiments are conducted and the thermo-electrical-mechanical contact status is modeled considering the effects of both electrical and mechanical heating subjected to the variations of speed, load, and current density. Heat partition, material thermal softening, and plastic deformation are included in the model. A special effort is made towards the optimal design of surface roughness for the best contact and least wear of materials.

3 – 3:30 pm – Break

3:30 – 4 pm
The Use and Misuse of the Pin-on-Disk Wear Test
The pin-on-disk (PoD) wear test remains one of the most widely-used in materials tribology. An ASLE survey published in 1976 exemplifies its historical use. Like any wear test method, the deceptively simple PoD has both advantages and disadvantages. This presentation overviews the use and the all-too-common misuse of the PoD test method. Topics will include its relevance to engineering components, the effects of pin tilt and alignment on cutting versus plowing, varying contact area ratio for conformal versus non-conformal contacts, non-constant sliding distance and contact pressure due to track widening, third-body effects from the orientation of the disk, and differences in results depending on whether a material is chosen for the pin or disk specimen. The repeatability of PoD data and the presumption of linear wear behavior when computing wear coefficients is addressed, as is the question of whether the popular ASTM G99 standard PoD test is really a standard.

4 – 4:30 pm
Investigating Scuffing Using a New Test Method
M. Ingram, C. Hamer, PCS Instruments, London, United Kingdom, H. Spikes, Imperial College, London, United Kingdom
Scuffing can occur in high sliding speed/high load contacts, during a breakdown of both the hydrodynamic and boundary films. The unprotected metal-metal contact that ensues exhibits high friction as the surfaces are momentarily welded and torn apart. A new testing method has been designed that can aid in the fundamental study of scuffing and screen the scuffing performance of formulated lubricants. The new testing method uses a high pressure, contra-rotating contact which accelerates the onset of scuffing in a controlled manner. The occurrence of scuffing is easily identified by a large change in the measured friction coefficient, and can then be classified in terms of the sliding speed or applied load at failure, which can be increased step-wise or linearly.

4:30 – 5 pm
Elastic Properties of the Fabric Liner and Their Influence on the Wear Depth of the Spherical Plain Bearing
X. Shen, P. Gao, Z. Liu, X. Chen, Department of Mechanical Automation Engineering, Shanghai University, Shanghai, China
The major failure mechanism of typical spherical plain bearings with self-lubrication is the wear of the woven fabric liner, which is an orthotropic composite of different elastic properties in different directions. The elastic properties of the liner are needed for studying the tribological properties of the spherical plain bearings. This paper aims to develop an elastic property analysis model suitable for three commonly used fabric liners through a theoretical analysis of the elastic properties in order to obtain the parameter expression of the compliance matrix. The influence of the elastic properties on the wear depth of the spherical plain bearings is further investigated. Suggestions are made for the optimal design of the spherical plain bearings based on wear reduction.
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BEARING CHALLENGES IN WIND TURBINES: ROLLING ELEMENT BEARINGS/ WIND TURBINE JOINT SESSION II

Session Chair: W. Anderson, Altion Chemical, Richmond, VA
Session Vice Chair: V. Bakolas, Shaefler Technologies, Schweinfurt, Germany

1:30 – 2 pm
Rolling Element Bearing Performance with Black Oxide and Tungsten Carbide-Reinforced Diamond-like Carbon (WC/a-C:H) Surface Treatments
R. Evans, C. Hager, Y. Kang, The Timken Company, Canton, OH,
G. Doll, Timken Engineered Surfaces Laboratory, The University of Akron, Akron, OH

Surface-initiated damage increasingly limits the service life of rolling element bearings in challenging environments. In particular, operation in the boundary and mixed lubrication regimes and/or excessive rolling element-raceway slip have led to the use of surface treatments on roller bodies and raceways to extend surface durability and component life. The tribological performance of two approaches are compared and contrasted: black oxide chemical conversion treatment and tungsten carbide-reinforced diamond-like carbon (WC/a-C:H) thin film hard coatings. Lubricated traction, adhesive wear resistance, and bearing fatigue test results are reported. Results from both bench-scale tribological tests and bearing tests indicate the superiority of WC/a-C:H roller coatings in protecting against severe adhesive wear damage and extending bearing fatigue life in boundary lubricated conditions.

2 – 5:30 pm
Panel Discussion
A panel discussion covering current and future challenges for wind turbine bearings. Panelists include experts from bearing suppliers, and wind turbine OEMs, suppliers and end users.

5:30 – 6 pm – Wind Turbine Business Meeting

Session 6K • America’s B

FLUID FILM BEARINGS I

Session Chair: F. Horvat, The University of Akron, Akron, OH
Session Vice Chair: J. Bouyer, Université de Poitiers, Futuroscope, France

1:30 – 2 pm
Study of Geometrically Imperfect Multirecess Hybrid Journal Bearing System with different Pocket Geometries
S. Sharma, A. Rajput, Mechanical & Industrial Engineering, IIT Roorkee, Roorkee, India

Bearing designers generally use rectangular pocket to analyze multirecess journal bearing due to its manufacturing simplicity. Recent advances in manufacturing provide flexibility to designers to use different geometries of pockets viz. square/circular/elliptical/triangular in their design. Despite of accurate and precise manufacturing processes and used, different types of geometric imperfections exist in manufacturing of journal. Most common geometric errors in journal are barrel, bellmouth and circumferential undulations types. The order of magnitude of errors is of the order of bearing clearance. Hence, inclusion of these imperfections in analysis becomes imperative to simulate realistic bearing performance. Present work deals with the effect of geometric imperfections on the performance of CFV compensated hybrid journal bearing with different pocket geometries. Proper selection of pocket geometry is desired to have least influence on the bearing performance.

2 – 2:30 pm
An Experimental Comparison of the Steady-State Performance Between Flat-land, Tapered-land, Pocket and Textured Thrust Bearings
J. Bouyer, Y. Henry, M. Fillon, Mechanical Engineering and Complex Systems, Institut Pprime, Futuroscope Chasseneuil Cedex, France

Recent studies of our group on the behavior of thrust bearings with textured surface have provided numerous experimental data, allowing characterizing the behavior of such devices operating under steady-state and transient (start-up period) regimes. The present work aims to compare the performance of several types of thrust bearings; both local characteristics as film/pad interface temperature or hydrodynamic pressure, and global characteristics as friction and minimum film thickness are discussed. The results are presented for a rotational speed of 6000 rpm and a load range varying from 1000 to 5000N. The main conclusion is that the tapered-land and pocket thrust bearings have better performance than that observed on a textured thrust bearing, in terms of minimum film thickness, maximum measured temperature and friction torque. It is finally found that the textured thrust bearing has no significant interest compared to classical thrust bearings, i.e. tapered-land and pocket bearings.

2:30 – 3 pm
Defining the Impact of Contact Degradation on the Tilting of Pivoted Journal and Thrust Pads
L. Branagan, Pioneer Motor Bearing Company, Kings Mountain, NC

Tilting pad radial and thrust bearings are designed with mechanical pivots which introduce minimal resistance to rotation. Recent works have shown the degradation in tilting associated with friction and resisting moments across this contact. For used bearings, deformation or fretting wear on one or both surfaces of the contact has the likelihood of further degrading the circumferential tilting. The impact on deformation on the friction is evaluated using contact mechanics, considering elastic and plastic deformation.
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3:30 – 4 pm

Numerical Investigation of a Large Hydroelectric Thrust Bearing

S. Duriseti, Mechanical Engineering, Auroras' Engineering College, Bhongir, Hyderabad, India

Two dimensional Reynolds’ equation is converted in to a set of simultaneous linear algebraic equations using a FDM method for determining the pressures. Integration of these values gives the load distribution. The Vogelpohl – Cameron equation gives the viscosity vs temperature variation. The heat governing energy equation is also solved using the FDM grid. Hot oil carry over effect is considered. A coupled FEM method using ANSYS calculates the thermo-structural deformation of the pad. The author's, Ettle's and Yuan's experimental results for pressures and film thickness showed good agreement. A study of stiffness and damping characteristics is done by varying the film thickness and considering vertical velocity of the runner. The optimal pad thickness for the thicknesses ranging from 20mm to 60mm is determined using the thermal stress distributions. The tilting stiffness determined for variation in film thickness and torque serves as an input in rotor dynamic studies.

4:30 – 5 pm

Thermal Effects in Pocketed Thrust Washers

A. Cross, F. Sadeghi, ME Tribology, Purdue University, West Lafayette, IN

A numerical and experimental investigation was performed to study thermal effects on pocketed thrust washer performance. Thrust washers with cylindrical shaped surface modifications were constructed with a thin layer of thermochromic material just below the bearing surface. During operation, heat generated in the lubricant warmed the thermochromic film enabling temperature measurement across the stationary surface. Experimental results showed significantly lower temperatures in the cavitation region with indications of recirculating flow. Real time thermal measurements showed warmer liquid reentering the cavitation region from upstream. A corresponding thermohydrodynamic (THD) model was developed to corroborate experimental results. The mass conserving scheme used the modified Elrod cavitation algorithm to model film rupture while the film energy equation was used to calculate the temperature rise due to shear heating effects. Experimental and numerical results corresponded well.

4:30 – 5 pm

Influence of Surface Texturing in Steady-State and Transient Lubrication Regime: Two-Dimensional Numerical Simulation Using a Mass-Conserving Cavitation Algorithm

A. Gherca, A. Fatu, M. Hajjam, P. Maspeyrot, Génie Mécanique et Systèmes Complexes, Institut Pprime, Futuroscope Chasseneuil Cedex, France

Although surface texturing is currently regarded as a promising solution for improving the tribological performances of lubricated devices, determining the optimal geometrical patterns remains particularly difficult due to the complex nature of the physical effects that come into play. In the present study, the influence of such effects on the hydrodynamic behavior of a two-dimensional parallel slider in both steady-state and transient flow conditions is examined by using a mass-conserving cavitation algorithm. In addition to analyzing the various geometrical parameters such as texturing ratio, texture density or dimple depth, particular consideration is given to the transient effects induced by a moving textured surface. It is shown that for an applied load, the presence of micro-pockets on both surfaces of the slider can lead to an increase in nominal film thickness and a reduction of the friction force.

5:30 – 6 pm – Fluid Film Bearings Business Meeting