Artificial ageing of engine oils according to currently used standardized procedures is an appropriate method for screening of the general stability. But when dealing for example with corrosion properties of used engine oils at the end and even beyond the conventional oil drain intervals.

Tribochemistry therefore is one of the most important and basic sciences and technologies for machine elements and operation of machinery. However it is very difficult to quantify the value of tribochemistry. Sir Jost and his team made analysis of lubrication losses in UK in 1966. Their achievement is known together with the terminology of “tribology”. Many institutes have discussed the role of tribochemistry for enhancing reliability and efficiency through the reduction of friction and wear. However the authors believe that it is difficult to make the management of companies understand the value of tribochemistry. Lately achievements of the management are evaluated on “Return on Assets (ROA)” and “Return on Equity (ROE)”. Why shouldn’t we use the same method to evaluate the value of tribochemistry for convincing management? In order to evaluate the value of tribochemistry from the macroeconomic viewpoint, the authors analyzed the statistical data published by Japanese Government and the financial reports of leading Japanese companies, which are published for investors. This paper discusses that maintenance of machinery is the job of optimizing ROA and intends to demonstrate that the value of tribochemistry is larger than hitherto thought.

The Value of Tribology (Part 1), Analyses from a Macroeconomic Viewpoint
A. Sasaki, Maintek Consultant, Yokohama, Japan, G. Sakhrani, Ferrocare Machines Private Ltd., Pune, India
In order for India to improve the standard of living, it is imperative to have enough electricity to promote industries. Power generating capacity is increasing in India and the data show that the balance between power generation and power consumption is in favor of power generation. But power shortage occurs in many provinces. There is some possibility that the facilities are not fully utilized by some reason. In order to improve productivity of power plants, we have worked with several power companies. This paper is intended to report the case of a power plant.

An Indian power company having 2 turbines of 235MW each had to shut down the turbines for 21 days every 3 years for inspection of the turbine guide bearings, and other maintenance and inspection tasks. After introducing a state-of-the-art contamination control using electrostatic oil cleaners, they found no wear on the guide bearings. Consequently, they could complete the tasks in 17 days instead of 21 days for inspection and repair and they could generate additional power of 470MW per day for 4 days. Therefore it can be said that the overall value of the state-of-the-art oil management has not only a major impact on ROA, but has also improved social and manufacturing economy parameters, in ways unimagined, hitherto.

8:30 - 10 am
Modified Artificial Ageing Procedure to Investigate the Influence of Fuel Quality on Engine Oil Condition
A. Graff, C. Schneidhofer, N. Doerr, AC2T Research GmbH, Wr. Neustadt, Austria
Artificial ageing of engine oils according to currently used standardized procedures is an appropriate method for screening of the general stability. But when dealing for example with renewable fuels for gas engines, these methods do not provide oil ageing pathways similar to those observed in real engines. There, components in the biogas lead generally to accelerated lubricant degradation - in many cases strongly focused on acidification. Thereby, unforeseen corrosion events on machine parts can occur. This paper presents results from modified artificial ageing tests adopted for more close to reality oil degradation pathways in biogas fuelled gas engines. Fuel gas type specific oil deterioration is achieved. Knowledge on detailed mechanisms of oil ageing according to engine oil type and quality is gained. Oil samples collected from such modified procedures also enable the evaluation of tribological and corrosive properties of used engine oils at the end and even beyond the conventional oil drain intervals.
Session Chair: K. Zhou, Northwestern University, Evanston, IL
Session Vice Chair: W. Chen, Northwestern University, Evanston, IL

8 - 8:30 am
EHD Lubrication in Spiral Bevel Gears
V. Simon, Budapest University, Budapest, Hungary

The full thermal EHD lubrication analysis in spiral bevel gears is performed by the simultaneous solution of the Reynolds, elasticity, energy, and Laplace's equations. The oil viscosity variation with respect to pressure and temperature and the density variation with respect to pressure are included. The system of equations, consisting of the Reynolds, elasticity, energy, and Laplace's equations, is solved by using the finite difference method and numerical integration. The corresponding computer program is developed. By using this program the pressure and temperature distributions in the oil film, the temperature distribution in the pinion and gear teeth, and the deformations of the contacting surface were determined. The influence of lubricant characteristics and operating parameters on maximum oil film pressure and temperature, EHD load carrying capacity, and on power losses in the oil film was investigated.

8:30 - 9 am
Contact Modeling of a Hard Sphere on a Viscoelastic Solid
W. Chen, Q. Wang, Northwestern University, Evanston, IL

Viscoelastic materials are widely used in automotive, medical, and structural applications. Because of the time-dependent material properties and existence of roughness on engineering surfaces, it is a challenging task to predict real contact area, penetration, and pressure distribution in the contact of viscoelastic solids. This research aims to develop a 3D semi-analytical contact model of viscoelastic materials and provide insight into the dependence of contact responses on the material properties and surface topographies. In order to account for the memory effect of viscoelasticity, the deformation cause by contact pressure history is computed through the discrete hereditary integral equation, which is then used to update the original surface topography in the contact equation. The governing contact equation in terms of unknown pressure distribution and contact area can then be solved based on the instantaneous property of viscoelasticity. Transient contact analysis has to be conducted at a sufficient number of time points to achieve acceptable solution accuracy. Advanced numerical techniques, such as the conjugate gradient method (CGM) and fast Fourier transform (FFT), can help accelerate the simulation speed. The present model is used to simulate an indentation test of a steel ball on a polyethylene terephthalate (PET) substrate, whose experimental measurements were reported in a literature. Agreements of results from the present model, the finite element analysis (FEA), and an experiment provide the model validation.

9 - 9:30 am
Scuffing Load Capacity of W-DLC Coated Gears Lubricated with the Adapted Oil Blend
B. Krzan, University of Ljubljana, Ljubljana, Slovenia, F. Novotny-Farkas, OMV Refining & Marketing, Schwechat, Austria, J. Vizintin, University of Ljubljana, Ljubljana, Slovenia

Increasing gear performance through applying a thin film coating on gear tooth flanks is attracting considerable attention. Several different gear tests show an increase in carrying load capacity or prolonged lifetime with tungsten-carbide doped DLC (W-DLC) coated gears. However, the lubricants used have been base oils or commercially available oil formulations that were primarily developed to interact with ferrous materials. Gear performance is likely to be further improved with a lubricant specially customized for W-DLC coated surface.

In the present study, the influence of different test lubricants on friction and wear of W-DLC coated gears was investigated using a reciprocating test rig. The most perspective oil formulation were primarily developed to interact with ferrous materials. Gear performance is likely to be further improved with a lubricant specially customized for W-DLC coated surface. Temperature rise of lubricants for ISF treated blocks was lower than the Ground and GR85 surface-finished specimens. The study demonstrated the effectiveness of the ISF Process over grinding and RF85 surface treatment in enhancing tribological properties of lubricated contacts.

2
A discussion will also be made about the importance of training those employees involved with formulating, recommending and maintaining metalworking fluids. Details on the STLE metalworking fluid systems will be discussed. Health & safety issues will also be covered.

However, cold rolling experiments on a lab based pilot mill lightened this. Temperatures were measured at the exit of the mill on coils and rolls. The coefficient of friction was modified via the lubricant efficiency whilst keeping the heat exchange coefficient constant. The results showed clearly the temperature increase due to the friction.

Aluminum machining is becoming more important in applications such as automotive which are taking advantage of this metal's lighter weight profile as compared to steel. This review will discuss the function of metalworking fluids and focus on the challenges involved in machining wrought and cast alloys of aluminum. Issues covered include machinability of aluminum, the types of fluids to be used, prevention of aluminum staining and the impact of aluminum metal on destabilizing the metalworking fluid. Key concepts that need to be done to maintain metalworking fluid systems will be discussed. Health & safety issues will also be covered.

A discussion will also be made about the importance of training those employees involved with formulating, recommending and maintaining metalworking fluids. Details on the STLE Certified Metalworking Fluids Specialist (CMFS) Certification Program will be included to indicate that there are ways for companies and individuals to obtain expertise in dealing with the issues faced in using metalworking fluids.

### Non-Ferrous Metals I

#### Session Chair: G. Biresaw, USDA, Peoria, IL  
#### Session Vice Chair: J. Cepec, Allegheny Petroleum Products Co., Wilmerding, PA

**8 - 8:30 am**

Embracing ILMA's Identity: The Ethics & Branding Strategies

J. Taglia, Independent Lubricant Manufacturers Association, Alexandria, VA

Jim Taglia, Independent Lubricant Manufacturers Association (ILMA) Past President and Chair of ILMA’s Industry Task Force will present an update on the Association’s Ethics and Testing Program as well as its Branding Initiative. These programs have become the core of ILMA and are having a positive impact on the lubricants industry.

**9:30 - 10 am**

Field Test for New Bioactive Contact Catalyst in Hot Rolling Emulsion

G. Kudermann, Hydro Aluminium Deutschland GmbH, Bonn, Germany, T. Lisowsky, multIBIND biotec GmbH, Köln, Germany

The new antimicrobial contact catalyst, AgXX, has been tested on the hot rolling pilot mill in the R&D Center, Bonn, Germany of Hydro Aluminium for 8 month. The contact catalyst is a silver-based bioactive coating that displays an innovative combination of ion effect and surface effect thereby achieving the efficient killing of bacteria and fungi. The lubricant tank and external pipes were cleaned and the emulsion was renewed before beginning the field test. Nevertheless, starting concentrations of mesophilic and thermophilic germs were 2x10^6 CFU/ml and 2x10^5 CFU/ml, respectively. The high microbiological load of the new emulsion was due to contaminated parts of the emulsion cycle which were difficult to access for cleaning measures. After one month of AgXX application thermophilic germs were completely eliminated. Mesophilic germs could be kept at 10^5 to 10^6 CFU/ ml over more than 8 months.

During the test period contaminating biomass was reduced and no growth of fungi, no decrease of pH due to microbial acids, no smell of biomass or decomposition of the emulsion was observed. The high level of mesophilic germs was caused by the very high contamination of the new emulsion and constant entry of new germs from deposits of biofilms, biomass and microbial contaminations in pipelines and machines. The new antimicrobial contact catalyst, AgXX, proved to be an advantageous long term alternative to biocides causing comparably low service and operation costs.

**9 - 9:30 am**

Heat Generation by Friction in Cold Rolling

P. Deneuville, Alcan CRV, Voreppe, France

In rolling there are several sources of heat transfer to the strip inside the roll bite: the energy of deformation, thermal diffusion from the rolls and the frictional heat generated by the sliding interfaces. The lubricant can play two main roles on the thermal phenomenon: cool down the sheet and the rolls outside the roll bite and interfere with the heat exchange in the roll bite. This paper presents the results of experiments to identify the contribution of the frictional heat to the overall temperature increase in the strip during rolling. The literature and theoretical calculations revealed that compared to the deformation energy the heat generated by the friction is low. This is partly due to the fact that in cold rolling the friction coefficients are low. However, cold rolling experiments on a lab based pilot mill lightened this. Temperatures were measured at the exit of the mill on coils and rolls. The coefficient of friction was modified via the lubricant efficiency whilst keeping the heat exchange coefficient constant. The results showed clearly the temperature increase due to the friction.

**9:30 - 10 am**

Challenges in Machining of Aluminum Alloys

N. Canter, Chemical Solutions, Willow Grove, PA

Aluminum machining is becoming more important in applications such as automotive which are taking advantage of this metal's lighter weight profile as compared to steel. This review will discuss the function of metalworking fluids and focus on the challenges involved in machining wrought and cast alloys of aluminum. Issues covered include machinability of aluminum, the types of fluids to be used, prevention of aluminum staining and the impact of aluminum metal on destabilizing the metalworking fluid. Key concepts that need to be done to maintain metalworking fluid systems will be discussed. Health & safety issues will also be covered.

A discussion will also be made about the importance of training those employees involved with formulating, recommending and maintaining metalworking fluids. Details on the STLE Certified Metalworking Fluids Specialist (CMFS) Certification Program will be included to indicate that there are ways for companies and individuals to obtain expertise in dealing with the issues faced in using metalworking fluids.

### Grease I

#### Session Chair: C. Coe, Grease Technology Solutions LLC, Manassas, VA  
#### PSC: R. Wurzbach, MRG Labs, York, PA

**8 - 8:30 am**

A Study of Friction Modifiers in Grease
The knowledge of different shaft surface topographies and their effect on the sealing system is now available. With this knowledge, it is possible to get a better understanding of the presented. Furthermore, the temperature within the sealing zone was analyzed.

In the present study, experimental test results of different shaft surface finishing techniques at various operating conditions, e.g., shaft speed, oil viscosity, and radial force, will be evaluated. Roughness and topography are key factors that impact the design of greases formulated to provide extended grease and bearing life. The base oil and thickener are important, but antagonism between components may occur. For long-bearing-life greases in particular, balancing oxidation, load carrying capacity, corrosion inhibition, and wear are key requirements and can lead to difficulties in optimizing the formulation. To provide an acceptable package in global markets, environmental considerations must also be given to the grease components. In this paper, we discuss the design of longer-life, environmentally friendly greases and their performance testing.

Friction decreases efficiency. Wherever there is friction, heat is created, indicating that some energy is lost. Efficiency, wear, and friction reduction in greases are such important parameters that, in some cases, the minimum levels of certain friction modifiers are specified. Molybdenum disulfide is probably the most widely used solid lubricant friction modifier. Recently, due to competition from the steel industry, the cost of molybdenum-containing additives has risen, encouraging researchers and engineers to look for cheaper alternatives. In this effort, a fundamental evaluation of various friction modifiers has been completed. Results from bench tests to evaluate friction and wear will be presented.

8:30 - 9 am
Development of Greases with Extended Grease and Bearing Life
G. Fish, W. Ward, The Lubrizol Corporation, Wickliffe, OH
Under typical operating conditions, the grease is the limiting factor of bearing life. By extending the useful life of the grease, increased replacement intervals for sealed-for-life bearings and extended re-lubrication intervals for serviceable bearings can be achieved. By using longer life grease, the impact on the environment can be reduced, and operating cost savings can be realized. There are many factors that impact the design of greases formulated to provide extended grease and bearing life. The base oil and thickener are important, but antagonism between components may occur. For long-bearing-life greases in particular, balancing oxidation, load carrying capacity, corrosion inhibition, and wear are key requirements and can lead to difficulties in optimizing the formulation. To provide an acceptable package in global markets, environmental considerations must also be given to the grease components. In this paper, we discuss the design of longer-life, environmentally friendly greases and their performance testing.

9 - 9:30 am
Thin-film Visible Spectroscopy of Greases
D. Wooton, Wooton-Consulting, Beavercam, VA, R. Wurzbach, L. Williams, E. Straub, MRG Labs, York, PA
A method for analyzing used greases is presented that relies on a thin-film deposition of the grease on a transparent substrate. The transparent substrate is introduced into a visible light path, and an analyser is used by a spectrometer in the 400-700nm wavelength. New fresh greases are evaluated in this method, and used grease samples are compared for analysis. The method allows for a colorimetric evaluation of changes in the appearance of the grease, and peak analysis is performed to determine grease mixing, oxidation changes, and the presence of specific contaminants. Experimental work with known quantities of contaminants are presented for the development of chemometric methods for quick and low-cost screening of grease samples.

9:30 - 10 am
Difficulties in Determining Application Quantities for Rail and Wheel Flange Lubrication
J. De Koker, University of Johannesburg, Johannesburg, South Africa
The paper discusses the effect of overheated wheels on attempts to scientifically quantify lubricant consumption by using the coefficient of friction between rail and wheel flange. In an attempt to quantify the skin temperatures generated due to friction in the wheel-rail interface, track tests were conducted. The temperatures induced by passing wheels were measured, as well as the spread of the heat through the rail profile. Unforeseen results pointed to a source of heat, not related to friction, induced into the rail by the passing wheels.

Session 1F
Palace 3

Seals I

Session Chair: R. Salant, Georgia Institute of Technology, Atlanta, GA

8 - 8:30 am
Radial Lip Seals - Overview and Function
F. Bauer, W. Haas, University of Stuttgart, Stuttgart, Germany
Radial Lip Seals are used to seal rotating shafts in all areas of mechanical and automotive engineering. The Elastomeric lip seal is a frequent and reliable sealing system in millions of cases. Based on its good static sealing and the active dynamic sealing mechanism, it is accepted by the market. However, limits are set to its area of application. The “Seal” is a system of the four partners Seal-Ring, the counterface, the lubricant and the surrounding. To choose the best fitting Seal, it is necessary to know how the Seal works and how the different parts influence one another. In this overview, different types of Radial Lip Seals will be presented, and their function will be explained. The influence on friction, wear, and temperature of the counterface, the production of the shafts, the influence of the lubricant and their additives and the influence of the surrounding (lubrication, temperature, speed, …) will be explained clearly and easily understandable. With this paper, scientists and users have a fundamental knowledge and can choose their Seal unerringly. The overview will be deepened in two papers in the seal session and another paper on testing-methods in the session Tribotesting.

8:30 - 9 am
Effects of the Shaft Surface Topography on the Friction of Radial Lip Seals
S. Jung, F. Bauer, W. Haas, University of Stuttgart, Stuttgart, Germany
Radial lip seals are the most widely used type of dynamic seals. Between the sealing edge and the rotating shaft is a thin oil-lubricated film. The thickness of this lubricating film depends on the operating conditions and on the characteristics of the shaft surface.

The friction torque is one possibility for evaluating the sealing system and the lubricating conditions. A common approach to classify mixed or full film lubricating can be assessed by the duty parameter diagram. However, this diagram is only relevant for sealing systems, whose shaft surfaces have been plunge ground. There is no explicit consideration of shaft surface roughness and topography yet. In the present study, experimental test results of different shaft surface finishing techniques at various operating conditions, e.g., shaft speed, oil viscosity and radial force, will be presented. Furthermore, the temperature within the sealing zone was analyzed.

9 - 9:30 am
The Influence of Additives in Synthetic Oils on Radial Lip Seals
M. Klaiber, F. Bauer, W. Haas, University of Stuttgart, Stuttgart, Germany
Due to increasing demands on products, demands on single components are getting higher. In the field of lubricating oils the reply is the increasing usage of synthetic oils charged with new additives. Although the performance of the overall product can be systematically improved, new difficulties for the sealing system arise, because of the chemical resistance. Elastomeric radial lip seals often unpredictably fail under these operating conditions. Static elastomer compatibility tests do not lead to an explanation. Furthermore, a basic understanding cannot be developed by function tests made with fully formulated lubricants. Instead, single additives from different chemical and functional groups are added to polyglycol- and polyalphaolefinoil. Therefore the influences of a single additive on the sealing system can be analyzed. The first results of friction torque - and pumping rate measurements, function tests and endurance tests will be presented.

9:30 – 10 am
Shaft Waviness Effect on Performance of Lay Down Radial Lip Seals
A. Berdichevsky, J. Jiang, T. Chieh, M. Azni, FNGP, Plymouth, MI
In order to improve robustness against aggressive oils, the traditional radial shaft seals are more and more being replaced with PTFE and ESS seals having extended contact areas with the shaft. Both these types of seals are employing a pumping mechanism different from the traditional radial shaft seals - instead of micro asperity pumping they use macro mechanical pumping generated by a spiral groove imbedded into the contact surface of the seal. This shift in the nature of the pumping mechanism requires a revision of the various shaft surface requirements to ensure robust sealing. In this paper the authors consider the effect of the waviness on the seal performance. Generally speaking any shaft waviness should lead to the reduction the sealing robustness. As a result of extensive FEA simulations, the authors came up with a waviness criterion imposed onto a dimensionless waviness parameter providing acceptable reduction in sealing robustness.

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**Session Chair:** G. Krauss, University of Michigan, Ann Arbor, MI  
**Session Vice Chair:** N. Gitis, Center for Tribology, Campbell, CA

8 - 8:30 am  
A preliminary study on effects of lubricant contaminated with biofuels  
G. Molina, V. Soloiu, S. Shanta, C. Hilliard, Georgia Southern University, Statesboro, GA  
This paper reviews available literature on the tribological effects of lubricant contamination with biofuels and it presents preliminary work on the use of a pin-on-disk tribometer to measure friction and estimate wear and contact temperatures for mixtures of mineral oil and biofuels. The aim of this research work is to evaluate wear and friction behavior of engine liner and piston ring material contact as part of a renewable energy multidisciplinary approach on and biofuels and biolubes.

8:30 - 9 am  
Friction Studies of Coated Pistons Against Cylinder Liners in Laboratory Test Conditions  
N. Demas, O. Ajayi, R. Erck, G. Fenske, Argonne National Laboratory, Argonne, IL

The piston-cylinder assembly accounts for a significant portion of friction losses of the internal combustion engine. Issues towards improved reliability, higher performance, reduced oil consumption and emissions may be addressed by coating the piston. However, coatings used in piston may have high wear rates hindering tribological performance of parts by changing the lubrication regime or by preventing additives from their intended function through chemical mechanisms. In this work, piston rings and skirt segments extracted from a commercial piston, were coated with Teflon®-based coatings, a graphite-resin coating and various diamond-like carbon (DLC) coatings and were tribologically tested using a reciprocating laboratory test rig against liner segments also extracted from a commercial system. The tribological tests were conducted in commercial synthetic motor oils. The friction and wear of the piston rings, skirt specimens and cylinder liner materials was studied as a function of load, sliding speed and temperature and the performance of the coatings was evaluated.

9 - 9:30 am  
Self-Lubricating Coating Systems Manufactured by High Velocity Particle Consolidation and the Tribotesting Challenges of Evaluating Them  
A. Segall, I. Smid, L. Stark, T. Eden, The Pennsylvania State University, University Park, PA

Because of the many difficulties associated with traditional thermal spray methods (volatilization of lubricants, phase transformations, excessive oxidation, evaporation, and/or crystallization to name a few), a new method of coating deposition known as the High Velocity Particle Consolidation (HVPC) or Cold-Spray was conceived. HVPC is a promising low-temperature spray method that rapidly and efficiently creates a coating through a process related to friction welding by exposing a substrate to a high-velocity jet of solid-phase particles. The unique and very practical feature of HVPC is that the solid-phase particles are accelerated by a supersonic jet of gas at temperatures well below the melting temperature of most materials. Currently, Ni with boron nitride or molybdenum-disulphide systems are currently under study with promising results seen thus far. However, as discussed in this paper, evaluating HVPC coatings does present a number of interesting tribotesting challenges given their unique properties and anticipated wear regimes.

9:30 - 10 am  
Measurement of Static Friction Coefficients and Comparison to Theoretical Models  
R. Ibrahim, R. Jackson, G. Flowers, Auburn University, Auburn, AL

A new experimental apparatus is used to measure static friction and then compared to existing computational models. The experiment uses the classical physics technique of increasing the incline of a plane and block, until the block slides. The angle at sliding is used to find the static friction coefficient. The experiment utilizes an automated apparatus, to minimize human error. The FEM based analytical model for static friction under full stick, by Cohen, Kligerman, and Elston as also used to make predictions using surface profile data from the experiment. The Cohen et. al model is built on the same statistical framework as the Greenwood and Williamson microcontact model. Comparison of the computational and experimental methods show similar qualitative trends, and even some quantitative agreement.
The use of incidental contact food grade lubricants continues to grow as food producing companies strive to minimize the consequences of accidental food contamination to the consumer. Oil blenders now have another component that they can use to formulate such lubricants - Synestic™ Alkylated Naphthalene basestocks from ExxonMobil Chemical are now registered as H1 and HX-1 incidental contact, non food compounds in the White Book™ at the National Sanitation Foundation (NSF®). Synestic™ AN basestocks deliver good hydrolytic and thermal-oxidative stability combined with lubricity that help formulators to improve the performance of technical white mineral oil or polyalphaolefin (PAO) based lubricants. Enhanced additive solubility and compatibility with seal materials also contribute to making Synestic™ AN the right blend-stock for lubricants in a variety of applications important to the food industry.

Session 2A

Power Generation II

Session Chair: G. Livingstone, Fluitec International, Rutledge, GA
Session Vice Chair: G. Khemchandani, Dow Chemical Company, Freeport, TX

1:30 - 2 pm
Varnish Problems of Modern Gas Turbines
A. Sasaki, Maintek Consultant, Yokohama, Japan; H. Tobisu, KLEENTEK Corporation, Tokyo, Japan
The combustion temperature of state-of-the-art gas turbines reaches 1500 degree C and that such combined cycle power generation systems achieve almost 60% thermal efficiency. As turbines are exposed to such high temperatures, it is essential to protect turbine bearings by delivering a large volume of oil for cooling. Currently varnish due to oil oxidation is a hot topic in gas turbines. All commercially available turbine oils have oxidation inhibitors and satisfy oxidation stability test of turbine oils like ASTM standards but varnish problems are increasing. The author has reviewed past studies on turbine oils and has also investigated factors that may cause local hot spots in gas turbine oil systems and found several proofs that spark discharges of static electricity might play an important role in varnish formation in turbine oils. This paper will review the history of development of turbines and the past studies on oil oxidation stability, and discuss the possible root causes of oil oxidation and suggest ways to extend the life of turbine oils.

2:00 - 2:30 pm
Effect of Temperature on Sludge and Varnish Formation in Turbine Oils using the MHI Dry-TOST Test
G. Wagenseiler, Analysts, Inc., Stafford, TX
Sludge and varnish formation has been a major issue with turbine oils in recent years. Mitsubishi Heavy Industries developed a Dry-TOST method as an alternative to ASTM D943 (Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils) to assess the tendency of turbine lubricants to form sludge. The QSA® test was developed to measure the Varnish Potential Rating (VPR) of these fluids. In this study the VPR and sludge tendencies along with other key parameters, are measured for different lubricants using the MHI-DRY TOST. The tests were carried out at the 120°C as specified by MHI, and at a lower temperature. The results were compared to determine if the lower temperature allows for a better distinction between the oils to form varnish and sludge.

2:30 - 3 pm
Selecting the Best Varnish Mitigation Technology based on the Application
G. Livingstone, Fluitec International, Rutledge, GA
A decade ago, there wasn’t a vendor in the industry that claimed to have a “varnish solution”. As varnish became recognized as a key factor in impacting reliability at power plants, some existing technologies refocused their product spec sheets to say “varnish removal systems” instead of sub-micron particulate removal. This led to the introduction of over a dozen new technologies that have been commercialized over the last few years that claim to “solve” varnish. Most of these technologies perform well however there is not one technology that is able to provide the solution to all problems. This paper will review the various types of varnish removal technologies available on the market and highlight appropriate applications for each technology. Included are some case studies of misapplied technologies and how plants went about rectifying the problem.

3:30 - 4 pm
Non-Varnishing Characteristics of PAG-based Synthetic Turbine Oil
G. Khemchandani, Dow Chemical Company, Freeport, TX
Plant engineers are aware of increased bearing and gear wear as well as servo valve failures due to oxidation of hydrocarbon oils in their machine systems. These machines especially compressors, gas turbines, hydraulic systems and wind turbine gear boxes all have faced failures at one time or another due to sludge and varnish formed by hydrocarbon based lubricants. In contrast to hydrocarbon oils, PAGs are high oxygen containing molecules that are inherently polar in nature. Polarity of the molecules can be adjusted according to monomer choice which in turn provides variable solubility in water and hydrocarbon oil. This unique polarity of PAGs provides significantly improved performance compared to petroleum, animal and vegetable oils as well as other synthetic base stocks. Their mechanism for oxidation is similar to that for hydrocarbon based oils, with the exception that the polar nature of PAGs keeps polar oxidation by products soluble in the PAG molecule. Hydrocarbon oils being non polar give rise to sludge and varnish. PAGs role in minimizing deposit formation in addition to helping maintain equipment cleanliness and reliability is discussed in the present paper.

4:00 - 4:30 pm
Turbine Troubleshooting Steam Turbine Phosphate Ester EHC Fluids
K. Brown, Eco Fluid Center Ltd., Toronto, ON, Canada; T. Austin, Forsythe Lubrication Associates, Hamilton, ON, Canada
The chemistry of these fluids is fairly well understood as are the maintenance requirements. However, some stations are still having fluid related issues. Also, just tightening up the specifications has not always achieved the desired improvements. In addition, there are many different types of systems out there, the turbine OEM's are subcontracting out components and prior knowledge at the stations has often been lost. Keeping the EHC fluid in good condition all the time generally just requires changing the purification media and filters a few times a year and when adding make-up fluid, to filter it first. But these systems are also aging and in most cases there have been modifications. Compounding this is that fewer staff are available to either monitor or maintain the systems. Plus, at nuclear stations making modifications to improve the monitoring or make the maintenance easier can be very difficult and time consuming. However, there are a number of simple things that can be done to help ensure that the fluid stays in good condition. The first step is to know where you are now to then be able to figure
Fabrication of Micro-/Nano-scale Hierarchical Structures for Reducing Adhesion and Friction Forces on Silicon Surfaces

E. Yoon, D. Pham, K. Na, S. Piao, S. Yang, J. Kim, Korea Institute of Science and Technology, Seoul, Korea

This work reports an investigation on fabrication of multi-scale micro/nano hierarchical patterns for reducing adhesion and friction forces of silicon surfaces. The hierarchical structures were created on silicon wafers (100) by using a MEMS fabrication process, by which the nano-sized pillars with different pitches (the distance between the pillars) were constructed on the micro-sized pillars. The patterned surfaces were further chemically treated by coating PFPEs thin lubrication films using a dip coating method. Adhesion and friction forces of the modified silicon surfaces were examined using an atomic force microscope (AFM). It was observed that the multi-scale hierarchical patterns greatly reduced the adhesion and friction forces of silicon surfaces. Moreover, the hierarchical structures coated by PFPEs were even more effective in decreasing these forces. This is due to the combined effects of reduced real contact area through the patterning and low surface energy of the PFPEs. The effects of the pitch of the nano-structures on adhesion and friction properties are also discussed in this study. The micro-/nano-scale hierarchical structures combined with a chemical modification as ones investigated could provide a potential method to enhance the tribological performance of micro elements which are composed of silicon.

The Effects on Rolling Contact Fatigue Strength and Friction Torque of the Thrust Rolling Bearing by Ultrasonic Nanocrystal Surface Modification


Ultrasonic Nanocrystal Surface Modification (UNSM) is an emerging technology which strikes the raceway 20,000 or more times per second with 1,000 to 10,000 shots per square millimeter using the tungsten carbide ball attached to an ultrasonic device. These strikes make micro dimples, induce compressive residual stress in surface, increase surface hardness, improve surface roughness, and refine the grain into nano crystal. Two types of rolling contact fatigue test showed that the cycles to failure of the UNSM treated test specimens were increased more than by two times. The effect of micro dimples surface on the friction was tested. Friction coefficient of UNSM treated raceways were reduced by 20~35%. Wear volume loss of raceways are compared by scanning electron microscopy (SEM). The main concept and effects of UNSM technology are also explained.

The Influence of Surface Roughness on Friction and Leakage in a Radial Piston Hydraulic Motor

P. Isaksson, D. Nilsson, R. Larsson, A. Almqvist, Luleå University of Technology, Luleå, Sweden

The performance of a radial piston hydraulic motor relies to a big extent on the frictional behavior of the sliding interfaces. Many of these interfaces are highly loaded conformal contacts where the lubrication regime varies from boundary to full film lubrication. This implies that the surface roughness plays an important role. In this paper, the effect of surface roughness is studied by numerical simulations and experiments conducted in a test rig. The test rig simulates the piston - roller contact; one of the most important interfaces in view of performance. The problems are divided into two different scales: a local scale considering surface roughness and a global scale considering geometry and the model is based on the Reynolds equation. The local scale effects are captured in flow factors derived by homogenization. These flow factors span from boundary to full film and include the contact mechanics of the rough surfaces. The local scale results, in terms of flow factors and contact mechanics, are incorporated in a FE-model representing the global scale of the piston - roller contact. The FE-model is then used to predict parameters such as friction and leakage. The boundary friction coefficient, applied at the regions where direct contact occurs, is taken from measurements. The experimental set-up is used to assess the friction characteristics, i.e., Striebeck-curves, for a set of surfaces. Numerical simulations of the piston - roller contact are conducted for the same set of surfaces and a comparison with the experimental results is performed.

Effect of Surface Topography Modifications on Rolling Contact Fatigue of Mixed Lubricated Contacts

M. Vrbka, I. Krupa, M. Hartl, P. Svoboda, Brno University of Technology, Brno, Czech Republic

The rolling contact fatigue (RCF) life of highly loaded machine components is significantly influenced by the surface roughness features so that there is a continuous effort to design the topography of rubbing surfaces to enhance lubrication efficiency and prolong the operation of machine components. It can be suggested from the recent experimental results that properly designed surface topography based on shallow micro-cavities can reduce the asperities interactions within rolling/sliding mixed lubricated contacts. However, the introduction of such roughness features into the rubbing surfaces of highly loaded non-conformal contacts should consider not only the effects on lubrication film thickness but also on RCF. That is why; this study is focused on the effects of surface texturing on RCF within non-conformal rolling/sliding contacts operated under mixed lubrication conditions. In this study the effect of shallow micro-cavities on RCF is studied using surfaces modified by surface texturing and shot peening. Obtained results have shown that properly designed surface topography can result in RCF life enhancement. Such an effect could be attributed to the positive contribution of micro-dens working as lubricant micro-reservoirs that reduce asperities interactions. Nevertheless, it is significantly influenced by the size of micro-dents and texture density within the contact.

On the State and Severity of Frictional Sliding Contacts Between Nominally Flat Metallic Surfaces

L. Chang, H. Zhang, Penn State University, University Park, PA

This paper develops and uses an analytically traceable model to study the state and severity of frictional contacts between nominally flat surfaces of elastic-perfectly-plastic materials. The state and severity of the contact is characterized by four area-of-contact variables. They include the real area of contact, the proportion of the real area of contact in full plastic deformation, the proportion of the real area of contact with high interfacial shear stresses, and the percentage increase of the real area of contact due to the friction-induced junction growth. Problems are studied ranging from very elastic to very plastic contacts under good to poor lubrication conditions. Dimensionless results are presented in a two-dimensional parameter space of the surface plasticity index and system friction coefficient. Judged by these dimensionless results, the state and severity of the frictional contact is primarily governed by two model parameters: the plasticity index of the equivalent surface and the coefficient of friction of the contact system. It is fairly insensitive other system parameters such as the applied normal load and height distribution of surface asperities. The results may shed some light to surface run-in, system operations and possible friction instability of the tribo-system.
In the present investigation, sliding experiments were conducted using an inclined pin-on-plate apparatus to identify the role of surface texture on coefficient of friction and transfer layer formation of polymeric materials. In the experiments, poly-vinyl chloride (PVC) was used for the pin and hardened steel was used for the plate. Two surface parameters of the steel plates - roughness and texture - were varied in tests. The experiments were conducted under both dry and lubricated conditions in ambient conditions. Based on the experimental results, it was observed that the transfer layer formation and the coefficient of friction were controlled by the surface texture. Moreover, the asperity slope had the strongest influence on friction. The results are also compared with soft metals. The comparison showed that both polymer and metals exhibited similar frictional response with surface texture. A large variation in friction with surface texture was observed for metals when compared to polymer.

Effects of Thermally Induced Inhomogeneous Shear and Surface Thermal Boundary Conditions on the Shear Stress in Sliding Elastohydrodynamic Contacts

Numerous research works have shown that significant thermally induced cross-film inhomogeneous shear or thermal shear localization may be developed in sliding elastohydrodynamic lubrication (EHL) contacts with pronounced consequences. This paper uses the theoretical framework established in previous research to further analyze the effects of the shear localization on the lubricant shear stress and thus the EHL traction. Results obtained suggest that the shear localization significantly accelerates the thermally induced reduction of the shear stress in sliding EHL contacts. The study also shows dramatic reduction of the shear stress in EHL contacts with one-insulated surface, which is significantly attributed to the more intensified thermal shear localization near the insulated surface. The practical significance of the dramatic shear stress reduction is discussed.
Session Chair: P. Deneuville, Alcan, France
Session Vice Chair: A. King, Houghton International, Valley Forge, PA

1:30 - 2 pm
US Vegetable Oil Market, Focus on Biolubricants
M. Woodfall, Bunge North America, St. Louis, MO

There are a wide variety of vegetable oils currently produced in the United States, many of which are utilized in formulating biolubricants. It is important to understand not only their physical properties, but also the overall market dynamics that impact supply. Over 27 billion pounds of vegetable oil are consumed annually in the US, with the vast majority being consumed in edible products. Due in part to its high oil content, soybeans are the largest domestic oilseed crop. Both liquid and solid forms of soybean oil are utilized in a variety of applications from frostings to fuels. Consumer demands for reductions of trans fats in foods and development of improved seed technologies all have an impact on product availability and economics. As with petroleum commodities, vegetable oils are traded globally, and therefore impacted by outside forces such as the weather and politics. An overview of the US market, with an emphasis on biolubricant basestocks will be provided.

2 - 2:30 pm
A Study of Antioxidant Combinations for the Stabilization of Vegetable Oil
G. Aguilar, R. Hiza, B. Stunkel, R. T. Vanderbilt Company, Inc., Norwalk, CT

Vegetable oils have excellent lubricity that far exceeds that of hydrocarbon base stocks. The hydrophilic/lipophilic balance of vegetable oils allows them to assemble onto metal surfaces and form strong lubricating films. The lubricity of vegetable oils is further enhanced by their high viscosity index values or their ability to resist thinning with increasing temperatures. The major drawback with vegetable oils is their lack of resistance to oxidative degradation. This limitation can be overcome by chemical and/or genetic modification to reduce polyunsaturation sites found in the fatty portion of these oils. However, the high cost of modified vegetable oils restricts their use in most commercial application. As an alternative, antioxidant chemistry offers a more cost effective approach to improve the oxidation resistance of vegetable oils. In this paper, the effect of hindered phenols, dialkyl dithiocarbamates, tolutrazole derivatives and combinations thereof was investigated. Results showed that tolutrazole derivatives was an effective synergist with hindered phenols, zinc dialkyldithiocarbamate and combination thereof.

2:30 - 3 pm
Development of a Human-Friendly, Renewable Resource-Based Metalworking Fluid Technology, and its Impact on Sustainable Manufacturing
J. Pajak, Houghton International Inc., Valley Forge, PA

The use of vegetable oils as alternatives to hydrocarbons as base stocks for lubricants and metalworking fluids is one way to attain sustainable manufacturing in industry. In addition, there is evidence that inhalation of oxidized hydrocarbon mists is a serious health hazard for humans. This paper discusses the development process of the worlds leading vegetable oil based metalworking fluid technology. The factors that are of significance are presented and data that has been generated to validate the acceptance of this technology as the new global best practice is outlined. The impact of the implementation of this technology in the manufacturing industry is analyzed from several perspectives. These include: Environmental, Human Health and Safety, Production Quality and Manufacturing Cost Reduction aspects. Data is presented that studies the impact of this technology in all of these aspects. Finally, a capability proposition is made for a fully integrated recycling option for the manufacturing industry. In this manner, the "Zero Waste" scenario is discussed.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Effect of Chemical Structure on Elastohydrodynamic Traction Coefficient
G. Biresaw, G. Bantchev, USDA-ARS-NCAUR, Peoria, IL

The elastohydrodynamic traction properties of a series of biobased and petroleum based oils of varying chemical structures in steel-steel contact were investigated. Traction was measured on a ball-on disk type elastohydrodynamic traction instrument. Elastohydrodynamic traction coefficient (tc) was measured as a function of slide-to-roll ratio (srr) at constant entrainment speed (u); or as a function of u at constant srr. Both types of experiments were conducted under various temperatures and contact pressures. Significant differences in tc properties between biobased and petroleum-based fluids were observed. These differences could not be accounted for based on differences in the viscosities between the biobased and petroleum-based fluids. This may be an indication of the importance of the differences in the chemical structures between these two types of fluids. In this presentation, the effect of chemical structure on tc of biobased vs petroleum-based fluids will be explored.

4 - 4:30 pm
Tribological Properties of Sulfide-Modified Vegetable Oil
G. Bantchev, G. Biresaw, A. Mohamed, USDA-NCAUR, Peoria, IL

In previous reports we described the synthesis of sulfide modified vegetable oil (SMVO) by radical addition of butanethiol to the double bonds of corn and canola oils. Corn and canola oils differ in the degree of the unsaturation. The modification resulted in eliminating the double bonds, introducing branching and introducing sulfide group in the vegetable oil molecule. The SMVO and its blends with unmodified VO and polyalphaolefin were evaluated for the following properties: pour point, cloud point, antiwear, oxidative stability, and extreme pressure using ASTM standard procedures. The oxidation stability was further investigated using differential scanning calorimetry. The effect of SMVO structure on lubricating properties will be discussed.

4:30 - 5 pm
Effect of Boundary Lubricants on Coolant Lubricity
D. Mahoney, Y. Barash, Diversified Chemical Technologies, Detroit, MI, H. Rowley, Micratop USA, Rochester Hills, MI

Mid chain length (C14 - C22) fatty acids are known to be effective coolant lubricant components; however, they may react with hard water to form soaps. In this work a tapping torque tester is used to evaluate the performance of a series of analogous soluble oils made with different boundary additives including fatty acids of varying molecular weight, amides, and nonionic surfactants.

5 pm - Non-Ferrous Business Meeting
Electrical Conductive Grease: study of their thermal stability and electrical properties.

High temperatures are known to harm grease more so than liquid lubricant where in excess heat often accelerates the collapse/aging of grease resulting in hardening or softening of the grease mixtures.

We were able to use this grease analysis technique and correlate with our vibration spectra to help find or narrow down the root cause of the bearing failure in some cases. We found grease analysis to be a promising new tool for the predictive maintenance specialist.

This paper is about a couple of bearing failure case histories using both grease and vibration analysis.

The grease mixtures will consist of various concentrations of soap in the base oil. Some of the properties of wormlike micelles that will be investigated are reptation - the snake-like motion of the micelles; and scission - the breaking and joining of micelles. The rheological methods will include small amplitude oscillatory shear (SAOS) and simple shear flows to study the linear viscoelastic properties of the mixtures. Large amplitude oscillatory shear will be used to study the nonlinear viscoelastic properties and perhaps give a rheological fingerprint of the grease mixtures.

Methods for Trending Wear Levels in Grease Lubricated Equipment

Oil analysis is well established as a routine tool to optimize maintenance activities, improve reliability and equipment life and prevent component failures. As part of a comprehensive Predictive or Condition Based Maintenance program, lubricant analysis is an effective complement to other diagnostic technologies such as vibration analysis, infrared thermography, ultrasonic detection and motor circuit evaluation. However, when the equipment is grease lubricated rather than oil lubricated, the important lubricant analysis piece is usually left out of the mix. However, new tools have been developed for improved sampling techniques and grease analysis tests to allow the inclusion of lubricant analysis for grease lubricated equipment. This paper will discuss the challenges and options to obtain representative and consistent grease samples from motors, motor operated valves, and other critical equipment, and the use of a hall-effect sensor device for reliably and repeatably determining changes in wear levels for samples of grease as small as 1 gram.

Measuring the “Worms” in Grease

Aqueous mixtures of surfactants have characteristic rheological properties. The responses are determined mainly by the micelle structure of the surfactants and are known as “wormlike micelles”. On the other hand hydrocarbon mixtures of surfactants (soaps) also have characteristic rheological properties that are determined by the micelle structure. In greases these micelle structures are described as threadlike. The uses of both aqueous and hydrocarbon mixtures depends heavily on the rheological properties or how these mixtures flow. This study will investigate the rheological properties of lithium complex thickened synthetic base oil grease using the same methods as those used to study wormlike micelles in aqueous solutions. The grease mixtures will consist of various concentrations of soap in the base oil. Some of the properties of wormlike micelles that will be investigated are reptation - the snake-like motion of the micelles; and scission - the breaking and joining of micelles. The rheological methods will include small amplitude oscillatory shear (SAOS) and simple shear flows to study the linear viscoelastic properties of the mixtures. Large amplitude oscillatory shear will be used to study the nonlinear viscoelastic properties and perhaps give a rheological fingerprint of the grease mixtures.

Rheology of Grease Under Thermal Stress - A Microscopic Perspective

High temperatures are known to harm grease more so than liquid lubricant where in excess heat often accelerates the collapse/aging of grease resulting in hardening or softening of the grease and a complete loss of consistency. This paper offers some microscopic perspectives on the effects of thermal stress on grease rheology and oil separation between soap and non-soap greases.

Electrical Conductive Grease: Study of Their Thermal Stability and Electrical Properties

Greases are well-known excellent insulators used in many voltage transformers. However, by adding various elements (Cu, Ag, Ni, Al, C…) and additives, they can become electrical conductive. In this work, we synthesized electrical conductive grease containing metal nanoparticles and surfactant for unusual dedicated applications. We studied their stability in function of the metal loading, the temperature and the current intensity. We also measured their conductivity in function of their nature and loading.

Methods for Trending Wear Levels in Grease Lubricated Equipment

Oil analysis is well established as a routine tool to optimize maintenance activities, improve reliability and equipment life and prevent component failures. As part of a comprehensive Predictive or Condition Based Maintenance program, lubricant analysis is an effective complement to other diagnostic technologies such as vibration analysis, infrared thermography, ultrasonic detection and motor circuit evaluation. However, when the equipment is grease lubricated rather than oil lubricated, the important lubricant analysis piece is usually left out of the mix. However, new tools have been developed for improved sampling techniques and grease analysis tests to allow the inclusion of lubricant analysis for grease lubricated equipment. This paper will discuss the challenges and options to obtain representative and consistent grease samples from motors, motor operated valves, and other critical equipment, and the use of a hall-effect sensor device for reliably and repeatably determining changes in wear levels for samples of grease as small as 1 gram.

2 - 2:30 pm
Grease Analysis with Vibration Analysis to Solve Premature Bearing Failures

R. Wenzel, L. Elam, Eli Lilly, Indianapolis, IN

The close correlation between vibration analysis and oil analysis on machinery is well established. But what about grease analysis as a companion technology for machine condition? Recently at Eli Lilly we had an opportunity to try a new grease analysis technique on some fans that were experiencing a large number of premature bearing failures. Fortunately, the problem was detected during the startup phase testing of a new manufacturing facility. It had to be addressed though because losing a fan would impact production. Vibration analysis was detecting the bearing failures, but what was the root cause? Oil analysis could not be practically used for a grease lubricated bearing. But a company, Maintenance Reliability Group, could analyze grease with only a few grams for a sample.

We were able to use this grease analysis technique and correlate with our vibration spectra to help find or narrow down the root cause of the bearing failure in some cases. We found grease analysis to be a promising new tool for the predictive maintenance specialist.
To satisfy the demand for ever increasing magnetic recording data storage density, it is necessary to provide ever smoother magnetic recording disk surfaces to avoid interference with various methods based on a realistic mechanical seal configuration and discuss the relevancy of such calculations to mechanical seal designs.

Numerical Analysis of a Surface Textured Mechanical Seal Operating in Mixed Lubrication
N. Brunetiere, B. Tournere, University of Poitiers - CNRS, Futuroscope, France

It is well known that surface texture can improve the performance of mechanical seals by reducing friction. Even if it has been experimentally proved, some theoretical explanations are needed. Thus, the aim of this paper is to study the mechanisms at the origin of the enhancement of the hydrodynamic lift observed with surface texture in mechanical face seals. The model solves the Reynolds equation coupled with a mass conservative cavitation algorithm and considers asperities contact. The performance of a rough surface is compared with that of the same surface equipped with textures. The geometrical parameters of the texture are varied in order to find an optimum.

Heat Transfer Coefficient Estimations for Mechanical Seals
T. Karis, Hitachi Global Storage Technologies, San Jose, CA, Y. Kajihara, Nagoya University, Nagoya, Japan

Due to significant heat generation occurring on the mechanical seal interface, heat transfer affects how high the face temperature may rise and the associated seal face thermal distortion and leakage flow. There had been numerous ways to estimate convection heat transfer coefficients for rotating cylinders and disks. This review intends to compare the estimates from various methods based on a realistic mechanical seal configuration and discuss the relevancy of such calculations to mechanical seal designs.

Analysis and Development of a Low Breakout Friction Dynamic Gasket for Large High Duty Seal Applications
L. Young, J. Davis, J. Benedict, Flowserve Corporation, Temecula, CA

In applications involving large vertical style pumps, it is well known that shaft motion can occur during startup and shutdown operation. Shaft motion can be as much as 3mm or more. Under these conditions it is important for the mechanical seal to be able to track this motion in the axial direction and maintain rotating face to stationary face contact. It is also known that elastomeric dynamic gaskets can, overtime, develop a bond to metal surfaces, in this case to the balance sleeve of the mechanical seal. Under low sealing pressure conditions, spring load may be the only significant force trying to move the dynamic gasket. If this force is insufficient, seal face separation will result and leakage of sealed product will occur. This bonding mechanism has been attributed to the elastomer gradually flowing into the micro asperities of the metal surface thereby increasing the force to break the gasket loose during gross axial motion. Breakout force has been measured by several sources and can be as much as three times the sliding friction force. This paper presents the analysis, design and testing of a novel dynamic gasket design. Results show a reduction of breakout load of 70% at low pressure and more than 50% at high pressure when compared to elastomeric gaskets.

Advanced Diamond Coatings for Mechanical Seals
J. Otschik, A. Schrüfer, Burgmann Industries GmbH & Co. KG, Wolfratshausen, Germany

Since 2007 crystalline diamond thin film coatings have found their way into the mechanical seal market. Now this new technology has been proven to be successful in a wide range of mechanical seal applications. The reliability and life time of mechanical seals was improved by factors with diamond coated faces under poor lubrication conditions or in applications with abrasive or chemical aggressive medium. Prior to field applications screening tests by means of a statistical test plan had been carried out in order to find the best ceramic-diamond-system for seal face applications with regard to friction, wear, adhesion and seal face flatness. Grain size, crystallite orientation, layer thickness and ceramic substrates had been varied and led to an ideal configuration implemented in the diamond faces technology. This paper presents results of the screening tests as well as experiences gained from various field applications.

A Multi-scale Approach of Mixed Lubrication - Application to Mechanical Seals
A. Nyameke, N. Brunetiere, B. Tournere, University of Poitiers - CNRS, Futuroscope, France

The lubricating fluid film developed between the faces of mechanical seals is a fraction of micron in thickness leading to a mixed lubrication regime. However, over a velocity threshold the fluid film can completely separate the faces because of the hydrodynamic effect due to the surface roughness even if the mean surfaces are parallel. To study this phenomena a deterministic model is preferable because the stochastic theory based on flow factors is unable to reproduce this effect. Unfortunately the deterministic approach needs a prohibitive amount of nodes and computation time. This is why a multi-scale model is proposed. It is composed of a micro-deterministic model working on small area coupled with a macro model giving the pressure distribution on a macro-mesh. The results of the multi-scale model are compared to a pure deterministic model in terms of accuracy and computation time when the area of the macro-cells is varied.

Radial Lip Seal Monte Carlo Simulation
K. Warren, L. Stephens, University of Kentucky, Lexington, KY

Radial lip seal models continue to improve, but the scope and complexity of a fully developed radial lip seal model is still a challenge to researchers. A model that accurately predicts seal behavior and experimental response is desired since such a model would be useful in seal conception and design, allowing performance to be more readily evaluated without dependence on trial and error testing. The current work explores the use of Monte Carlo simulation to incorporate the evolution of radial lip seal performance into modeling efforts. Radial lip seal systems are stochastic in nature due to the wear of the elastomer lip which occurs during operation, making them a good candidate for Monte Carlo methods. The details of the model employed in this work are discussed and comparison of simulation to experimental results is shown. Of particular interest is how accurately friction torque is modeled by the simulation.
the read/write head sensor element. The magnetic layers and carbon overcoat of thin film magnetic recording disks are vacuum deposited, the disk is coated with about 1 nm of lubricant, and then it is polished with a mild abrasive tape to remove asperities above typically 5 nm for advanced disk products. Polishing must avoid damaging or scratching the 3 to 4 nm thick carbon overcoat which protects the magnetic layers from corrosion while effectively machining down the asperities. This presentation describes measurements of the friction force between the polishing tape and the thin film recording disk. A laboratory bench top friction tester was set up to automatically load the polishing pad load and sweep across the disk similar to the manufacturing disk polishing tools. The load and friction force are simultaneously recorded to measure the friction coefficient. The load and velocity dependence of the friction force, the effect of lubricant type and bonded fraction and soft and hard tape binder are described. The tape friction generally follows Amontons law with adhesion, and the tape is partially supported by an air bearing at low load and high velocity. A friction and wear model is developed for relating changes in the friction coefficient to the adhesion stress and real contact area.

2 - 2:30 pm
Tribological Characterization of Surface Engineered Tooling
A. Biksas, S. Veldhuis, McMaster University, Hamilton, ON, Canada

Effect of Temperature on Friction Behavior under Boundary Lubrication Regime
O. Ajayi, C. Lorenzo-Martin, R. Erck, G. Fenske, Argonne National Laboratory, Argonne, IL
Friction behavior of lubricated sliding surfaces is determined the operating lubrication regime. Under hydrodynamic and elastohydrodynamic (EHD) regimes, the lubricant fluid film properties determine the friction. For mixed and boundary lubrication regimes, in addition to the lubricant fluid film, the boundary films, and the near-surface materials all combine to determine the frictional behavior. Since the boundary films are formed by surface chemical reactions, the rate of its formation and perhaps its properties is strongly dependent on temperature. In the present study, the frictional behaviors of lubricated steel surfaces in reciprocating contact under boundary lubrication regime were evaluated as a function of temperature. Friction measurements were conducted under both isothermal and continuously varying temperature conditions in the range of 10 to 120°C for a fully formulated lubricant. In both types of test, the lowest friction was observed in the temperature range of 50 to 100°C. The observed frictional behavior in the present study is attributed to the effect of temperature on the competition between boundary film formation and stability.

2:30 - 3 pm
Effect of Temperature on Friction Behavior under Boundary Lubrication Regime
O. Ajayi, C. Lorenzo-Martin, R. Erck, G. Fenske, Argonne National Laboratory, Argonne, IL

3 - 3:30 pm - BREAK

3:30 - 4 pm
Tribological Testing Methods for the Analysis of Seals
F. Bauer, W. Haas, University of Stuttgart, Stuttgart, Germany

Lip seals are used to seal rotating shafts and reciprocating rods in all areas of mechanical and automotive engineering. The lip seal is a frequent and reliable sealing system in millions of cases. Based on its good static sealing and the active dynamic sealing mechanism it is accepted by the market. However, limits are set to its area of application. The "Seal" is a system of the four partners Seal-Ring, the counterface, the lubricant and the surrounding. To choose the best fitting Seal it is necessary to know how the Seal works and how the different partners influence one another. Therefore all tribo-partners have to be well understood. This deep understanding can only be achieved with intensive test methods. In this paper the scientific methods like elipsometry, microscopy (light, laser, SEM) and the measurement of Elastomer-metal-hardness, radial force, roughness, microstructures, topography will be presented. Furthermore the analytical tribotests like pin on disk and tests with real seals like long-time tests (wear, tightness and Elastomer compatibility), flow analysis through glass-hollow-shafts, pumping rates, friction-tests and the test of working conditions will be described and the results presented. All methods and results will be evaluated. With this paper scientists and users have a fundamental knowledge of the useful and unerring tribotesting-methods in the field of seals. The paper will be deepened in several papers from the University of Stuttgart in the session Seals.

4 - 4:30 pm
Microtribology Under Potentiostatic Control
J. Keith, N. Argibay, R. Colbert, W. Sawyer, University of Florida, Gainesville, FL

In sliding electrical contacts anode/cathode wear rates have been shown to have order of magnitude differences. The state-of-the-art in high performance brushes and current collectors are copper and precious metal fiber brushes. Saturated carbon dioxide environments are frequently used to promote low friction μ<0.25 and low wear. This presentation reports on the development of a rotating pin-on-disk tribometer that can operate at loads below 1mN and perform experiments on a single metal fiber. The tribometer operates within an electrochemical cell under potentiostatic control.

4:30 pm – Tribotesting Business Meeting

Session 2H

Commercial Marketing Forum II

Session Chair: TBD

1:30 - 2 pm
CORFREE® Diacid Mixtures from INVISTA Continue to Provide Optimal Corrosion Inhibition Performance
M. Jurychuk, C12 Specialty Materials, INVISTA S.à r.l., Wilmington, DE

CORFREE® M1 and M2 diacid mixtures (available only from INVISTA) have been used globally in corrosion inhibitor formulations for more than 20 years. They offer exceptional corrosion inhibition performance in end-applications such as metal working fluids (synthetic and semi-synthetic), metal cleaning fluids, engine coolants, aqueous hydraulic fluids, die-cast release agents and heat transfer fluids. CORFREE® M1 is a diacid mixture specially tailored for the corrosion inhibitor market and offers exceptional hard water stability. CORFREE® M2 diacid is a single-component diacid, favored in some regions of the world. In this presentation, we will highlight INVISTA’s continued commitment to the CORFREE® diacids product range. We will provide an overview of recent quality improvements to CORFREE® M1 and M2 diacid mixtures, highlighting the resulting performance benefits. We will also review recently-developed test data, showing that CORFREE® M1 and M2 diacid corrosion inhibitors continue to provide optimal corrosion inhibition performance with low foaming and exceptional hard water tolerance.
This presentation will explore these challenges and the next generation RP technologies designed to meet them.

- Refrigerants such as hydrofluorocarbon (HFCs). Despite the environmental advantages of CO2, its implementation in air-conditioning systems has been limited, partly because CO2 requirements. Today's RPs are frequently expected to:
  - Be compliant with the divergent standards and availability requirements of a global market
  - Be compatible with a wide range of metal substrates
  - Eliminate workplace and disposal hazards associated with heavy metal exposure
  - Reduce the processing time associated with cleaning protective films
  - Deliver competitive advantage by providing exceptional resistance to salt spray and other corrosive challenges
  - Remain stable at cold temperatures without crystallizing or separating

This presentation will explore these challenges and the next generation RP technologies designed to meet them.

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**Session 3A**

**Tuesday**

**Environmentally Friendly Fluids I**

- **Session Chair:** B. Sharma, UIUC, Urbana, IL
- **Session Chair:** M. Miller, Terresolve Technologies, Eastlake, OH
- **Session Vice Chair:** J. Perez, Penn State University, Pennsylvania Furnace, PA

**8 - 8:30 am**

**Biodegradable Lubricants - Real World Performance**

M. Miller, Terresolve Technologies, Eastlake, OH

This paper compares the performance of several types biodegradable hydraulic fluids. Testing was done by a variety of different test protocols. This testing shows that there are major performance differences among types of biodegradable lubricants. Over the past decade several different type of biodegradable fluids have emerged including synthetic esters, PAGs and other glycols, biopolylefins and many more. This paper reviews the strengths and limitation of each type of fluid. Commercially available biobased, biodegradable synthetic and petroleum fluids were tested for physical and chemical characteristics, application performance, dielectric properties, seal compatibility, military and OEM Specifications, OEM evaluations and field performance. Each parameter was evaluated utilizing industry recognized testing protocol. The results of each test is reviewed and supported with the original data, and tables or graphs as was appropriate.

**8:30 - 9 am**

**Effect of Carbon Dioxide Mass on the Tribological Behavior of Materials Used in Air-Conditioning Compressors**

A. Polycarpou, E. Escobar Nunez, UIUC, Urbana, IL

Carbon dioxide (CO2) is an alternative natural and environmentally friendly refrigerant as it has no ozone depleting potential and negligible global warming potential compared to synthetic refrigerants such as hydrofluorocarbon (HFCs). Despite the environmental advantages of CO2, its implementation in air-conditioning systems has been limited, partly because CO2 systems operate at very high refrigerant pressures. In this study, the effect of the amount of CO2 molecules on the tribological performance of three different interfaces (gray cast iron, Al390-T6, and Mn-Si brass) was examined using a specialized tribometer. The amount of CO2 molecules was set to 5, 50, and 100 grams and to achieve the desired chamber pressure, the chamber was further pressurized using Argon. Pressures were set at 100, 400, 600, 800, and 1000 psi. Results showed that the pressure has a more positive affect compared to the amount of CO2 molecules on the tribological behavior during the experiments performed using gray cast iron. It was found that the formation of dangling bonds allows chemical reactions on the surface of gray cast iron towards the formation of iron carbonates which protect the interface against scuffing.

**9 - 9:30 am**

**Key Aspects of Choosing Polyalkylene Glycols in Hydraulic Equipment for Environmentally Sensitive Areas**

L. Johnson, M. Greaves, G. Khemchandani, Dow Chemical Company, Freeport, TX

Fluids exhibiting good performance and favorable environmental profiles offer comprehensive solutions to today’s equipment operators. Natural and synthetic ester-based hydraulic fluids have traditionally been preferred choices for use in equipment in environmentally sensitive areas. However polyalkylene glycols (PAGs) provide an excellent alternative, offering excellent equipment reliability while also having favorable environmental profiles. PAGs can be chemically engineered to be water-miscible and non-sheening. This is beneficial in applications where fluids can leak into water-ways. Their non-sheening performance differentiates them from hydrocarbon oils and ester lubricants. Several benefits of PAGs are highlighted including their ability to minimize deposits in equipment. PAG fluids can also be designed to have low eco-toxicity, where their exposure to humans, animals, and other organisms is less likely to lead to harm. We evaluated several PAG-based fluids and they were readily biodegradable, allowing them to be broken down to simple molecules and putting less strain on an ecosystem.

**9:30 - 10 am**

**Glossamer® L6600 Biobased Cosmetic Additive**

W. Everett, International Lubricants, Inc., Seattle, WA

Glossamer® L6600 is a completely biobased, biodegradable, hypoallergenic polymer replacement for lanolin in a variety of skin and hair cosmetic applications. This polymer, which is
free of catalyst or other additives, results from a thermal polymerization of pure agricultural seed oil starting materials. Glossamer® L6600 exhibits moisture barrier and skin moisturization properties that are superior to those of lanolin and additives used in a major competitive lotion. Equally important are the wear related benefits that Glossamer® L6600 imparts to cosmetic products. These wear benefits include sunscreen UV chromophore retention in water (65% retention for Glossamer® L6600 vs. 18% retention for mineral oil), the water resistance of Glossamer® L6600 enhanced sunscreen upon immersion (after 80 minutes the SPF level was retained), the resistance to rub off, and the retention of volatile fragrances.

10 - 10:30 am - BREAK

10:30 - 11 am
Formulating Strategies for Biobased, Biostable, High Performance Metalworking Fluids
R. Bingeman, Croda, New Castle, DE
Corporate responsibility initiatives and regulations such as the USDA BioPreferred program are generating an increasing need for environmentally friendly metalworking fluid solutions. Biobased coolants can be important in meeting the environmental objectives of many customers. These biobased coolants must provide acceptable performance which historically has been a challenge. Achieving good biostability from a biobased coolant can be a major challenge because biobased products typically have inherently poor biostability. This paper will address formulating strategies to create biobased coolants that are biostable and offer good multimetal cutting performance.

11 - 11:30 am
Bulk Modulus and Viscosity Measurement Under High Pressure Conditions
S. Drumm, A. Fatemi, A. Wohlers, H. Murrenhoff, RWTH Aachen University, Aachen, Germany
The Cluster of Excellence “Tailor made fuels from biomass”, funded by the German research foundation (DFG), is an interdisciplinary collaboration of about 15 institutes and 50 researchers. The aim of the project is to find an optimized process to synthesize new fuels based on biomass. Furthermore the combustion and injection system shall be optimized by reconsidering the new fuel as a design element. The task of the authors is to develop a guide line for designing an injection system adapted to these fuels. The focus is especially on the high pressure pumping of the new fuels within common rail systems. In this paper the investigations to characterize the tribological behavior of the new fuels will be presented. A test rig to measure the viscosity and the bulk modulus under high pressure conditions of up to 800 MPa has been built up. The design of the test rig and the measuring principle for these extreme conditions will be shown. Furthermore measurement results for the first tailor made fuels will be presented. These data are needed to parameterize simulation models of the injection system which are set up parallel to the experiments.

11:30 - Noon
A Natural Way to Develop Top-tier Hydraulic Fluids
A. Vergauwen, OLEON NV, Oelegem, Belgium
Presentation will present Oleon's full range of ester hydraulic base oils & thickeners. Saturated and unsaturated esters with viscosities from ISO VG 15 till 68 for the base oils and the thickener range going from ISO VG 100 to ISO VG 6000. Physical data and test results will be presented. Next to this standard industrial range, products for Factory Mutual formulations will be discussed. Third range is the NSF approved base oils for HX1 fluids.

Session Chair: R. Mourhatch, University of Texas at Arlington, Irving, TX

8 - 8:30 am
Modeling the Chemical Reactivity of Tribo-stressed Nascent Metallic Surfaces
J. Martin, M. De Barros Bouchet, T. Le Mogne, Ecole Centrale de Lyon, Ecully, France
We have developed a model experiment to study the reactivity of lubricant additives towards nascent and tribo-stressed metallic surfaces. Activated surfaces are created and friction tests are conducted using an Environmentally Controlled Analytical Tribometer (ECAT) equipped with XPS/AES analysis. A reactive gas partial pressure simulates the lubricant additive chemistry or the environment. The metal surface is cleaned by ion etching to remove the passivation layer. A pin-on-flat friction test is then performed in UHV conditions (100 nPa residual gas pressure) on this pure metallic surface previously obtained. Afterwards, a selected reactive gas is introduced in the chamber and can react with the different activated surfaces which are exposed: the ion-etched and the tribo-stressed surfaces, respectively. A second friction test is performed on the ion-etched surface in presence of the gas. At the end, the chamber is pumped down to UHV and XPS analyses are carried out on the different locations, inside and outside the two wear scars. We have performed such model experiments on two metal surfaces (steel and a titanium alloy) and with different partial pressures of gases (air, nitrogen, oxygen, tri-methyl phosphate, tri-methyl phosphite, organic polysulfides) and at different temperatures of the substrate from ambient to 400 °C. In the absence (or low content) of oxygen in the gas molecule. Results show that reactions take place preferentially on the tribo-stressed nascent surface but not on the ion etched only.

8:30 - 9 am
Growth Kinetics and Morphology of Thermal Films from Ashless and Ashed Antioxidant Additives
P. Aswath, B. Kim, University of Texas at Arlington, Arlington, TX
The thermal route to form films provide valuable insight into the mechanism of formation of tribofilms. In this study a thermal approach was used to study the kinetics of thermal films formed on ferrous substrates for a variety of antioxidant chemistries that include Zinc Dialkyldithiophosphate (ZDDP), short and long chain ashless dialkyldithiophosphates and amine phosphates. The thermal films were deposited on ferrous substrates by immersion in an oil containing these additives at a nominal concentration of 0.1 wt.% phosphorus for durations ranging from 1 to 60 minutes. The chemistry of the films were analyzed using X-ray absorption near edge spectroscopy (XANES). P and S K and L spectra were used to determine the nature of phosphorous and sulfur compounds and their distribution within the thermal films. Acknowledgement: XANES works was conducted at The Canadian Light Source, Saskatoon, Canada which is supported by NRC of Canada. Other analytical work was conducted at CCMB at University of Texas at Arlington.

9 - 9:30 am
Influence of Friction Modifiers on Boundary Film Formation Properties
J. Guervmont, M. Devlin, J. Loper, K. Garelick, K. Hux, T. Jao, Afton Chemical Company, Richmond, VA
Friction modifiers are added to modern engine oil formulations to reduce boundary friction in an effort to improve fuel economy. Yet, zinc dialkyldithiophosphate (ZDDP), the most common anti-wear additive used in engine oils, is known to form thick glassy polyphosphate films that can cause friction to increase, which is detrimental to fuel economy performance. Previous work has shown that additives can affect the composition of anti-wear films, and in turn the frictional properties of the new surfaces. Also, friction modifiers can behave differently on steel as compared to the ZDDP anti-wear film. In an effort to further explore the impact of additives on tribofilm composition, the frictional characteristics of various friction modifiers with ZDDP have been studied. By using a Mini Traction Machine with a Spacer Layer Imaging System (MTM-SLIM) we have observed the influence of the friction modifiers on the ability
of ZDDP to form tribofilms and the frictional properties of these films. The films formed were then studied with energy dispersive X-ray spectroscopy (EDX) to obtain chemical composition.

9:30 - 10 am
Influence of Succinimide Dispersant on Film Formation, Friction and Antiwear Properties of Zinc Dialkyl Dithiophosphate
J. Zhang, Imperial College London, South Kensington, United Kingdom, E. Yamaguchi, Chevron Oronite Co. LLC, Richmond, CA, H. Spikes, Imperial College London, South Kensington, United Kingdom

Most of today’s engine oils contain the two lubricant additives, polyisobutylsuccinimide-polyamine (PIBSA-PAM), which acts as a dispersant, and zinc dialkyldithiophosphate (ZDDP), which is a combined antiwear agent and antioxidant. Both of these additives are generally regarded as the most cost-effective of their class and are pivotal in the design of high performance engine oils. Unfortunately PIBSA-PAM can be antagonistic to ZDDP in the latter’s role as an antiwear additive. This antagonism may become more important in future since engine emission control requirements coupled with extended drain intervals are likely to lead to an increase in the relative concentration of dispersant to ZDDP in engine oil formulations. This presentation describes a study of the influence of PIBSA-PAM concentration on the film forming, friction and wear properties of ZDDP solutions. It is shown that the relative concentration of N to P influences ZDDP film formation as measured by MTM-SLIM but has less effect on ZDDP film removal. Based on these measurements, the mechanisms by which PIBSA-PAM influences ZDDP antiwear behaviour are discussed.

10 - 10:30 am - BREAK

10:30 - 11 am
Observing the Boundary Layer Formation at a Tribological Contact
J. Wong, Imperial College London, London, United Kingdom

The successful formation of a boundary layer is crucial to friction reduction at the boundary lubrication regime. Stearic acid is commonly used as a boundary lubricant due to its ability to form a monolayer on the tribological surface of interest. In this work, fluorescent imaging was used to examine how stearic acid molecules interact with various substrates. The process of boundary layer formation under various tribological conditions was observed. The effect of base oil composition will be discussed.

11 - 11:30 am
Effect of Slide Roll Ratio and Additive Interactions on Reaction Layer Formation - A Dual Approach: Experimental and Molecular Dynamics Studies
A. Naveira-Suarez, M. Zacheddu, R. Pasanibu, SKF Engineering and Research Centre, Nieuwegein, Netherlands, M. Grahn, R. Larsson, Lulea University of Technology, Lulea, Sweden

Lubricant additives will compete to adsorb and react with rubbing steel surfaces. One non-polar and one polar model base oils and two EP/AW additives, ZDDP and phosphoric acid ester (PAE), were studied experimentally and numerically with Molecular Dynamics simulations (MD). MD is employed to simulate the base oil blended with the two additives. Simulations show that the presence of PAE influences the adsorption and tribological behaviour of ZDDP.

The influence of slide roll ratio on the functionality of additives related to reaction layer formation is studied. The reaction layer formation was monitored in-situ using an adapted interferometry technique. The chemical composition of the layers, analysed using X-ray photoelectron spectroscopy, and their nanomechanical properties, are discussed in relation to tribological performance. The MD simulations and the experimental observations are compared and discussed.

11:30 - Noon
Analyses of the Anti-Wear Boundary Film on an Oxygen-Diffused Titanium Surface
J. Qu, H. Meyer, J. Howe, P. Blau, Oak Ridge National Laboratory, Oak Ridge, TN

Previous work has demonstrated that oxygen diffusion (OD) used as a surface treatment for titanium alloys can enable the formation of an anti-wear boundary film in a lubricated environment. The interactions between the lubricant additives and the OD-treated titanium surface and the resulting chemical compounds, however, remain unclear. Surface chemical analyses using X-ray photoelectron spectroscopy (XPS) were performed on the wear scars produced in a sliding wear test for both untreated and OD-treated Ti-6Al-4V (OD-Ti64) lubricated by a fully formulated engine oil. High energy resolution XPS spectra revealed distinct chemical compositions. A 50 nm thick boundary film was detected on the worn OD-Ti64 surface and it contains significant amounts of Ti, Zn, Ca, S, P, N, and O. While no such film exists on either the unworn OD-Ti64 surface or the worn, untreated titanium surface. This indicates that both the OD treatment and the thermo-mechanical stresses involved in the tribotesting are essential for boundary film formation. Shifts of bonding energy peaks were observed for elements extracted from the lubricant additives (such as Zn, Ca, S, and P) as well as the elements from the OD-Ti64 surface (such as Ti and O) implying that the additive molecules broke down, reacted with the OD-Ti64 surface, and formed new compounds during the wear process. Further analyses using an Auger parameter plot for Zn confirmed the existence of ZnS and ZnO in the surface boundary film.
Effectiveness of Various Surfactants on the Dispersion of Sub-micron Size Boric Acid Particles in Oils

8 - 8:30 am
Session Chair:
Session Vice Chair:

In the current study, sub-micron size boric acid particles were manufactured using a ball milling machine and blended into synthetic base oils. A variety of surfactants was added to the oils, and the effectiveness of these surfactants in dispersing the boric acid particles was evaluated. Two surface engineering methods were applied to alloy Ti-6Al-4V to improve its galling resistance: an oxygen diffusion treatment, and the formation of a composite with TiB2 under intense infrared radiation. A newly developed, three-pin-on-flat test method was used to compare the galling behavior of the titanium surfaces with cobalt-based alloy Stellite 6B™ at 485°C. The magnitude of the torque, the surface roughness, and observations of surfaces were used to characterize behavior. Galling resistance of the Ti-alloys, even non-treated, was better at high temperature than it was at room temperature.

9:30 - 10 am

Atomic Factors Governing Adhesion Between Diamond, Amorphous Carbon, and Model Diamond Nanocomposite Surfaces

P. Piotrowski, G. Gao, J. Urban, J. Harrison, USNA, Annapolis, MD; R. Cannara, National Institute of Standards and Technology Center for Nanoscale Science and Technology, Gaithersburg, MD; R. Carpick, University of Pennsylvania, Philadelphia, PA

Molecular dynamics simulations were performed to study the work of adhesion for two diamond surfaces, C(111)(1x1) and C(001)(2x1), with different amounts of hydrogen termination. The counterfaces were either self-mated diamond, amorphous carbon, or model diamond nanocomposite surface. For the self-mated diamond surfaces, there was no significant difference in the work of adhesion between the C(111)(1x1) and C(001)(2x1) surfaces. However, at each hydrogen coverage, the average adhesion for the C(001)(2x1) system was smaller than for the C(111)(1x1) system. Pairing the diamond surfaces with an amorphous carbon counterface led to a reduction in the work of adhesion, for both systems. An even further reduction in adhesion was obtained from pairing the C(111)(1x1)-H with a model diamond nanocomposite. While there was some dependence on hydrogen coverage, the most significant affect on the work of adhesion was the atomic scale roughness of the countersurface. These results were compared to experimental measurements conducted with atomic force microscopy.

10 - 10:30 am - BREAK

10:30 - 11 am

Surface Characterization Metrics for Use in Modeling Polymer Tactility

M. Darden, C. Schwartz, Texas A&M University, College Station, TX

The sensation of touch is central to the human interaction with products as well as with product utility. Potential customers frequently assess products based on the tactile experience, but the surface characteristics that instill tactile qualities have been challenging to identify. This study focused on methods of surface texture characterization that would identify a universal set of parameters that could be used to represent the topography of complex textures. Relationships between these parameters and tactility can then be investigated. Through the use of white light interferometry, textured polypropylene plaques with varying imprinted geometrical patterns were scanned, resulting in a three-dimensional texture maps. These topographies were then processed using computational wavelet and fractal techniques to develop the set of universal characterization parameters, where each texture corresponds to unique parameter values in the universal set. It is also shown that once these values are identified, the three-dimensional topology of a particular texture can be recreated using an algorithm. Human evaluations has been been performed to quantify the rate these textures with respect to a set of tactile descriptors. Analysis has been undertaken to identify correlations with surface parameter values and particular tactile descriptors.

11 - 11:30 am

Titanium Carbide/Carbon Nanotube/Nickel Composites for Surface Engineering Applications

T. Scharf, W. Tu, J. Hwang, R. Banerjee, The University of North Texas, Denton, TX

Metal-matrix composites comprising of titanium carbide and carbon nanotube (CNT) reinforcements in a nickel matrix have been processed via the laser engineered net shape processing technique. The carbide precipitates are formed in these composites by the reaction between liquid nickel and carbon during the laser deposition process. The details of the structure and compositional changes across the TiC/Ni interface have been characterized by 3D atom probe tomography coupled with transmission electron microscopy studies. The results indicate the formation of a thin Ni-rich interface layer that might be responsible for improved adhesion between the carbide and the nickel matrix. Unidirectional and high frequency reciprocating sliding tests showed improvement in friction and wear behavior compared to CNT/Ni composites and pure Ni. Mechanisms of solid lubrication were investigated by micro-Raman spectroscopy spatial mapping of the worn surfaces to determine the formation of tribochemical products. The TiC/CNT/Ni composites exhibit a self-lubricating behavior, forming an in situ, low interfacial shear strength graphitic film during sliding, resulting in decreased friction coefficients. Recommendations will be given for potential surface engineering applications.

11:30 - Noon

Ultra-fast Boriding as a Novel Surface Engineering Process for Extreme Tribological Applications

A. Erdemir, O. Eryilmaz, G. Kartal, Argonne National Laboratory, Argonne, IL; S. Timur, Istanbul Technical University, Istanbul, Turkey

In this study, we introduce an ultra-fast boriding process that can produce very thick (i.e., 100 -150 μm) boride layers in less than an hour, depending on the type of steel being processed. Compared to conventional boriding techniques such as pack, paste, plasma, or salt-bath boriding techniques, ultra-fast boriding provides great advantages in terms of environmental cleanliness, productivity, product quality, and cost. It can be done in a molten salt electrolyte at elevated temperatures. Steel samples or parts to be borided are attached to the cathode of the electrochemical cell, while the crucible that contains the electrolyte may act as an anode. The very thick boride layers produced on the surface of steel substrates exhibit excellent resistance to wear, erosion, and corrosion. Under boundary lubricated sliding conditions, the boride layers are able to provide low friction and extreme resistance to wear and scuffing. The hardness of borided steel surfaces are in range of 17 GPa to more than 20 GPa (depending on the steel type). The new boriding technique is cheap and environmentally friendly (produces no gaseous emissions and solid wastes).

Session 3D
Bronze 4

Nano-Joint Session I - Nano-Colloidal Lubrication Sponsored by the Lubrication Fundamentals and Nanotribology Technical Committees

Session Vice Chair: A. Malshe, University of Arkansas, Fayetteville, AR
Session Chair: A. Erdemir, Argonne National Laboratory, Argonne, IL

8 - 8:30 am
Effectiveness of Various Surfactants on the Dispersion of Sub-micron Size Boric Acid Particles in Oils

H. Chipman, M. Chipman, K. Mistry, O. Eryilmaz, A. Erdemir, Argonne National Laboratory, Argonne, IL

In the current study, sub-micron size boric acid particles were manufactured using a ball milling machine and blended into synthetic base oils. A variety of surfactants was added to the
blends to study the effect of surfactant chemistry on the dispersion of boric acid particles in oils, by studying the change in settling time and the extent of agglomeration as well as tribological performance. Six different commercially available surfactants were evaluated in the study for their effect on improved dispersion and their ability to further aid in the reduction of the size of the boric acid particles. The effect of surfactant chemistry and its compatibility with the blend was also investigated. It was observed that some surfactants improved the stability and dispersion of sub-micron size particles in the base-oils. However, the chemistry of the surfactants played an important role in the dispersibility of the boric acid particles. Thus, current investigation provided valuable information that can lengthen the stability of sub-micron boric acid particles in lubricants, reduce agglomeration, and hence increase effectiveness of these particles in further improving the lubrication capacity of base oils.

8:30 - 9 am
Tribological Properties of Graphite Intercalation Compounds: Correlation To Their Electronic Structure
K. Delbé, J. Mansot, P. Thomas, Y. Bercion, Université des Antilles et de la Guyane, Pointe à Pitre, France, F. Boucher, Université de Nantes, Nantes, France, D. Billaud, Université de Nancy, Vandoeuvre les Nancy, France
The good tribologic properties of lamellar compounds (MoS2, Graphite...) are classically associated to the presence, in their structures, of van der Waals gaps through which weak interlayer interactions exist leading to low critical shear rate along directions parallel to the layers. In the present work the intercalation [1] of selected nucleophile (alkaline atoms) and electrophile (Transition metal chlorides) species in graphite is used in order to modulate in a controlled manner the intergraphene layer distances and interactions. Ab initio band structure calculations (pseudo-potentials and FLAPW methods) carried on the various studied intercalated graphite allowed us to obtain band structure, Density of State diagrams, valence electron density maps and then to access to the bonding interactions between the intercalants and the graphene planes. Tribologic investigations are carried out above high purity argon atmosphere on thin films of intercalated compounds deposited onto the friction surfaces by burnishing. The drastic reduction of the friction coefficient from 0.20 in the case of graphite down to 0.10 when graphite is intercalated is correlated to the graphene/graphene planes interactions reduction resulting from the presence of intercalated species or intercalated species mobility.

9 - 9:30 am
Understanding Lubrication Mechanism of Colloidal Boron Nitride Particles
N. Matsumoto, K. Mistry, H. Chipman, O. Eryilmaz, A. Erdemir, Argonne National Laboratory, Argonne, IL
The interaction mechanism of nano-particles on attaining superior tribological performance is not well-reported. In the current work sub-micron particles of Boron nitride were tested and the tribological tests were conducted on HFRR (High Frequency Reciprocating Rig) to evaluate friction and wear performance. Surface analysis was carried out on the post-test samples to investigate tribochemical interaction of sub-micron Boron nitride on the steel contact surface. Wear mechanism was observed using FEG-SEM (Field Emission Gun - Scanning Electron Microscopy). The cross-sectional details of tribofilm and nano-Boric acid were investigated using TEM (Transmission Electron Microscopy). The chemical characterization of the tribofilm was investigated using ToF-SIMS (Time of Flight - Secondary Ion Mass Spectroscopy) and XPS (X-ray Photoelectron Spectroscopy). It was observed that sub-micron Boron nitride formed unique tribochemical film under tribological conditions that offered significantly improved tribological performance than conventional lubricants. The current investigation provides important details on lubrication mechanism of sub-micron Boron nitride and its influence on tribological performance.

9:30 - 10 am
C60 Intercalated Graphite as an Additive in Oils and Grease
K. Miura, Aichi University of Education, Kariya, Japan
We prepared a novel C60 intercalated graphite using alkyllamine, which structure provides alternately stacked single graphene oxide sheet and C60 two-dimensional array. It is quite important to uniformly disperse the particles in grease and in oil and moreover control the size and the shape of particles in order to obtain an excellent lubrication. In this work, we report that particles of C60 intercalated graphite provide more excellent lubrication as an additive in oil and grease than MoS2 and PTTE particles, and moreover as an additive in film coating.

10 - 10:30 am - BREAK

10:30 - 11 am
Tribological Performance and Tribochemical Characterization of Different Boron-based Lubricants
K. Mistry, M. Naohiro, H. Chipman, O. Eryilmaz, A. Erdemir, Argonne National Laboratory, Argonne, IL
The combination of oil based lubricant and solid lubricants forming colloidal lubricant is anticipated as way forward to attain good tribological performance with minimal usage of sulfur, phosphorous based lubricant additives. In the present work boron based lubricants were tested: sub-micron Boric acid and sub-micron Boron nitride. The tribological tests were conducted on three test rigs to evaluate friction, wear and scuffing performance. Post-test surface analysis was carried out to investigate tribochemical interaction of nano-lubricants on the steel contact surface. Wear was measured using optical profiometry and wear mechanism was observed using FEG-SEM (Field Emission Gun - Scanning Electron Microscopy). The chemical characterization of the tribofilm was investigated using ToF-SIMS (Time of Flight - Secondary Ion Mass Spectroscopy) and XPS (X-ray Photoelectron Spectroscopy). It was observed that Boron based nano-lubricants offered significantly improved performance in terms of friction and wear than conventional lubricants. The superior tribological performance was associated with novel tribochemical film formation on the contact surface.

11 - 11:30 am
Advanced Nanolubricants Additives for Formulated Oils
A. Malshe, University of Arkansas, Fayetteville, AR, D. Demydov, NanoMech LLC, Fayetteville, AR, A. Adhvaryu, P. McCluskey, Caterpillar Inc., Peoria, IL, A. Erdemir, Argonne National Laboratory, Argonne, IL
Systematic investigation of nanoparticles (molybdenum sulfide modified with additional functional groups) that positively impact friction and wear behaviors will be discussed. These nanoparticles were specially designed for addition to oils as additives for extreme pressure and high temperature applications. A low SAPS approach was considered for nanoparticles architecture and their impact on tribological properties and emission regulations. Their performance showed synergistic effect when combined with others additives in formulated oils. The research efforts were focused on tribological testing of nanoparticles, improvement of their dispersion, and investigation of their behaviors in the presence of other additives in formulated oils.

11:30 - Noon
Influence of the Size, Morphology and Structure on the Tribological Properties and the Lubrication Mechanism of IF-MeS2 (Me=W, Mo) Nanoparticles
F. Dassenoy, J. Tannous, J. Martin, Ecole Centrale de Lyon, Ecully, France
A major challenge in the field of additives is to find solutions to replace the sulphur and phosphorus based anti-wear and anti-friction additives which are currently used in engine lubricants and highly toxic for the environment. In this context, the use of nanoparticles as additives of lubrication is more and more considered. Increasing number of articles have reported superior anti-friction and anti-wear performances of these nanoparticles. Most of these research activities focused on carbon based nanoparticles (nano-onions, nanotubes, nanodiamonds, ...), boron nitride nanoparticles, or inorganic fullerences (IF) of metal dichalcogenides as IF-MoS2 or IF-WS2. These latest are currently among the most studied. Their tribological properties can sometimes be exceptional. Different synthesis routes exist to obtain IF nanoparticles. Depending on the process and by adjusting the synthesis parameters (temperature, reaction time, annealing ...) it is possible to obtain particles of different size, morphology and crystallinity [1-2]. The influence of these parameters on the tribological properties of the nanoparticles is difficult to establish precisely. In this paper, we will compare the tribological properties of WS2 and MoS2 inorganic fullerences obtained using two distinct synthesis routes and we will try to see how the size, the morphology or the structure of these nanoparticles affect their tribological properties.
Biocidal Efficacy Versus Anaerobic Bacteria in Metalworking Fluids

T. Williams, C. Schultz, Dow Chemical Company, Spring House, PA

Understanding the fundamental tribology associated with the cutting of rock process under extreme high pressure and high temperature (HPHT) conditions is extremely important in mining and oil industries. In this paper, chip formation process during mechanical cutting of rock is simulated using an explicit finite element code, LS-DYNA. In the simulation, a tool is orthogonally moved against a stationary rock material. The rock material properties have been modeled using a specialized damage constitutive material model. The simulations were performed for various rake angles at different sliding velocities and cutting depths. The variation of cutting forces, stresses, chip morphology and the amount of chip formation have been investigated. Overall, the results indicate that the explicit FEM is a powerful tool for simulating rock cutting and chip formation process. More specifically, the separation of chip from the work-piece was distinctly shown using this numerical model. The cutting forces and chip formation was strongly influenced by rake angle when compared to cutter velocities for a given depth of cut. This information is shown to be highly pertinent to better understanding cutting rates and tool wear.

Cost-effective Condition Monitoring For Microbial Contamination in Metalworking Fluids and Metalworking Fluid Systems

F. Passman, BCA, Inc., Princeton, NJ

Uncontrolled microbial contamination is a major failure mechanism for water-miscible metalworking fluids (MWF). The long delay between sampling and data availability distinguishes microbiological testing from the other condition monitoring tests typically run on in-service MWF. It's well known that microbial population densities can increase by four to six orders of magnitude during the time it takes between starting a culture test and having viable colonies to count. ASTM E 2694 - ATP in water-miscible MWF provides a real-time alternative for determining whether a significant bioburden is present. Samples with > 10 pg ATP/mL can then be tested further to determine the predominant organisms present.

Numerical Study of Metalworking Fluid Flow in the Abrasive Contact Region

S. Mihic, S. Cioc, I. Marinescu, University of Toledo, Toledo, OH, M. Weismiller, Master Chemical Corporation, Perrysburg, OH

The objective of this work is to investigate numerically the metalworking fluid flow in the contact region between the grinding tool and the work. The regions of the three-dimensional model built using a commercial software are: porous grinding wheel, solid work, abrasive contact and surrounding air. The physical parameters investigated are the useful and total fluid flows, as well as the heat transfer and temperature distribution. The metalworking fluid properties (temperature-dependent density, viscosity, surface tension and heat capacity) and the wheel features (porosity and geometry) are varied in order to establish their influence on the flow and heat field properties. The research outcome of the paper is to establish the influence of the aforementioned parameters on the multiphase flow (fluid properties, velocity and pressure distributions, boundary layer formation and influence, process fluid flow rate and volume fraction) and on the heat transfer (temperatures and heat fluxes) in the abrasive contact region.

Evaluation of Lubricants for Minimum Quantity Lubrication

B. Tai, A. Shih, University of Michigan, Ann Arbor, MI, J. Dasch, General Motors, Warren, MI

Minimum Quantity Lubrication (MQL) is a relatively new method of applying cutting fluids during the machining process in which a fine mist of oil is applied instead of a flood of coolant. Since only a small amount of fluid is used, it is essential to understand the properties of fluids in order to control and improve the machining processes. The purpose of this study was to evaluate different commercial MQL lubricants, in terms of thermal properties, wettability, lubricity, mist characterization, and machinability. In comparing nine MQL fluids, the properties of the fluids in terms of thermal properties, wettability, lubricity, mist characterization, and machinability were investigated. Overall, the results indicate that the explicit FEM is a powerful tool for simulating rock cutting and chip formation process. More specifically, the separation of chip from the work-piece was distinctly shown using this numerical model. The cutting forces and chip formation was strongly influenced by rake angle when compared to cutter velocities for a given depth of cut. This information is shown to be highly pertinent to better understanding cutting rates and tool wear.
To help maintain a coolant system, regular testing and monitoring must be conducted on the coolant and the equipment. Typical coolant testing will include pH, concentration, tramp oil, cast iron corrosion, and biologica. Some systems require additional testing including hardness, chlorides or biocide levels. It may even become necessary to monitor a specific ingredient in the product such as boron, phosphorous or sulfur. In addition to the chemical characteristics, it is also important to monitor some of the system characteristics such as water and coolant additions and system temperature. There are many methods available to monitor the various coolant properties. Determining which tests and methods to run for a particular system takes education and an understanding of the coolant chemistry and the machining demands. Testing that is conducted on a synthetic product may not be applicable to a soluble oil. Likewise, testing done for an aluminum machining system may be altered for a cast iron grinding system.

**Session 3F**

**Fluid Film Bearings I**

**Session Chair:** M. Braun, University of Akron, Akron, OH

**8 - 8:30 am**

**Experimental Investigation On The Influence Of Surface Roughnesses And Bearing Materials On The Friction Coefficient During Start-up**

J. Bouyer, M. Filion, C. Dobre, University of Poitiers, Futuroscope Chasseneuil Cedex, France

The start-up friction coefficient is a useful parameter for engineers who design journal bearings. Considering the few studies that can be found in literature on this topic, the authors conducted several studies dealing with the measurement of this parameter. This work deals with the influent bearing characteristics on the friction coefficient: surface roughnesses and bearing materials.

Indeed, the authors studied two bushing materials (bronze and Babbitted bearings) with several aspect ratios and five shafts having different roughnesses. The analysis of the experimental results shows that the friction coefficient at start-up was directly correlated to the surface finish and the materials involved in the contact. As expected, the maximum torque at start-up is increased with the roughness. Furthermore, it was found to be higher with Babbitted bushes than with bronze bushes.

**8:30 - 9 am**

**Comments on Flows and Mixing in Vertical Oil Sumps**

L. Branagan, Pioneer Motor Bearing Company, Kings Mountain, NC

Operation of fluid film bearings for vertical shafts often involves the circulation of oil within a self-contained oil sump. The sump must meet several goals, most notably the delivery of cool, clean oil to the leading edge of the thrust or guide bearing, with significant space constraints. Undesirable sump designs or modifications can lead to stagnant regions resulting in hot bearing operation. Excessive circulation can lead to foaming. Circulation patterns may be non-intuitive, requiring some level of CFD analysis to understand the momentum and thermal flows. This presentation reviews several recent investigations of flow distribution within vertical sumps, discussing and assessing the computational techniques involved. A simplified technique is employed for a “well mixed” sump. Boundary conditions for hydrodynamic films are reviewed. Finally, a relevant short coming of commercial codes is addressed.

**9 - 9:30 am**

**Pressure Field Measurements of a Circumferential Groove Journal Bearing**

A. Cristea, University “Politehnica” of Bucharest, Bucharest, Romania; J. Bouyer, M. Filion, M. Pasovici, University of Poitiers, UMR CNRS 6610, Futuroscope, France

The present study concerns the experimental determination of the lubricant pressure distributions in one land of a symmetrical two-land circumferential groove journal bearing in steady-state conditions. The lubricant film pressure is measured in both axial and circumferential directions. Circumferential pressure distributions are determined using three equally-spaced sensor tap locations, in five different axial sections, corroborated with the rotation of the bearing with a ten degrees step. This method of measurement is valid as the operation of circumferential groove journal bearings is independent on the angle of loading. Two lubricant supply pressures (0.1 and 0.2 MPa, in relative pressure) have been considered. In the divergent zone, downstream the minimum film thickness, sub-atmospheric regions are detected; the minimum recorded film absolute pressure value was around 0.037 MPa for both lubricant supply pressures. Above-atmospheric pressure isobars, in the divergent zone, are shifted significantly in the axial direction towards the bearing lateral boundaries.

**9:30 - 10 am**

**A New Mass-conserving Complementarity Formulation to Study Cavitation in Textured Bearings**

M. Giacopini, A. Strozzi, Università degli Studi di Modena e Reggio Emilia, Modena, Italy; M. Fowell, D. Dini, Imperial College London, London, United Kingdom

A new mass-conserving formulation of the Reynolds equation has been recently developed using the concept of complementarity (Giacopini, et al.). This new method overcomes the drawbacks previously associated with the use of such complementarity formulations for the solution of cavitation problems in which reformation of the liquid film occurs. The methodology, already successfully applied to solve textured bearing and squeeze problems in 1D is now extended to the solution of 2D textured bearings in the presence of cavitation. The evolution of the cavitated region and the pressure distribution within the pockets are studied for a series of geometrical configurations. Guidelines for the design optimization of textured surfaces based on the maximization of the load support are also provided.

**10 - 10:30 am - BREAK**

**10:30 - 11 am**

**A General Form Model for Porous Medium Flow in Squeezing Film Situations**

B. Bou-Said, INSA Lyon, Villeurbanne, France; M. Nabhani, M. El Khilfi, University Hassan II, Mohammedia, Morocco

The present paper deals with a numerical investigation of the hydrodynamic lubrication of a porous squeeze film between two circular discs. To this purpose, the thin film (reduced) Navier Stokes equations, and a generalized porous medium model are solved. The numerical results show that the effect of the porous disc is to reduce the fluid film lubricating properties. This effect is increased during the squeezing action. In addition, it is shown that the film pressure, the load-carrying capacity and the velocity field based on the Darcy model are higher than those obtained from the generalized porous medium model.

**11 - 11:30 am**

**Three Types of Active Lubrication Systems for Main Bearings of Reciprocating Engines**

I. Santos, E. Estupinan, Technical University of Denmark, Kgs. Lyngby, Denmark

In the paper the authors investigate three different schemes for the realization of the controllable oil injection system to be coupled to the main engine bearings. The use of active lubrication in fluid film bearings helps to enhance the hydrodynamic fluid film by increasing the fluid film thickness and consequently reducing viscous friction losses and vibrations. One refers to active lubrication when conventional hydrodynamic lubrication is combined with dynamically modified hydrostatic lubrication. In this case, the hydrostatic lubrication is modified by injecting oil at controllable pressures, through orifices circumferentially located around the bearing surface. The computed bearing fluid film forces are coupled to the set of nonlinear equations that describes the dynamics of the reciprocating engine, obtained with the help of multibody dynamics (rigid components) and finite elements method (flexible components). The main equations that govern the dynamics of the injection for a hydraulic-actuated, a piezoelectric-actuated and a mechanical-actuated oil injector are presented in this study. The global system is numerically solved using as a case of study a single-cylinder combustion engine, where the conventional lubrication of the main bearing is modified by applying radial oil...
injection. The performance of such a hybrid bearing is compared to an equivalent conventional lubricated bearing in terms of the maximum fluid film pressures, minimum fluid film thicknesses and reduction of viscous friction losses.

11:30 - Noon
Impacts on the Friction Force Between Piston and Bushing of Swash-Plate Machines
U. Piepenstock, S. Gels, H. Murrenhoff, Institute for Fluid Power Drives and Controls, Aachen, Germany
Rising energy costs lead to the imperative of high energy efficiency of fluid power systems in mobile and stationary applications. So efficiency has become a very important factor for components and single tribological contacts. This paper focuses on the tribological contact between piston and bushing in swash-plate machines. Keeping friction as low as possible is not only important for over-all efficiency of the component but also for wear of the tribological system which has a strong impact on the components durability. At IFAS it is possible to measure the axial friction with single-piston test-stands at either low speed or high speed to validate tribological simulation results. The mixed friction coefficient is a very important input parameter for tribological calculations and a test-stand is used for measuring the mixed friction in axial direction at different speeds and without hydrostatic pressure in the gap. It uses the same test parts as the high speed single-piston test-stand and allows the use of different lubricants. Friction force measurements with different lubricants at different speeds will be presented. The findings also help to improve the modelling of the tribological contact between piston and bushing.

Session 3G
Seals III

Session Chair: S. Jahamir, MIT Heart Corporation, Gaithersburg, MD

8 - 8:30 am
Comparison of Different Leak Tightness Test Methods for Hydraulic Rod Seals
L. Hoerl, W. Haas, University of Stuttgart, Stuttgart, Germany, U. Nissler, Paal Verpackungsmaschinen GmbH, Remshalden, Germany
The rod seal of a hydraulic cylinder is a crucial point, since there leakage gets directly into the environment. There are different testing methods to detect a decreasing sealing ability even before leakage occurs. This paper describes the results of leakage measurements, pumping rate measurements, optical film thickness measurements on the rod surface and leakage calculation done by FE contact simulations. The differences between the individual methods are described and discussed.

8:30 - 9 am
Influence of Rod Surface Roughness on Hydraulic Seal Wear
A. Buck, L. Höfl, W. Haas, University of Stuttgart, Stuttgart, Germany
For hydraulic rod seals, there is only little knowledge about the influence of surface roughness on the tribological behavior of the sealing system. As a result, the existing surface specifications have evolved over the last decades and are mainly based upon empirical values. These specifications work well for standard hard chrome plated rods. However appliance of these specifications to alternative materials or coatings often leads to high leakage and excessive seal wear. This paper describes experiments with hydraulic rods with different surfaces. During the experiments the rod surface roughness, seal wear, leakage and friction have been measured. This data has been analyzed by simulative and analytical means to improve our understanding of the influence of surface roughness on hydraulic seal wear.

9 - 9:30 am
Transient Elastohydrodynamic Simulation of a Viscoelastic Hydraulic Rod Seal
A. Thatte, R. Salant, Georgia Institute of Technology, Atlanta, GA
A numerical model of the transient operation of a viscoelastic hydraulic rod seal, used in an injection molding application, has been performed. The model consists of coupled fluid mechanics, contact mechanics and deformation analyses. The results include predictions of the histories of the fluid transport and friction force on the rod, as well as contact pressure, fluid pressure and film thickness distributions. The viscoelastic results are compared with the corresponding results of a purely elastic analysis.

9:30 - 10 am
Numerical Modeling of a Hydraulic Elastomeric Rod Seal: From FEM Static Assembling Modeling to Hydrodynamic Seal Analysis
A. Fatu, M. Hajjam, University of Poitiers, Angouleme, France
The elastomeric seal is one of the simplest seal designs used in hydraulic systems. Its role is critical in hydraulic assemblies for obvious safety and environmental reasons. Hydraulic seals are typically constrained in grooves and highly compressed by the sealed pressures, which induce large structure deformations. This behavior suit the finite element method (FEM) as numerical analyzing tool. Consequently, a FEM commercial code is used to predict the dry contact pressure and the contact width between the pressurized seal and the rod. Several comparisons are made for different sealed pressures and material description laws. The results are used to perform a fast prediction of the seal hydrodynamic behavior by using the inverse hydrodynamic lubrication (IHL) theory. Supposing that the lubricant hydrodynamic pressure entirely replaces the contact static pressure, the classical 1D Reynolds equation in the unknown film thickness is solved. Furthermore, the direct lubrication theory is used to perform an elastohydrodynamic analysis of the seal. The results and the computing time are compared with the IHL theory.

10 - 10:30 am - BREAK

10:30 - 11 am
Analysis of Compliant Surface Foil Thrust Bearings and Face Seals Using Coupled Finite Difference and Finite Element Methods
H. Heshmat, Z. Ren, Mohawk Innovative Technology, Inc., Albany, NY
A novel axial foil seal has been developed and validated in earlier papers. The objective of this paper is to present an analytical technique economical and prudent in design refinement and performance prediction. Foil seals are applied to extreme environments precluding many conventional sealing systems. Conceptually, axial foil seals comprise foil thrust bearings with extremely small land over diameter ratios, and seal plates with edges extended to form skirt like secondary static seals sandwiched in-between seal cartridges. The developed analytical technique was first applied to thrust bearing portion while omitting the secondary seal segment. The enhanced computation technique was then applied to complete seal configurations with variable boundary conditions and large deferrential sealing pressures. Bearing compliance comes from smooth top foils and elastic foundation. Coupled finite difference and finite element methods were applied to foil thrust bearing design parameters. The technique was then improved to address elasticity effects of combined smooth top foils and elastic foundation consisting of multilayer compliant stack of bump foils and thin plates. The combined elastohydrodynamic and hydrostatic pressure profiles were computed separately using FD-based foil seal program. The pressure was used as input to the FEA to evaluate complex structural compliance, iteratively. Results from the enhanced technique showed that convergence criterion was reached within a few iterations. The analytical methodology proved to be efficient and in good agreement with experiment.

11 - 11:30 am
Advanced Oil-Free Hydrogen Centrifugal Compressor Development - Part I: Theoretical and Experimental Design Study of Foil Bearings and Seals
Z. Ren, H. Heshmat, Mohawk Innovative Technology, Inc., Albany, NY
Efficient and reliable large-scale compressors are required for hydrogen economy to transport hydrogen from production sites to end-users. Due to inherent nature of the gaseous hydrogen and operating requirements of the system, oil-free and non-contacting bearings and seals have been identified as the important subcomponents that deserve focused attention. They are critical to successful development of new centrifugal compressors. Non-contacting low-leakage foil seal is an efficient film riding sealing technology for hydrogen centrifugal compressors and the like and expected to overcome limitations of existing conventional and state-of-art seals.

Radial foil seals comprise foil journal bearings and smooth top foils with flange like fingers. Novel computational technique was employed to foil journal bearings, and then to complete foil seal configurations. Solutions with variable boundary conditions and large deferential pressures were generated and presented. Elastohydrodynamic pressure profiles were computed using finite difference method, and input to finite element model of multilayer compliant foil seal, iteratively. Optimum seal configuration was achieved with new analytical tool and validation of analysis via preliminary experimental investigation. This paper describes the methodical analytical and experimental investigations. It explores modelling and computational techniques and provides sample experimental data for validation of theorectical predictions. The foil seal investigation demonstrated excellent performance and achieved extremely good correlation with theory.

11:30 - Noon
A Leakage Model For Static Compressive Seals
J. Streator, C. Green, Georgia Institute of Technology, Atlanta, GA

Static seals are found in a variety of technological applications. However, there are few published studies that relate seal performance to physical parameters, such as compressive load, surface topography, elastic modulus, and yield strength. In this work, we present a model for the leakage of gas across a metal-metal static seal interface. A commercial finite element package is used to determine the macroscopic stresses and deformations in the sealing interface, while a recently developed microscale contact mechanics is employed model to account for the role of surface roughness in determining the mean interfacial gap. An averaged Reynolds equation from mixed lubrication theory is applied to model the leakage flow. In conjunction with the mathematical modeling, leakage tests are performed. Here, an annular Inconel tube is pressed against a mica sheet that is supported by an aluminum substrate, creating an annular sealing zone. The inside of the tube is pressurized with a test gas, the mass of which is monitored during the leakage experiment. Test results are compared to model predictions.

Session 3I
Silver Room

Wear I - Panel: Using Radioactive Tracers to Measure Real-time Wear and Corrosion

Session Chair: J. Qu, Oak Ridge National Laboratory, Oak Ridge, TN
Session Vice Chair: H. Gao, ConocoPhillips, Ponca City, OK

8:00 am - 9:00 am - Panel Starts at 9:00 am
9 - 9:20 am
An Overview of Radiotracer Methods for Wear Measurement

21
Radioactive tracer methods have been used for many decades to measure wear in operating machinery, such as automotive engines. The techniques offer many advantages over conventional wear testing procedures. Wear can be measured in near real time, with extremely high sensitivity (magnitudes of nm or µg). The use of unique isotopes allows for the simultaneous determination of wear from multiple discrete surfaces within the engine.

Wear rates can be established in a short period of time without having to disassemble and inspect. This allows rapid correlation between test conditions and wear response. This presentation gives an overview of the various techniques employed to label surfaces with radiotracers and to make and interpret the measurements.

9:20 - 9:40 am
Radiation Basics and the Statistical Nature of SLA Data
K. Oxorn, ANS Technologies, Montreal, Canada
Over the past 30 years, a number of techniques have been developed and improved to use radiotracers for the measurement of various phenomena in real time. The first of these is Surface Layer Activation (SLA), which allows the measurement of wear to high precision while the engine or rig is operating. The methods of SLA have often been described, but much of the physics behind the process has not. This presentation will describe the concepts of radiation and radioactivity, as well as statistical nature of the raw data of SLA, which is due to quantum mechanics.

9:40 am – 10 am
Valvetrain Wear Measurements: Effect of Engine Oil Formulations and Surface Modifications
A. Gangopadhyay, Ford Motor Co., Novi, MI
Reducing the concentration of phosphorous in engine oils is still being pursued to reduce the impact of catalyst poisoning on exhaust emissions. However, the reduction of the antiwear and antioxidant additive, ZDDP, raises concern for wear of engine components. Therefore, the concentration of phosphorous in engine oil needs to be critically balanced to meet these two conflicting requirements. A motored valvetrain test rig was used to evaluate the wear of cam lobes and bucket tappets using radiotracer technique for a series of low phosphorous engine oils with supplementary anti-wear additives. The investigation included both fresh oils and oils aged in vehicles from 3000 miles to 15000 miles. The investigation also included wear evaluation of a couple of surfaces modified for low friction.

10 - 10:30 am - BREAK

10:30 - 10:50 am
The Effect of Fluid Condition on Wear in Heavy Duty Diesel Engines
J. Truhan, Caterpillar, Mossville, IL
The effect of fluid condition on wear in the lubricating and fuel systems of heavy duty diesel engines was studied using radioactive tracer techniques such as surface layer activation. The quantitative relationship between fluid cleanliness, as affected by filtration and wear was determined by irradiating critical engine components such as piston rings, cylinder liners, valve train components, and fuel injectors and measuring their wear in running engines. As would be expected, cleaner fluids resulted in lower wear rates, however, different components had different sensitivities to particulate contamination in the fluids. Also improvements in the additive packages of lubricating oils resulted in a lower sensitivity to contamination for ring wear allowing for a better balance between filtration efficiency and filter life.

10:50 am – Noon - Panelist/Audience Q & A Session
Advances in Polyalphaolefin (PAO) Basestock Chemistry
S. Mazzo-Skalski, ExxonMobil Chemical, Paulsboro, NJ
ExxonMobil Chemical’s is one of the world’s largest polyalphaolefin (PAO) producers and its SpectraSyn™ products offer a broad PAO basestocks portfolio, from SpectraSyn Plus™ PAO, with a combination of low volatility and low-temperature fluidity that enables the production of more-advanced lubricants, to SpectraSyn Ultra™ PAO, which provides increased film thickness, energy efficiency and low-temperature fluidity across a full range of viscosities.

Corruguard EXT – The Innovative Solution for Improving Metalworking Fluid Life and Performance
J. Conklin, Angus Chemical Company, Buffalo Grove, IL
TOTAL offers a comprehensive range of metalworking fluids that will enable you to increase your competitiveness by combining machining quality and reduced production costs. Formulation of the fluids originates from others by using specially selected base oils and performance additives. Our formulas are tested on special instrumented machine tools that aim to optimize machine performances in terms of cutting force and tool wear. As a result, the fluids provide reduced energy consumption and lengthened tool service life.

TOTAL & SCILIA “Low Viscosity” Neat Oils and Their Applications
P. Leus, Metalworking Department, Total Lubricants, Cedex, France
VLANA & SCILIA oils are designed for a wide range of machining, from non-severe to very severe operations. This wide range enables the user to find the right product compatible with the metals to be machined and type of machining to be performed. They guarantee a high performance level while remaining environmentally friendly due to their chlorine-free formulation.

The Influence of Nanoparticles on the Lubricating Properties of Rapeseed Oil
D. Drees, S. Achanta, T. Maliar, Falex Tribology, Rotselaar, Belgium
Two current trends are combined: use renewable lubricants and nanoparticles to reduce friction, therefore fuel consumption. The main hypothesis of magnetic nanoparticles like Fe, Co, Ni in the tribocounter, is that they are able to reduce friction. Furthermore, a hypothesis states that these particles can penetrate local microcracks, thereby immobilizing them and even forming a protective tribolayer that controls wear and local temperature increase. The present paper explores the effect of Fe based micro-/nano-particle additions to lubricating oils when subjected to unidirectional and bi-directional sliding conditions. The ranking of various unmodified (Base oil, rapeseed oil and mineral oil) and modified oils (oils with Fe particles) is done by measuring friction and quantifying wear loss on the sliding surfaces. Further, a comparison between Fe micro-/nanoparticle blended oil and the commercially known glycerol monoooleate (GMO) additive is reported.

Influences of Autoxidation Of Vegetables Oil on Tribological Properties
M. Nakasako, Kure National College of Technology, Kure, Japan, I. Minami, Iwate University, Morioka, Japan
Vegetable oils are renewable resources and are expected to be environmentally adapted industrial materials. It is well known that they have been used as lubricants from ancient days. However their applications to modern machineries are limited, mainly due to insufficient oxidation stability. In fact, peroxides, one of the active intermediates formed in the initial stage of the autoxidation of vegetable oils, decompose organic sulfide type antwear agents which results in unsuccessful wear prevention. In this work, model autoxidation of rapeseed oil and modified triglycerides in laboratory was traced by detecting peroxide value (POV) and total acid number (TAN). The tribological properties of oxidized oils were evaluated by a four-ball test in terms of antiwear and load carrying properties. The results were analyzed in the light of autoxidation stage. Influence of chemical structure in vegetable oils on oxidation stability and on the tribological properties will be discussed.
Session Chair: P. Aswath, University of Texas at Arlington, Arlington, TX

2 - 2:30 pm

Tribological Characteristics of Low and Zero SAPS Antwear Additives
J. Benedet, H. Spikes, Imperial College, London, United Kingdom
J. Green, G. Lamb, Castrol Ltd, Pangbourne, United Kingdom

There is currently great interest in developing engine lubricants which have low or zero levels of sulphated ash, phosphorus and sulphur (SAPS) since these components have been shown to degrade the filters and catalysts used in engine exhaust after-treatment systems. A particular problem is to find replacements for the antwear additive zinc dialkyldithiophosphate (ZDDP), which is used almost universally in engine lubricants and which contains all three undesirable components, sulphated ash, phosphorus and sulphur. This paper reviews the impact of SAPS on after-treatment systems and describes the main classes of low SAPS antwear additive that have been suggested as possible alternatives to, or partial replacements for ZDDP. A range of potential low and zero SAPS antwear additives based on phosphorus, sulphur, phosphorus/sulphur, boron and other zero SAPS-containing molecules are identified and their film-forming, friction and wear properties are compared to those of ZDDP using MTM-SLIM, AFM, non-contact optical profilometry and TOF-SIMS. In general it is found that the low SAPS additives studied form boundary films more slowly and the films they produce are thinner than those generated by ZDDP. The relationship between the thickness of boundary film formed and its wear-reducing capability is discussed.

2:30 - 3 pm

Structure, Morphology and Chemistry of Diesel Soot
M. Patel, P. Aswath, University of Texas at Arlington, Arlington, TX

Exhaust gas recirculation (EGR) systems have been used in heavy duty diesel engines in an attempt to limit the amount of particulate matter that comes out of the tailpipe. Using techniques like EGR brings the exhaust gases back to combustion chamber resulting in soot accumulation in the oil. This accumulated soot results not only in an increase in viscosity of the oil and the formation of sludge reducing fuel economy, but also in enhanced wear. The origin of enhanced wear in the EGR engines is poorly understood and the role played by diesel soot is not well understood. In this study we have examined the structure, morphology and chemistry of diesel soot from a EGR engine and compared it with structure of fresh carbon black as well as carbon black that has been subjected to oxidation and reaction in a diesel oil. The soot particles and carbon black were extracted from the spent engine oil and oxidized soot is not well understood. In this study we have examined the structure, morphology and chemistry of diesel soot from a EGR engine and compared it with structure of fresh carbon black as well as carbon black that has been subjected to oxidation and reaction in a diesel oil.

3 - 3:30 pm - BREAK

3:30 - 4 pm

Investigation on Antwear Films Derived From Bio-lubricants by Synchrotron Light Based Techniques
J. Zhou, Canadian Light Source, Saskatoon, Canada

As an alternative lubricant, bio-lubricant with the low ecotoxicity and complete biodegradability is steadily gaining attention and significance around the world. Rather than applying the bio-lubricant as an additive in the mineral diesel, we use it as a base lube in the engine oil. The lubricity properties of bio-lubricants blended with different anti-wear additives, ZDDP or ashless additives have been studied on a Plint tribometer under a pin-on-flat configuration. The lubricity has been measured using the friction coefficient and the wear scar on the pin. To understand the tribocorporal process the chemical nature of films in the wear track has been investigated by synchrotron light based techniques. X-ray absorption near edge structure XANES at the S, P, O, N, B, and Zn edges were used to investigate the interactions of zinc dialkyldithiophosphate (ZDDP) and different dispersants. XANES measurements using total electron yield (TEY) and fluorescence yield (FY) allowed us to identify the chemical nature of the above elements in the surface and the bulk of the antwear films. Photon energy variable X-ray photoemission (SR-XPS) has also been used to elucidate the compositions variation at the top layer of the antwear film. Finally the spectromicroscopy, X-PEEM, of the antwear film resolve the spatial distribution (at 100 nm scale) maps of different structures. Based on these results, the antwear properties of these oil blends have been correlated with the chemistry of the antwear films (at macro and micro scales) on the substrate.

4 - 4:30 pm

Friction Modifier - Antwear Film Interactions
B. Papke, R. Herrera, C. Coleen, Shell Global Solutions (US) Inc, Houston, TX

Automotive lubricant friction modifiers function in part by mitigating the high friction properties of antwear films generated from zinc dithiophosphate additives on contacting metal surfaces under normal engine operating conditions. The properties of both the antwear film and the friction modifier are significantly affected by lubricant aging. The present study evaluates mechanisms through which friction modifier performance may change as a function of lubricating aging.

4:30 - 5 pm

Friction and Fuel Economy Retention in Passenger Car Motor Oil Formulations
T. Miller, V. Palekar, D. Uppal, Y. Suen, Chevron Oronite Company, Richmond, CA

Fuel economy of internal combustion engines has played an important role for engine designers for decades. The interest in fuel economy is driven by competitive market forces as well as government mandates and regulations. For PCMO formulations, the Sequence VI engine test has been optimized over time to evaluate Phase 1 fresh oil fuel economy as well as Phase 2 aged oil fuel economy. Phase 1 fuel economy seems to be driven by a combination of lubricant rheology such as HTHS viscosity as well as lubricity additives such as friction modifiers. With ageing in the engine, the additive package degrades in a thermo-oxidative environment. Consequently the additive package in the formulation has a greater impact on the fuel economy retention and Phase 2 fuel economy. This paper addresses lubricant degradation or ageing and the changes that lubricant components go through in the Sequence VI engine test. The impact of various aspects of engine oil formulations on friction and fuel economy will be discussed. The evaluations discussed in this paper are based primarily on friction measurements in laboratory test(s).

5 - 5:30 pm

Tailor-made Polyalkylmethacrylate Additives for Fuel Efficient Driveline Lubricants with Improved Fatigue Life
M. Mueller, T. Bartels, C. Wincierz, T. Stoehr, B. Eisenberg, Evonik RohMax Additives, Darmstadt, Germany
Polyalkylmethacrylates (PAMAs) are widely used as VI improvers in engine and transmission oils. They are able to adsorb from oil solution on metal surfaces, to produce thick and viscous boundary films which lead to a significant reduction of friction and wear. This paper explores the ability of tailor-made film forming PAMAs to increase the fatigue life of lubricants. This is exemplified for low viscosity manual and automatic transmission fluids. A variety of pitting test methods have been applied in this study to determine the pitting performance of different PAMA film formers in comparison to conventional VI improvers. Besides the well-known FZG gear pitting test which was operated under different test conditions and the FAG FE8 bearing pitting test a newly developed pitting screening test based on a four ball test set up is introduced. Also, recent results generated using a 4 disc pitting and micropitting rig are discussed.

Session Chair: S. Ingole, Texas A&M at Galveston, Galveston, TX

2 - 2:30 pm
AlMgB14-TiB2-C and DLC Coatings to Improve the Startup Efficiency for Hydraulic Motors
The mechanical efficiency of hydraulic motors has a strong relationship to the motor rotational speed, and drops linearly when the speed is below several rpm, as at start-up. As a result, the pump’s power has to be conservatively derated. In this study, AlMgB14-TiB2-C (BAMC) and diamond-like-carbon (DLC) coatings were applied to two key bearing components to improve the motor startup efficiency in a simulative bench test. Both coatings were produced by physical vapor deposition (PVD). A special oscillatory sliding test was established to simulate the sliding and rolling motions between the motor bearing components. Test parameters, e.g. load and speed, were determined by correlating with the actual motor operation conditions to cover the full range of contact stress and rotational speed during startup. Tests were conducted at room temperature and lubricated by the Mobil DTE-24™ hydraulic fluid. Results of tests, using various combinations of coatings, showed that a combination of DLC and BAMC coatings may substantially reduce the startup torque compared to the conventional steel-steel contact. The self-mated BAMC contact, however, showed little benefit. Modeling of the interactions between the bearing components confirmed the experimental observations.

2:30 - 3 pm
Surface Engineering of Aerospace Components Using Pulsed Laser Texturing and Adaptive Nanocomposite Coating Technologies
A. Korenyi-Both, Tribolox Inc., Dayton, OH, R. Jacobsen, Mound Laser & Photonics Center, Inc, Miamisburg, OH
We have successfully developed pulsed laser surface texturing methodologies that, when combined with adaptive nanocomposite solid film lubricant technology, can greatly extend the wear life of machine components. We are commercializing these newly developed methods for use for gas turbine engines as well as diverse other military and commercial applications. We are currently refining the laser and coating methodology to raise the Technology Readiness Level. We have created newly engineered interfaces with low friction and long wear lives and have provided proof of concept by conducting tribological and other bench level testing in our laboratories. Our advanced surface engineering initiatives provide orders of magnitude improvements in wear lives, even under highly loaded conditions. We present a brief overview of the technologies used to achieve our results, including data from our laboratory investigations and discuss some future directions.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Compositional Effects on the Surface Finish of the PS400 Solid Lubricant Coating
C. DellaCorte, NASA, Cleveland, OH
A new solid lubricant coating, NASA PS400, developed for high temperature tribological applications, exhibits a smoother surface finish than its predecessors PS200 and PS300. In this paper, the baseline composition is perturbed to investigate the role of each individual constituent on the achievable surface finish through a series of coating deposition, grinding and polishing experiments. In addition, several tribological tests were conducted on PS400 coatings that contained excess amounts of traditional solid lubricants to determine possible tribological effects. The results showed that PS400 achieves a smoother surface finish via a reduced fluoride content level. Friction and wear were not reduced and surface finish was degraded when up to 5wt% graphite, molybdenum disulphide and boron nitride were used as supplementary solid lubricants. Future research will concentrate on seeking methods to ensure a rapid coating “break in” process during which a lubricious glaze forms on the rubbing surface and low friction and wear are exhibited.

4 - 4:30 pm
Friction and Wear Maps of Solid Lubricating Coatings, Films, and Powders
K. Miyoshi, S. Watanabe, R. Vander Wal, Nippon Institute of Technology, Miyashiro, Japan, K. Street, Pennsylvania State University, State College, PA
Results of fundamental studies on the coefficients of friction, specific wear rates (dimensional wear coefficients), and/or durability of various solid lubricating coatings, films, and powders in sliding contact with different counterpart materials in air, nitrogen, and high-vacuum are presented. Mapping friction and wear of nano-scale layered composite coatings (such as sulfides and diamond like carbons), micro-scale layered coatings and films (such as soft metals, sulfides, diamond and diamondlike carbons, and oxides), and powders (such as carbon nanotubes and nano onions) indicated that the coefficient of friction and wear coefficient or lifetime of any lubricant generally vary with the environment. These lubrication systems have different characteristics under different conditions. Friction and wear mapping assists evaluation of the performance for solid lubricants in their operating environment and identify lubricants that could provide extremely low friction and negligible wear.

4:30 - 5 pm
Performance and Lifetime Monitoring of Solid Lubricated Bearings
T. Kuemmenerle, H. Birkhofer, Technische Universität Darmstadt, Darmstadt, Germany
When conventional lubricants do not meet the advanced requirements of modern technology, solid lubricants are applied. Such conditions are e.g. high vacuum and extreme temperatures, aggressive environment and radiation. Although there are wide fields of application for solid lubricants, they are not common. Factors which restrict the application of solid lubricants are the absence of proper design rules and validated lifetime estimations. To change this absence a friction energy model for rolling contacts has been developed. This model has been verified in general by test with deep groove ball bearings and coated specimens in a modernized dynamic four ball tester. The calculated results are determined by load, contact velocity, material and bearing geometry. The lifetime of solid lubricated contacts is caused by the wear rate and film thickness. Due to this fact the lifetime could be described with the remaining film. Monitoring the lubricant size could reveal the exact wear rate and thus the influence of many operating conditions. The film thickness could be measured direct or due to the effects of decreasing film thickness, like solid-born sound emission, temperature or friction torque. The objective of this paper is to show the performance of solid lubricants for ball bearings and options to determine their remaining lifetime. Further a friction energy model was described which estimates the lifetime for MoS2 lubricated rolling contacts.
The panel discussion will concentrate on the most recent advances in this field and address current industrial practices as well as future prospects. Considering tougher environmental regulations that restrict the use of current sulfur and phosphorous based additives, this might be an opportune time to consider nano-colloidal additives. However, there exist some major hurdles that need to be overcome before implementing these additives in large-scale applications. Accordingly, this panel will address the fundamental questions related to:

- Surfactant research (including surface functionalization) for improved dispersibility of nano-particles.
- Advanced cost-effective synthesis techniques of nano-particles.
- Understand nano-particles based lubrication mechanisms.
- Discussion on scale-up and blending issues for large-scale applications.
- Numerical simulations/theoretical modeling of nano-particles behavior under lubricated tribological conditions and comparison with experimental results.

**Panelists:**
- R. Herrera, Shell Global Solutions
- M. Jungk, Dow Corning GmBH
- Niles Fleischer, ApNano Materials
- J.M. Martin, Ecole Central
- O. Shenderova, International Technology Center
The development of high performance rotating machinery, growing attention has been paid to the design of new active (mechatronic) devices able to actively control vibrations and improve its dynamic behavior, i.e. magnetic bearings piezoelectric bearing pushers, hydraulic actuator journal bearings, variable impedance bearings, actively controlled bearing surface profiles or simply deformable bushes, active journal bearings with flexible sleeves, active lubricated bearings or pressurized bearings among others. The active systems composed of deformable bushes, journal bearings with flexible sleeves and active lubricated bearings belongs to a special category of tribological devices where "controllable" elastohydrodynamics plays an crucial role. In such devices the bearing surface profile is intentionally modified and/or adjusted in order to control rotor vibrations and improve bearing dynamic properties. The actively controlled bearing surface profiles can be generated by attaching any kind of actuator (hydraulic, electromagnetic or piezoelectric) to deformable bushes. In this paper the elastohydrodynamic model is used to investigate static and dynamic properties of a tilting-pad journal bearing under hybrid elastohydrodynamics (open loop control) as well as controllable radial oil injection (closed loop control). The bearing dynamic coefficients are heavily influenced by the control parameters and pad compliance. Strong synergy between elastohydrodynamics and active control is observed, in particular for bearings with injection orifices far from the pivot line.
S. Sharma, N. Ram, S. Jain, Indian Institute of Technology, Roorkee, India

The work presented in the paper is aimed to study theoretically the influence of wear on the performance of a non-circular 2-lobe four-pocket multirecess hybrid journal bearing system. The Reynolds equation governing the flow of lubricant in the clearance space of a non-circular 2-lobe multirecess worn hybrid journal bearing system has been solved using FEM together with appropriate boundary conditions. The bearing performance characteristics have been presented for a wide range of values of non-dimensional external load and wear depth parameter. The numerically simulated results have been presented in terms of maximum fluid film pressure, minimum fluid film thickness, lubricant flow rate, direct fluid film stiffness and damping coefficients. The results indicates that as offset factor and wear parameter increases, in general, the bearing dynamic characteristics deteriorates. The results presented in the paper are expected to be quite useful to the bearing designers and to the academic community.

5 - 5:30 pm
Combined Influence of Journal Misalignment and Wear on the Performance of Orifice Compensated Non-Recessed Hybrid Journal Bearing in Turbulent Regime
S. Sharma, N. Ram, S. Jain, Indian Institute of Technology, Roorkee, India

In recent years, an ever increasing trend in operating speeds of machines the bearings are generally required to operate in turbulent regime. Further in recent years several studies have been reported in literature that addresses the influence of wear in fluid film bearings. These studies clearly demonstrate that wear greatly affects the bearing performance. Further, it may also be realized that in a practical situations the journal is not perfectly aligned with the bearing. Therefore, for realistic prediction of bearing performance the influence of wear and journal misalignment is essential to be considered in the analysis. The present work is aimed to theoretically study the performance of a worn non-recessed misaligned hybrid journal bearing system operating in turbulent regime. The numerically simulated results have been presented for a wide range of bearing operating and geometric parameters, wear depth parameter and misaligned parameters for the various values of Reynolds numbers.

2 - 2:30 pm
Experimental Investigation of a Compliant 3-Layer Padded Finger Seal
E. Duran, M. Aksit, Sabanci University, Istanbul, Turkey

Derivation of closed form function for oil temperature has been performed and the shear heat dissipation effect has been successfully integrated into the lift force formulation. Oil pressure is successfully derived by tracking three different ways, all of which give very similar results to each other (Duran et. al., "AIAA-2006-4755_Effect of Shear Heat on Hydrodynamic Lift of Brush Seals in Oil Sealing", "Oil Temperature Analysis of Brush Seals", IJTC2007-44397, "A Study of Brush Seal Oil Pressure Profile Including Temperature-Viscosity Effects", AIAA-2008-4622). All these analyses are advanced fluid mechanics and heat transfer analyses, which give consistent results with real-life applications. In this study, function of shear heating effect included in hydrodynamic lift clearance formulation. For a different pressure loads, change of hydrodynamic lift clearance with rotor surface speed and temperature can be found without requiring any experimental leakage data. Theoretic lift clearance gives correlated results with the experimental lift data.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Cavitation in Mechanical Seal and its Effects on Sealing Performance
Y. Li, W. Huang, S. Suo, Y. Liu, Y. Wang, State Key Lab. of Tribology, Tsinghua University, Beijing, China

Cavitation in mechanical seal with grooves over one of its mating rings is numerically and experimentally investigated. The surface grooves induce a series of pressure fluctuation and cavitation occurs around the end of the groove’s windward edge as the local pressure drop. The hydrodynamic pressure effect is enhanced by the cavitation. Optimization of the surface grooves to obtain maximum hydrodynamic effect is performed basing on the CFD simulation. A test rig with friction torque and temperature sensors is used to validate the effect of the surface grooves. Additionally, a digital camera is adopted to observe the cavitation over the grooved mating ring. It is found that cavitation decreases the friction and heat substantially. Moreover, the cavitation can partially obstruct the water film between the mating rings and reduce the leakage of the mechanical seal.

4 - 4:30 pm
Parametric Study on Two-stage Tandem Dry Gas Seals with Closed Interspace
W. Huang, Tsinghua University, Beijing, China

Two-stage tandem spiral-grooved dry gas seals with closed interspace ports were numerically investigated based on Reynolds equation. The balance-state interspace pressure which
was automatically established was calculated by using the condition of mass flow continuity. The seal performance parameters such as leakage, film stiffness and balance clearance of the two stages were obtained in the balance state. The influence of inlet pressure, rotational speed and spiral groove parameters on the balance-state interspace pressure and the seal performance was studied. It was found that when the seal dam extent was larger than a critical value, the balance state of the two-stage dry gas seal could not establish, it means only one stage would work normally.

4:30 - 5 pm
Effect of Oil Volume to Seal Volume on Elastomer Performance
K. Cooper, A. Galiano-Roth, ExxonMobil Research and Engineering, Paulsboro, NJ
Performance considerations for industrial gear lubricants include the effect they have on elastomers used within the machinery. Compatibility between the lubricant and elastomer must be accounted for since the fluid comes in intimate contact with the mechanical seal faces. Interactions between the elastomer and lubricant are commonly evaluated by various static seal industry test methods that determine the change in elastomer properties. The ability of elastomers to retain their properties and provide adequate protection against fluid leakage is impacted by the design and composition of the seal, conditions of equipment operation and lubricant composition. This presentation will discuss the influence that oil volume has for 2 key elastomer characteristics; volume change and hardness change.

Session 4H | Palace 4/5

Practical Lubrication Applications

Session Chair: W. Needelman, Filtration Science Solutions, Huntington Bay, NY
Session Vice Chair: T. Schiff, ExxonMobil Lubricants & Specialties, Fairfax, VA

2 - 2:30 pm
Maintaining Equipment and Lubricants during Extended Shutdown
Y. Lev, J. Haspert, Castrol Industrial, Chicago, IL
For Practical Lubrication Solutions session at 2010 STLE Annual Meeting.
Due to the current economy, various facilities are going through extended shutdowns. The purpose of this paper is to remind maintenance and production personnel that even when their facilities are in shutdown mode, equipment and lubricants continue to deteriorate.
This paper provides very practical recommendations for equipment maintenance, storage and lubrication during extended shutdowns putting any manufacturing facility in a better position for returning to normal production. This paper will also review other challenging tasks a plant is asked to complete to prepare critical equipment for an extended shutdown. There are a number of steps that can be taken before the shutdown to help ensure equipment start-up is nearly without incident. Careful planning in the shutdown process utilizing the processes and recommendations noted above will certainly extend the life of critical plant equipment and facilitate a more successful restart.

2:30 - 3 pm
Multi-Level Used Oil Management
D. Smolenski, General Motors R&D, Warren, MI
In the late 1990’s, General Motors Worldwide Facilities Group (WFG) had a vision of recycling used industrial oils from the plants and returning the recycled oil products to the plants for cost savings and improved environmental performance. Concurrently, the GM LS2 Maintenance Lubricant Standards committee developed comprehensive physical and chemical property and performance requirements for the most commonly used plant lubricants, either virgin or recycled. The LS2 committee also developed a used oil management protocol that provides opportunities for better oil management at several levels, including, product selection, re-conditioning lubricants at the production machine, careful collection and segregation of used oil streams, and off-site reprocessing and re-refining. The presentation summarizes the successful implementation of this program, including significant volumes of on-site oil re-conditioning and the purchase of 50% recycled oil in GM US and Canadian operations. Substantial cost savings were realized - the program is sustainable.

3 - 3:30 pm - BREAK

3:30 - 4 pm
W. Needelman, G. LaVallee, Donaldson Company, Inc., Minneapolis, MN
Water is a harmful oil contaminant leading to: corrosion, additive drop-out, increased friction, metal fatigue, and microbial growth. Traditional methods for controlling water contamination are limited. Desiccant dryers have low water-holding capacity. Water absorbing filters, coalescers, and centrifuges remove only free water. Vacuum dehydrators are labor intensive and have high capital costs. This paper describes a novel and robust technology for both inhibiting water ingress and for effectively and economically removing water contamination from lubricating and hydraulic oils. Under all operating conditions, a blanket of -40 C dew point dry air is supplied that sweeps over the surface of oil in reservoirs. Ingression of humid air is prevented. All free and most dissolved water is rapidly removed from the oil. Part I of this series describes the operating principles of this water control technology, presents laboratory data, and quantifies rates of water removal. Part II presents two case studies.

4 - 4:30 pm
Dry Air Blankets: An Effective and Economical Method for Eradicating Water Contamination. Part II: Case Studies
G. LaVallee, W. Needelman, Donaldson Company, Inc., Minneapolis, MN
As discussed in Part I, a blanket of -40C dew point air sweeping over the surface of a reservoir is an effective and economical method for preventing humidity ingress and for water removal. Part II of this series presents two industrial case studies in which water contamination problems were solved by this technology. In one study, water contamination in a large recirculating lubrication system was controlled to under 200 ppm (30% saturation), in spite of major steam leak ingressions. Corrosion of metal parts was abolished, and rolling bearing life increased. The second case study is of a hydraulic press system operating in a humid environment. Water levels were successfully maintained to less than 100 ppm (5-10% saturation). Corrosion and stoppage-causing deposits due to water contamination were eliminated. The paper concludes with sizing and implementation guidelines for end-users.

4:30 - 5 pm
A New Method for the Determination of Volatile Organic Compounds in Metalworking Fluids, Vanishing Oils and Rust Inhibitors
J. Burke, B. Bittle, J. Howell, Houghton International, Valley Forge, PA, M. Pearce, W. S. Dodge Oil Company, Inc, Maywood, CA
Since the inception of the US EPA Clean Air Act of 1970, the scientific community has been struggling to create a definitive method to measure the volatile organic compounds (VOC) in semi-volatile compounds such as metalworking fluids, rust inhibitors and machine lubricants. In fact, there is debate on what is a VOC in these lubricant categories. One common method is EPA Method 24; however this method does not produce reliable results on low VOC containing compounds. EPA specifically states that Method 24 should only be applied to coating and printing type sources. Several member companies of the Independent Lubricant Manufacturers Association (ILMA) worked together to develop a reliable measurement method. A preferred method is the use of thermo gravimetric analysis (TGA) at a specific time and temperature criteria. This paper will summarize the progress on this activity, show results on
various lubricants and explain the rationale for selection of TGA.

5 - 5:30 pm

Wear Behaviour of PTFE Seals Under Different Pressure Conditions in a Gasoline Pumping and Measurement System

Y. Liu, J. Liu, Y. Chen, Advance Manufacture Engineering, Guangzhou, China

The main elements of the flowmeter in fuel dispensers are a piston with Polytetrafluoroethylene (PTFE) seals and a stainless steel liner. The work conditions of flow meter will affect the dispenser's stability and reliability. Wear of PTFE seals is a much more important factor in determining the life of flowmeter. This paper reports the effect of different pressure conditions in a gasoline pumping and measurement system on the wear response of PTFE seals. The pressure signals at the pump inlet, the pump outlet and the flowmeter outlet, after detected by pressure transducers and sampled by the data acquisition card, are transmitted to computer for analysis. It is shown that the Larger scale pressure variation causing the worse PTFE seals worn and the earlier the failure of sealing systems. Possible explanation for this phenomenon is pressure oscillations obstacle the formation of uniform transfer film, and then Affect the frictional properties of PTFE seals, which reduces the life of meter finally.

5:30 pm – Practical Lubrication Business Meeting

Session 4I

Engine and Drivetrain II/Wear II - Joint Session

3:30 - 4 pm

Handling the Impact of Biodiesel Fuel on Lubricants

M. Egiziao, P. Fasano, D. Chasan, Ciba part of BASF, Tarrytown, NY

Biodiesel or FAMEs (fatty acid methyl esters) from renewable sources are of increasing interest for use in mixtures with petroleum-based diesel fuel. Biodiesel fuel blends generally will not negatively affect the mechanical workings of an engine. However, high molecular weight biodiesel-containing fuel can accumulate within the lubricant as a result of engine blow-by. The functionality of the lubricant can therefore be compromised. Potential problems were observed in laboratory testing of a commercial diesel oil contaminated with 1-6% of various FAMES. The negative impact of soy, rapeseed, palm and coconut methyl esters on the lubricant were compared in oxidation, deposit control, and copper/lead corrosion bench tests. Four synergistic antioxidant mixtures were evaluated for their ability to control the oxidation problems induced by each of the FAMES. A blend of metal deactivators was also developed to handle the copper/lead corrosion issues.

4 - 4:30 pm

Eco-marathon Vehicle Engine and Drivetrain Efficiency Improvements

M. Siniawski, Loyola Marymount University, Los Angeles, CA

Loyola Marymount University students have participated in the 2008 and 2009 Shell Eco-marathon Competitions. In 2008, the vehicle placed 15 out of 29 schools in the prototype combustion class, with an overall fuel efficiency of 313.4 mpg. In 2009, two vehicles were entered and placed 9 and 15 out of 43 schools, with fuel efficiencies of 858.4 and 531.1 mpg, respectively. This talk will present some of the drivetrain and engine efficiency improvement efforts that occurred within the vehicles as a result of improved tribological design. In particular, drivetrain component superfinishing and engine component coatings will be discussed.

4:30 - 5 pm

Correlation of Tribology and Tribochrome Between Fired Operating Engine and a Benchtop Tribometer Tests

P. Lee, University of Leeds, Leeds, United Kingdom

Bench top tribometers are regularly used to screen lubricants and help understand the tribology and tribochrome processes in an engine. However, recent work by the authors (Lee and Morina) presented at the STLE 2009 Annual Meeting showed that the tribofilms formed on a cylinder liner in a simulated bench top tribometer have significant differences to those formed in an operating engine. The current study aims to evaluate the tribology and tribochrome performance of a range of oils in fired engine tests and to evaluate the ability of designed bench tribometer to simulate this performance in laboratory conditions. This study focuses on understanding the key factors that determine the tribology and chemistry of
surfaces produced from an engine test and from a TE-77 reciprocating bench tribometer using oils with conventional additives. The tribological contact of interest is the ring/liner contact and TE-77 is a common tribometer used for investigating tribological performance of a ring/liner system. Liner and ring samples were produced from engine tests as well as from TE-77 tests using same oils. TE-77 tests were also run using aged oils collected following the engine test. Tribofilms formed on all surfaces were chemically characterized using the Fourier Transform Infrared Spectroscopy (FTIR) and Secondary Ion Mass Spectroscopy (SIMS) while the wear was evaluated using 3D TalySurf. In this paper, results obtained from the engine and bench tribometer tests are discussed in detail with the aim of demonstrating the extent to which the TE-77 bench tribometer can simulate the tribology performance and tribochemical reactions that occur in engine ring/liner contact.

5 - 5:30 pm
Contribution of the Engine Oil to Heavy Duty Vehicle Fuel Economy
D. Green, Shell Global Solutions (UK), Chester, United Kingdom
With the increasing number of vehicles on our roads the demand for energy is growing rapidly, and with this the associated rise in emissions. It is also clear that as easily accessible supplies of oil will no longer keep up with demand after approximately 2015, then intelligent options for using energy more efficiently will be required. Through the careful use of optimised lubricants it is possible to significantly reduce vehicle fuel consumption by an average of 2%, as shown by recent fuel economy field trials. But to develop such optimised lubricants, a highly detailed understanding of engine operation is required. Through a detailed study of engine design with a focus on the lubricant related components, an assessment is provided of the most important areas within an engine and operating conditions where fuel economy gains can be made.

In order to provide an in-depth understanding of some key areas within the engine, tribological tests have been developed to investigate lubricant effects in typical heavy duty diesel engine valvetrain contacts and journal bearings. These tests are developed to be run on standard laboratory equipment to demonstrate a simplified but realistic mimic of an engine contact, and have been developed to correlate to the trends seen in engine fuel economy tests.

Further insight to the detailed effects of lubricant composition on fuel economy is also being assessed using engine friction and temperature measurements. When combined this information provides the ability to demonstrate how such lubricants provide the fuel consumption benefits.

### Session Chair: TBD

#### Session 4J

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#### 2 - 3 pm
Afton Chemical’s 8th Annual Key Driver Seminar - Uncertain Energy and Climate Policy: What is a Lube Marketer to Do?
O. Kean, American Chemistry Council, Arlington, VA; P. Rohrer, Afton Chemical, Richmond, VA

Lubricants play a crucial role in many aspects of our everyday lives, contributing to industrial efficiency and effectiveness, helping industry address our current energy and climate challenges. While there remains uncertainty around what energy and climate policy will survive the current legislative process, there are common themes and drivers to consider in your marketing plans. Come hear a Washington insider’s perspective on how developing energy and climate policies are creating opportunities for lubricants in your marketplace. We will consider how you can take advantage of these drivers to grow your lubricants business while helping industry respond to these challenges.

#### 3:30 - 4 pm
Market Demands New Approach to Rust Preventive Fluids
J. Ineman, Metalworking Additives, The Lubrizol Corporation

At the end of the day, manufacturers who work with metals want one thing from rust preventive (RP) technologies: the assurance that their metal products will arrive at their destinations free of rust or stain. Environmental concerns and competitive pressures have complicated that challenge for blenders and formulators in recent years with additional, more complex requirements. Today’s RPs are frequently expected to:

- Be compliant with the divergent standards and availability requirements of a global market
- Be compatible with a wide range of metal substrates
- Eliminate workplace and disposal hazards associated with heavy metal exposure
- Reduce the processing time associated with cleaning protective films
- Deliver competitive advantage by providing exceptional resistance to salt spray and other corrosive challenges
- Remain stable at cold temperatures without crystallizing or separating

This presentation will explore these challenges and the next generation RP technologies designed to meet them.

#### 4:30 pm
The Use of Optimal Alkanolamine Blends and Additives for Improved Metalworking Fluid Stability
M. Gernon, K. Buyse, C. Dowling, Taminco

Structurally optimized alkanolamines and alkanolamine derivatives are known to provide significant supplementary biostability, colloid stability and corrosion inhibiting benefits to metalworking fluids, but the exclusive use of certain pure alkanolamines can sometimes be prohibitively expensive. More economically feasible formulations may be obtained by using only the requisite amount of a “specialty” alkanolamine and/or alkanolamine derivative along with a greater amount of a cheaper bulk neutralizing amine. This talk will describe logical approaches to the development of optimal alkanolamine and/or alkanolamine based additive blends based on obtaining the maximum performance for minimum cost. The specific utility of amine blends based on Taminco’s SynergeX® alkanolamines will be described in detail along with some methods for producing effective emulsion stabilizing and corrosion inhibiting derivatives from SynergeX® alkanolamines. A consideration of the potential impact of emerging VOC (volatile organic content) regulations on the use of alkanolamines in metalworking formulations will be included

#### 4:30 - 5 pm
A Review of Croda Lubricant Additive Products
S. Davis, Croda Lubricant Additives, Chicago, IL

Croda Lubricant Additives is a global supplier of a broad range of products designed for use in industrial and automotive lubricants including esters and surfactants. In a continuing effort to help customers meet formulation challenges, Croda has developed new products including: high activity, oil soluble Perfad™ corrosion inhibitors; a new Priolube™ water soluble ester for metal forming; and a new polymeric friction modifier -- Perfad™3000. This presentation will review the range of Croda Lubricant Additive products.
Certain vegetable oils offer performance advantages in industrial hydraulic and gear lubrication, including natural friction reducing and film-forming properties, fire resistance, low volatility & high viscosity index. In addition, in a time of increased environmental awareness and uncertainties about the long-term future of petroleum, the prospects of low toxicity, biodegradability and renewability are worthy of serious consideration. A formidable limitation of most vegetable oils, however, is their vulnerability to oxidative and thermal degradation, especially at elevated temperatures. Supplementary additives may further enhance oxidative stability, but rational additive choices must not compromise the good environmental credentials of the vegetable medium. Any performance additives bearing even a hint of aquatic toxicity, skin sensitization, bio-accumulation, or other serious ecological problems would cancel out the positive environmental attributes of the medium. Laboratory traction and frictional comparisons help to illustrate important rheological properties of certain vegetable-based media versus mineral and synthetic oils. Also, some additive formulating approaches are suggested for maximizing oxidative stability without sacrificing environmental friendliness.

The relative importance of the hydromechanical and volumetric losses will impact the overall efficiency of a hydraulic pump. Efficiency measurements were conducted in a vane pump at 150 and 250 bars. Several fluids having different viscosity indices and shear stabilities were tested to determine the effect of fluid viscometrics on efficiency. Results obtained on all test fluids showed that hydromechanical losses increased with pressure and fluid viscosity. At a given pump inlet temperature, the maximum difference in hydromechanical loss between the test fluids is 0.28 kW. The volumetric losses are highly dependent on the fluid, especially at high temperature. Hydromechanical losses range up to 1 kW over the range of conditions investigated compared to volumetric losses of up to 7 kW. Use of a high VI shear stable fluid can reduce the volumetric losses by up to 2 kW while contributing to no significant increase in hydromechanical losses.

Energy efficiency has become a driver for many industries due to increasing interest in reducing carbon footprints and obtaining associated benefits. Since hydraulic systems are widely used for transmitting power, much attention has focused on increasing hydraulic pump efficiency. The energy efficiency of these pumps is dependent on the type of pump, operating conditions, and the hydraulic fluid used. Testing has been carried out using a vane pump operating in a tightly controlled environment under a range of speeds, temperatures, and pressures. Three different viscosity grade fluids (ISO 32, 46 & 68) have been used in this study. Volumetric, mechanical, and total efficiencies were measured for each of the fluids under the varying operating conditions. Initial results demonstrate the expected improvement in volumetric efficiency resulting from use of a higher viscosity grade fluid. Mechanical efficiency differences between the fluids are less dramatic. These efficiency benefits vary significantly with operating conditions.

Comparison of Zinc-containing and Zinc-free Hydraulic Packages Using Severe Laboratory Performance Tests
T. Rossrucker, T. Ruehle, S. Sandhoefner, Rhein Chemie Rheinau GmbH, Mannheim, Germany

Air compressors are used in general manufacturing, power generation, mining operation, paper manufacturing, cement manufacturing, fertilizer plants, chemical plants, oil refineries and oil production. These air compressors have discharge pressure that can range from 20 psig (pounds per square inch) to 5,000 psig in moving components/products in general manufacturing to compressed air in oil production. While proving to be a valuable tool there is also potential for risk. This presentation discusses the mechanism of fires, explosions, and detonation in compressed air systems, and answers the questions of why a maintenance program is important, and why choosing synthetic lubricants may reduce risk.

Impact of Hydromechanical Losses on Hydraulic Pump Efficiency as a Function of Pressure, Temperature and Fluid Viscometrics
D. Deneen, S. Herzog, Evonik RohMax, Horsham, PA, M. Alibert, Evonik RohMax, Darmstadt, Germany, C. Neveu, Evonik RohMax, Paris, France

Hydraulic Pump Efficiency
R. Davidson, S. Higuchi, Alton Chemical Corp., Richmond, VA

Comparison of Zinc-containing and Zinc-free Hydraulic Packages Using Severe Laboratory Performance Tests
T. Rossrucker, T. Ruehle, S. Sandhoefner, Rhein Chemie Rheinau GmbH, Mannheim, Germany

Ever increasing demands on productivity, performance, worker's safety, as well as realization of total cost management lead to new and higher requirements placed on industrial lubricants. Higher machining speeds and new processes may cause much more thermal stress to the whole lubricating system. The paper will focus on comparison of traditional and modern hydraulic additive technology, considering highly refined base oils, synthesis and chemistry of major additive components, compatibility of additive systems as well as widely used specification requirements.
New Oil Soluble Synthetic Polyalkylene Glycols

Conventional polyalkylene glycols (PAG) that are derived from the polymerization of ethylene oxide and/or propylene oxide provide many technical benefits such as excellent friction control, good low temperature properties, high viscosity indices and excellent deposit control. One limitation is their poor miscibility in hydrocarbon oils. A new range of oil soluble PAGs has been developed using higher alkoxides that provide superior miscibility in hydrocarbon base stocks while retaining many of the traditional benefits of PAGs. The new base oils offer formulators an alternative option to upgrade hydrocarbon oils by using them as co-base oils in compositions. Examples of their structure property relationships will be discussed and also aspects of how this technology may enable application expansion of PAGs in the future.

Session Chair: J. Guevermont, Alton Chemical Corp, Richmond, VA

8 - 8:30 am
Lubricant Oxidation and Antwear Performance in the Sequence IIIG Engine Test
R. Herrera, B. Papke, C. Chin, P. Parthasarathy, Shell Global Solutions (US) Inc, Houston, TX

Lubricant oxidation in crankcase applications is a significant concern as affecting the lubricant performance properties. To better understand and characterize lubricant performance as a function of automotive crankcase aging, the chemical, physical and performance properties of ASTM reference oils aged in the Sequence IIIG engine were evaluated by a variety of analytical and performance methods.

8:30 - 9 am
Noack Volatility Study of Base Oil by TGA
H. Shen, Bel-Ray Company, Inc., Farmingdale, NJ

Noack volatility has significant effects on the volatility of finished lubricating oils. Study of volatility of base oils will provide assistant on formulation of finished lubricating oils. Traditionally, Noack volatility test as standarized in ASTM D5800 is widely used to determine volatility of lubricating oils. Thermogravimetric analyzer (TGA) is also recommended to measure evaporation loss of lubricating oils as standarize in ASTM D6375. This study analyzed Noack volatility on more than 30 commercial base oils by TGA method. The results from TGA method matched very well with the literature reported data by the Noack method. Those samples belong to API groups I, II, III, IV (Polyalphachlefins) and V (all others).

9 - 9:30 am
Anti-wear and Extreme Pressure Properties of High Sulfur Greases
P. Aswath, A. Suresh, University of Texas at Arlington, Arlington, TX

Greases contain various different additives that can interact synergistically to provide improved wear and load bearing capacity. In this study a mixture of three compounds, a thio phosphate, a fluoro polymer and several different sulfur compounds were blended into lithium based greases. A statistical design of experiments approach was used to determine the interaction of these three components on the wear behavior using a ASTM D2266 standard test. The load bearing capacity of these greases were evaluated using ASTM D2596. Response surface plots, cube plots and design equations were developed to determine the one, two and three factor interaction of these components on the wear and weld behavior of the grease.

9:30 - 10 am
Determination of Interfacial Temperatures Under Extreme Pressure Conditions
T. Blunt, P. Kotvis, Benz Oil, Milwaukee, WI, W. Tysoe, University of Wisconsin-Milwaukee, Milwaukee, WI

Interfacial temperatures attained in a pin and v-block apparatus under extreme pressure (EP) conditions were measured using pins made from either copper or an aluminum alloy from the asymptotes in the curve of removal rate versus applied load since these have been shown to correspond to the temperatures at which the interfacial materials melts.

10 - 10:30 am - BREAK

10:30 - 11 am
Effect of Roughness Orientation on the EHL Film Thickness
D. Zhu, Tsinghua University, Beijing, China, N. Ren, Q. Wang, Northwestern University, Evanston, IL

Effect of roughness orientation has been an important topic for long. However, it has never been systematically studied for various contact types in a wide range of operating conditions, especially in the mixed EHL at low λ ratios. Widely recognized Paiir and Cheng’s study (1978) demonstrated some basic trends for line contacts. However, it was based on a simplified stochastic model for line contacts only. The trends may be different for circular or elliptical contacts due to significant lateral flows. In the present study, a recently developed deterministic model is used for different types of contact geometry. The speed range for analyzed cases covers 11 orders of magnitude so that the entire transition from full film and mixed EHL all the way down to dry contact (corresponding λ ratios are from 3.3 down to 0.001 or so) is simulated. Three types of machined surface are employed, representing isotropic, transverse and longitudinal roughness, respectively. Obtained results show that in line contacts the transverse roughness yields thicker EHL film than the isotropic and longitudinal. This qualitatively agrees with Paiir and Cheng. However, in circular or elliptical contacts with the ellipticity smaller than one, the longitudinal becomes more favorable. Overall, the orientation effect is significant in the mixed EHL regime where the λ ratio is around 0.05-1.0. It is insignificant for the full film EHL (λ>1.5 or so) due to the EHL film much greater than the roughness. It is also insignificant for the boundary lubrication/dry contact (λ<0.05) due to vanishing hydrodynamics.

11 - 11:30 am
Experimental Study of Real Roughness Attenuation in Concentrated Contacts
P. Sperka, M. Hartl, I. Krupka, Brno University of Technology, Brno, Czech Republic

This study is focused on the experimental validation of an approach based on Fourier decomposition of the surface roughness into sinusoidal components. Two optical measurement techniques - phase shifting interferometry and thin film colorimetric interferometry are combined to provide undeformed surface topography and film thickness data within elastohydrodynamic contact formed between a smooth disk and a ball having real rough surface. Results obtained under pure rolling conditions showed not only the qualitative agreement with the general principle described in the previous studies as to differences in the attenuation of short and long wavelength components but also the quantitative correlation was found between measured data and numerically predicted attenuation curve. In this way amplitude reduction approach represents the promising tool for the prediction of lubricated contacts behaviour between highly loaded machine components.

11:30 - Noon
Effect of Surface Roughness on Thermal Elastohydrodynamic Lubrication of Infinite Line Contacts Using Average Flow Model
A complete solution of a thermal elastohydrodynamic lubrication (EHL) of rolling/sliding rough surfaces is obtained. The modified average Reynolds equation, elasticity equation and energy equations are solved simultaneously using Newton-Raphson technique. The dimensionless pressure, film thickness, mean film temperature and surface temperature distributions are obtained for various values of surface roughness parameters. The results are compared with that of isothermal rough EHL and thermal smooth EHL. The effect of hydrodynamic roughness parameter, surface pattern parameter and slide/roll ratio on the maximum mean-film temperature rise, maximum surface temperature rise, dimensionless minimum film thickness, dimensionless maximum pressure, dimensionless mass flow rate, dimensionless contact load and hydrodynamic load have been investigated. The inclusion of roughness significantly influences the bearing characteristic for thermal EHL problem.

8:30 - 9 am
Measurement of Residual Stress in Si-doped Amorphous Carbon Films
J. Schall, R. Petrach, Oakland University, Rochester, MI; J. Harrison, United States Naval Academy, Annapolis, MD
The addition of silicon dopants to amorphous carbon films (a-C) has been shown to decrease friction and provide enhanced wear resistance. (He et al., J. Vac. Sci. Technol. A, 18 (2000) 2143.) Furthermore, Si-doping has been shown to reduce residual stress in a-C which leads to better film-substrate adhesion. Using molecular dynamics simulation and a newly developed interatomic potential for C, Si, and H interactions, we have characterized the structure and mechanical properties of Si-doped a-C and hydrogenated a-C. We find that the addition of Si increases the sp3 character of the films and has little effect on the bulk modulus of the films. The increase in sp3-content is apparent to be more pronounced in H-free films. We will also present results on the measurement of residual stress of Si-doped a-C and a-C:H films deposited on Si substrates.

9 - 9:30 am
Tribological Behavior and Tricochemistry of Non Hydrogenated Amorphous Carbon Coatings Under Boundary Lubrication Conditions
C. Matta, O. Eryilmaz, A. Erdemir, Argonne National Laboratory, Argonne, IL; B. Vacher, J. Martin, Ecole Centrale de Lyon Laboratory of Tribology and System Dynamics, Ecully, France
There already exist a notable amount of studies on reactivity between the diamond-like carbon (DLC) coatings and various additives. On the other hand, chemical and physical effects of base oils and some isolated functional groups were investigated very scarcely. However, polar molecules are known to affect friction and wear in steel contacts via the adsorption on steel surfaces, which represents one of it's fundamental boundary lubrication mechanisms. Accordingly, it is relevant to investigate if such molecules have similar effect on DLC coatings. In our study the effect of alcohol adsorption on DLC was studied under "static" conditions with AFM as an analytical technique. Hexadecanol in various concentrations (0 wt. % - 0.63 wt. %) was allowed to adsorb on the DLC surface and the amount of surface coverage and number of adsorbed islands of alcohol molecules were analysed using contact mode AFM analyses. The results show that the molecules adsorbed on DLC coatings and steel under room temperature, as well as at elevated temperature. Tribological experiments were performed to compare with the AFM study, and they support and effect through adsorption of polar groups on steel and DLC surfaces.

9:30 - 10 am
The Stribeck Response of 4 Different DLC Coatings
T. Haque, M. Webster, D. Yablon, L. Fan, A. Tsou, ExxonMobil Research and Engineering Company, Annandale, NJ
In recent years the use of Diamond-like Carbon (DLC) coatings applied to engine and machine components has emerged due to the combined friction and wear benefits they can offer. Components such as cams, gears bearings etc typically operate over a wide range of lubrication conditions. However published literature covering DLC lubrication has often been restricted to a relatively narrow set of conditions and little has been published covering the friction and wear response over multiple lubrication regimes. We have performed a systematic study to generate Stribeck curves (friction coefficient vs. contact severity) using a wide range of lubricant components on four characteristically different DLC coatings. Our initial test results obtained from the Mini Traction Machine (MTM) showed that unlike conventional ferrous surfaces, hydrogenated (a-C:H) and non-hydrogenated (a-C) DLC coatings exhibit a reduction in friction as the lubrication regime shifted from mixed to boundary conditions. However, this result is not repeated for non-hydrogenated tetrahedral amorphous carbon (ta-C) and tungsten doped hydrogenated DLC coatings. Surface analysis has revealed that lubricant/DLC surface interactions may have a strong influence on the Stribeck response of DLC coatings. The results highlight the different friction and wear results that can be obtained between various DLC types and lubricant components.

10 - 10:30 am - BREAK

10:30 - 11 am
Study of Tungsten Carbide Coating Remelt Using CO2 Laser: Coating Expansion and Crack Generation
S. Saenz de Santa Maria, M. Hadfield, Z. Khan, Bournemouth University, Bournemouth, United Kingdom; R. Gonzalez, R. Vijande, Universidad de Oviedo, Gijon, Spain
While remelting tungsten carbide coatings, cracks have appeared along the laser welds. These cracks affect considerably the rolling contact fatigue (RCF) durability of the material. This paper explains the crack generation mechanism as well as the consequences in terms of RCF. Three WC coatings are analyzed: WC - 12% Co; WC - 10% Co - 4% Cr; WC-27% [80% Co 20 % Cr] All of them are 300 micrometer thick and are sprayed using high velocity oxifuel flame. The substrate material is low allow steel. Using X ray diffraction (XRD) techniques, stress values in the coating are given. Scanning electron microscopy (SEM) results show where the weak spots within the laser weld are, becoming crack origins.

11 - 11:30 am
Surface Properties of Si Micro-molds Modified by DLC Coatings Deposited with DC Magnetron Sputtering
E. Liu, S. Biswajit, S. Tor, Nanyang Technological University, Singapore; Singapore; D. Hardt, J. Chun, Massachusetts Institute of Technology, Cambridge, MA
This work studied the effect of nitrogen (N) doping on the structural, mechanical and tribological properties of N and silicon (Si) doped DLC coatings and evaluated the performance of the DLC coated Si micro-molds in a hot-embossing replication process with reference to the uncoated Si molds. The N and Si doped DLC coatings were deposited on Si micro-molds by DC magnetron sputtering. The surface Roughness, contact angle, critical load, friction coefficient and wear rate were determined by means of various analytical techniques such as atomic
force microscopy (AFM), contact angle measurement, scratch test and ball-on-disc tribological test. Ethylene glycol and deionized water were used to measure their contact angles with the sample surfaces, which were used to evaluate the surface energies of the samples. The total surface energy of the coated Si micro-molds increased with increase in N2 flow rate from about 38.2 to 66.5 dyne/cm. The COF of the DLC coated samples decreased with increased N2 flow rate. A better replication quality along with a longer lifetime was observed from the DLC coated micro-molds.

11:30 - Noon
A Study on In-flight Characteristics of Inconel 718 Particles During HVOF Thermal Spraying Process
S. Komandur Sudarshan, K. Ramak, R. Chinnakuru Suryanarayana, T. M Nadaf, PES Institute of Technology, Bangalore, India
The quality of coating in HVOF spray process is directly related to the particle parameters such as velocity, temperature and state of melting or solidification. Hence, the prediction of the particle motion within the thermal spray gun is of paramount importance to optimise the design of the spray gun leading to high quality coatings. In this regard, there is a tremendous interest in exploiting the commercially available CFD based software in optimizing the gun design. However, meager information is available on the CFD analysis of the spray gun. Most of the particle models are based on the gas fuelled HVOF systems, while the technology trend is moving towards high throughput liquid fuelled systems which have the advantage of using low cost fuel such as kerosene instead of propylene. The existing simulations on liquid fuelled HVOF guns are very limited. The earlier model from the literature survey do adopt only 2-dimensional one, which is not a realistic representation of the 3D spray gun. In the light of the above, this paper reports on 3-D CFD analysis of liquid fuelled HVOF gun system. Modeling of the spray gun system has been carried out using Catia V5R18 software. Meshing of the constructed model has been done using Hyper mesh 8.3 software. The in-flight particle motion of Inconel 718 and the heat transfer within the gas flow field for various spray parameters are being studied using Fluent 6.3 software.

8:45 - 9:30 am
Challenges and Opportunities in Nanotribology
S. Hsu, George Washington University, Washington, DC
Nanotechnology is the science and engineering practices of the ability to see, measure, manipulate, and organize matters at nanoscale. As Nanotechnology receives enhanced support around the world, innovations in instrumentation, testing methods, positioning devices create a suite of new tools, enabling the creation of new materials, devices, smart materials, integrated multi-functional systems through self-assembly or physical manipulations. Nanotribology focuses on controlling the frictional forces at nanoscale in devices and the lubrication of nanomaterials. As novel nanomaterials are being created at an increasingly rapid rate, introducing these materials into applications requires corresponding development of nanotribology theory and practices. This talk will examine the role of friction in devices and methods used so far to achieve “lubrication” to control friction. The nanomechanical properties of nanomaterials are receiving increasing attention as the nanomaterials are growing rapidly worldwide in various applications: thin films, nanocomposites, ultra-hydrophobic surfaces, self-sterilization surfaces and treatments, nanoparticle sprayed coatings, etc. Manipulation of nanoparticles to create functional entities requires the control of frictional resistance without chemically contaminating the particles, which poses a serious challenge. Health and safety issues surrounding the nanoparticles are also a major concern.

9:30 - 10 am
New Inorganic Fulleranes Nanoparticles (MoxW1-xS2): Understanding of Tribocompositional Mechanisms Under Boundary Lubrication
J. Tannous, F. Dassenoy, M. Belin, B. Vacher, Ecole Centrale de Lyon, Ecully, France, A. Bruhacs, W. Tremel, Johannes Gutenberg-University, Mainz, Germany
Recently, it has been established that MoxW1-xS2 nanoparticles (IF) mixed in oil, appear to improve the tribological properties under boundary lubrication [1]. These IF particles were synthesized by MoCVD in a customized reactor described by Tremel et al. [2]. They are significantly smaller than IF nanoparticles studied previously in the literature. Their morphology is of spherical IF-type with concentric nested layers showing considerable amounts of point defects and grain boundary, hereby proving their poorly crystalline character. Their tribological performances seem to be related, not only to the particles size but also to the crystalline character and the presence of defects in the particles, which facilitate the exfoliation of layers under external pressure. To clarify these proposed hypothesis, TEM on a transverse section of the tribofilm made by focused ion beam (FIB), X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy were used to characterize the nanoparticles and the tribofilms obtained after friction. In situ video tribology was used to study the effect of the agglomeration of the nanoparticles on their lubricating properties.
Development of a Testing Rig for Erosion with Nanofluids
G. Molina, M. Rahman, Georgia Southern University, Statesboro, GA
Nanofluids are fluids containing engineered colloidal suspensions of nanoparticles (nanometer-sized particles of metals, oxides, carbides, nitriles, or carbon nanotubes) in a base fluid. Common base fluids include water and organic liquids. Nanofluids exhibit enhanced thermal properties, particularly higher thermal conductivity and heat transfer coefficients as compared to those of the base fluid. Simulations of nanofluids dynamics predict large enhancement in transport properties, especially in thermal ones. The work is presented of building, setting up and testing of an erosion-test instrument for nanofluids. This instrument will allow control of the parameters for a fluid jet which will impact a material target for accelerated testing of typical cooling-system materials in a laboratory environment. Reviews are presented of existing literature on erosion testing of nanofluids, and of the authors’ preliminary simulations of nanoparticles transport in laminar free convection in square enclosure.

11:30 - Noon
Nanotribological Characterization of Hydrocarbon-Lubricated Single Asperity Contacts
J. Bares, R. Carpick, University of Pennsylvania, Philadelphia, PA, T. Haque, M. Webster, D. Yablon, ExxonMobil Research and Engineering, Annandale, NJ
Engine oil formulations are designed to modify friction, wear resistance, and corrosion of ferrous materials under boundary lubrication conditions. Traditionally the tribological properties of oil lubricated contacts have been studied under macroscopic sliding conditions. Understanding the relationship between macro- and nanoscale tribological properties requires these measurements to be performed in similar environments. In the present study, lateral force microscopy (LFM) was utilized to measure nanoscale friction properties of a model surface in the presence of synthetic basestock, poly alpha olefin (PAO). A first step toward enabling quantitative nanoscale studies requires ascertaining the effect that the surrounding hydrocarbon medium has on the nanoscale single asperity friction measurements. A LFM tip sliding on smooth and rough model substrates was used, and friction was measured for both dry and lubricated sliding contacts. The effect of viscosity was explored by conducting experiments in a range of viscosity grades of PAO, and by varying the velocity of sliding. We will discuss how the results compared with models of lubricated asperity sliding.

Handheld Lubricant Condition Monitor for At-Site Analysis
A. Toms, Gastops, Inc., Pensacola, FL
A handheld infrared instrument providing at-site in-service lubricant condition monitoring will be described and demonstrated. It protects machinery by determining when a lubricant needs to be changed due to excessive contamination, degradation or fluid mix-up. It detects lubricant degradation and contamination by other fluids (water, glycol, incorrect lubricant) at the point of use by measuring key oil condition parameters in both synthetic and petroleum based lubricants. Parameters such as soot, water, glycol, TAN and TBN and additive depletion are reported in physical measuring units when reference is made to unused (new) lubricant. It uses a unique flip-top sampling cell that requires only a drop or two of sample fluid and which can be wiped clean without rinse solvents. At the core of the instrument is a patented, mid-infrared spectrometer with no moving parts which will also be demonstrated.

11:30 - Noon - Hands-on Demonstration of Equipment and Applications

Fluid Film Bearings III
I. Santos, Technical University of Denmark, Lyngby, Denmark

Session Chair: I. Santos, Technical University of Denmark, Lyngby, Denmark

8 - 8:30 am
On the Determination of Fluid-film Bearing Rotordynamic Coefficients Using Multi-frequency, Pseudorandom Excitation Signals
M. Conlon, A. Dadouche, W. Dmochowski, National Research Council Canada, Ottawa, ON, Canada
A common approach to bearing rotordynamic coefficient determination involves single- or multi-frequency excitation, and further analysis in the frequency domain, under the assumption that the bearing behaves as a mass-spring-damper system. If the noise affecting each signal is random, uncorrelated, and has a mean value of zero, its influence can be eliminated by judicious application of the power spectral density, that is, the Fourier transform of the auto-covariance functions and cross-covariance functions for a finite sampling time. Measurement uncertainties associated with the rotordynamic coefficients themselves can be assessed using the method of propagation of error. Although this frequency domain analysis (and, in particular, excitation with a multi-frequency, pseudorandom signal) greatly hastens rotordynamic coefficient determination, it can also mask some of the physics. This paper highlights some of the pitfalls inherent in this experimental method.

8:30 - 9 am
A Novel Bearing Design Reduces Performance Variability Providing Increased Stability in High-Speed Turbomachinery
K. Bischof, J. Zhou, Waukesha Bearings Corporation, Pewaukee, WI
A new oil-lubricated tilting pad journal bearing (patent-pending) designed to reduce bearing dynamic performance variability, providing increased machine stability, is introduced in this article. This design offers a solution with reduced pad flutter, particularly in unloaded pads and less vibration, fatigue and wear. The design achieves high pivot stiffness without sacrificing the benefits associated with freely tilting journal pads. Overall, reducing machine variability translates into improved quality, higher productivity, and lower costs. Experiments and applications have been conducted at loads up to 450 psi and speeds up to 100,000 rpm, respectively.

9 - 9:30 am
A Comparative Linear and Nonlinear Dynamic Analysis of Compliant Journal Bearings
M. Cha, E. Kuznetsov, S. Glavatskih, Lulea University of Technology, Lulea, Sweden
In this paper we analyse linear and nonlinear dynamic behaviour of a compliant journal bearing. Such a bearing has a soft elastic liner. We consider the effect of different liner thicknesses on the dynamics. The linear dynamic analysis is based on the approach presented in [1]. A commercial software package is used to model nonlinear bearing dynamics. Obtained results are presented and discussed. Time and engineering efficiency of commercial software package for bearing dynamics is also discussed.


9:30 - 10 am
Temperature Influence on the Equivalent Coefficients Estimation for Journal Bearings
G. Daniel, D. Alves, K. Cavalca, Unicamp - University of Campinas, Campinas, Brazil, R. Cruz, ThyssenKrupp Metralúrgica Campo Limpo Ltda, Campo Limpo Paulista, Brazil
This work aims to analyze the influence of the temperature on the equivalent coefficients estimation for journal bearings. To verify this influence, a comparison between the equivalent coefficients obtained by isothermal method and thermal method is accomplished. In the isothermal method, the Reynolds’ equation is resolved considering a constant temperature distribution in the journal bearing, consequently considering a constant viscosity for the oil film. Otherwise, in the thermal model, the Reynolds’ equation is solved simultaneously with the energy equation. In this case, the pressure distribution obtained by the solution of the Reynolds’ equation depends on the temperature distribution in the oil film, which is evaluated by the energy equation. From the pressure distribution, it is possible to evaluate the supporting forces at the bearings and, consequently, the equivalent coefficients for fluid film. In this work, the equivalent coefficients are obtained with a spring-damper concept, in order to represent the inherent flexibility and damping of the lubricant. Hence, they are evaluated by the perturbation theory applied to the displacements and velocities of the shaft center inside the bearing. The results show the equivalent coefficients obtained by both methods (isothermal and thermal) and the sensitivity of these coefficients in the frequency domain of the rotor-bearing system.

10 - 10:30 am - BREAK

10:30 - 11 am
Dynamic Characteristics of Compliant Journal Bearings Considering Thermal Effects
E. Kuznetsov, S. Glavatskih, Lulea University of Technology, Lulea, Sweden
Hydrodynamic white metal bearings are widely used in various types of rotating machinery. Some improvements in bearing tribological performance can be obtained by substituting white metal by a compliant composite material. The effect of such compliant layer on bearing steady state performance has been presented in [1]. An isothermal analysis shows that compliant bearings can improve stability of a rotor bearing system with a rigid rotor [2]. In this paper we perform a comparative analysis of the dynamic performance of white metal and compliant bearings considering thermal effects and thermal expansion of bearing and shaft. The Reynolds equation with three dimensional viscosity field, three dimensional energy and heat transfer equations are solved. Compliant layer deformation model is based on the plain strain hypothesis. Stability analysis is carried out using Lund’s approach extended to compliant layer bearings. Results of the analysis are presented and discussed.

11 - 11:30 am
Inertia and Cavitation Effects on the Dynamic Coefficients of a Self-Circulating Porous Bearing With an External Reservoir
A. Balasoiu, S. Moldovan, M. Braun, University of Akron, Akron, OH
The hydrodynamics and thermal characteristics of a self-circulating, self lubricated porous bearing which has an external reservoir wrapped around it has been previously presented by these authors. This paper will present calculations regarding the dynamic coefficients using two models: (i)the first involves the Reynolds equation and (ii) using the full Navier-Stokes. The computational fluid dynamics software CFD-ACE+ was used to implement a numerical perturbation technique for the calculation of the dynamic coefficients. This method moves the shaft physically around its equilibrium position to calculate the dynamics coefficients by numerically differentiating the bearing forces with respect to small finite displacements and velocities. In contrast a closed form mathematical perturbation solution is used in conjunction with the Reynolds equation to determine the same dynamic coefficients. By comparing the results of these two methods one can isolate the effects of the inertia forces on the magnitude of the dynamic coefficients. Both computational methodologies implement cavitation models, to take into account the cavitation effects as well.

11:30 - Noon
Stopping Criterion in Iterative Solution Methods for Fluid-Film Lubrication Analysis
N. Wang, S. Chang, Chang Gung University, Tao-Yuan, Taiwan, H. Huang, Industrial Technology Research Institute, Tai-Chung, Taiwan
Iterative solution methods are usually used for solving a variety of Reynolds equations in lubrication analysis due to their simplicity and effectiveness. In this study, the compressible- and incompressible-fluid Reynolds equations are solved by popular relaxation methods. An efficient preconditioned conjugate gradient method is also applied in a case for verification. The objective is to present a robust stopping criterion for iterative methods, by which the iterative process of the methods can be terminated with high execution efficiency and adequate solution accuracy. The proposed stopping criterion for iterative methods is based on a coarse-grid truncation error analysis. In the numerical models examined, the amount of truncation error in a model is insensitive to the gridwork used. It is also found that the best reference numerical solution for used in calculating the truncation error is the average film pressure. It is shown that for all the cases tested the proposed stopping criterion can meet the objective stated. The stopping criterion can also be applied when the efficiency of iterative methods is to be compared for the solution of Reynolds equations.
The selection of lubrication product is very important. In addition, the monitoring of the lubricant and overall component condition is key in maximizing the overall turbine reliability. This presentation will review the lubrication requirements of various wind turbine components as well as the elements of a successful condition-monitoring program including the best oil analysis testing and flagging limit criteria.

Investigation of Oil Conditioning and Monitoring Techniques for Wind Turbine Gearboxes
S. Sheng, F. Oyague, National Renewable Energy Laboratory, Golden, CO, R. Errichello, Geartech, Townsend, MT

The wind industry has been characterized by premature gearbox failures, which with the increase in turbine size have proven to be extremely costly. The National Renewable Energy Laboratory initiated the Gearbox Reliability Collaborative (GRC) to investigate the causes of these premature failures. The collaborative combines the use of dynamometer and field testing, analysis, and condition monitoring to gain a better understanding of gearbox behavior and possible problem sources. The GRC’s goal of improving gearbox reliability is closely related to oil cleanliness. Therefore, our testing has implemented state-of-the-art filtration and deployed several oil condition monitoring systems in order to understand particle generation and oil cleanliness levels under different loading conditions. This presentation will describe the current state of the art of filtration systems used in the wind industry, including online filtration, kidney loops and desiccant breathers. Preliminary results from several oil condition monitoring systems will also be presented.

Rolling Element Bearings I

Session Chair: V. Bakolas, Schaeffler KG, Herzogenaurach, Germany

8 - 8:30 am
Wind Turbine - Lubrication and Condition Monitoring
P. Hetherington, Fluid Life Corporation, Edmonton, AB, Canada

Energy from Wind Turbines is becoming one of the most abundant sources of renewable energy in many countries around the world today. Due to the remote location of many wind turbines, and given the fact the working elements of the turbine are located tens of meters in the air, the overall reliability of the various components is very critical. The cost of simple inspections, repairs, or complete change out of components can be significantly more than similar sized equipment located at ground level. The overall lubrication program, including the right selection of lubrication product is very important. In addition, the monitoring of the lubricant and overall component condition is key in maximizing the overall turbine reliability. This presentation will review the lubrication requirements of various wind turbine components as well as the elements of a successful condition-monitoring program including the best oil analysis testing and flagging limit criteria.

8:30 - 9 am
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9 – 10 am
O&M - Real World Solutions
K. Dinwiddie, Amsoil, Inc., Superior, WI

Owners, investors and operators have a vested interest in enhanced wind turbine profitability & reliability. Gear oil performance and evaluation is the critical link to achieving extended gear oil drain intervals and operational profitability.

* Gear Oil Foaming & Air Entrainment, Understanding The Differences: Make correct decisions on when gear oil needs to be changed.
* Water Ingress, Challenges & Measurements: Water decreases additive concentrations causing foaming, microspitting, sludging and filter plugging impacting gear oil condition and change intervals.
* Pore Blockage vs. Optical Particle Counting, Optimizing Particle Control: Accurate determination of particle size and amounts plays an important role in gear oil life optimization.
* Gear Oil Analysis, Sampling, Testing, Interpretation and Reacting: Wind turbine gearbox performance hinges on understanding these critical links

10 - 10:30 am - BREAK

10:30 - 11 am
Wind Turbine Gear Oil Conversion
K. Harrington, ExxonMobil Lubricants & Specialties, Fairfax, VA, G. Mazzaro, COT-Puritech Wind, Minneapolis, MN

With rapid growth in wind power generation, much of the industry’s effort is directed toward continued growth through development of additional wind farm sites, fabrication and installation of additional turbines. However as the installed wind power base grows, and as turbines reach the end of their OEM warranty periods, operations and maintenance concerns receive more attention. This discussion will focus on the gearbox and the issues related to changing the oil in a gearbox located 250 feet (75 meters) above the ground. Questions related to oil changes (replacing used oil with oil from the same supplier) or oil conversions (replacing used oil with oil from a different supplier) and those related to compatibility between used and new oils are routine for lubrication engineers. However, these questions take on added significance when they relate to valuable equipment that is operated in a remote area.

This paper will discuss compatibility testing of used and new wind turbine gear oils with particular emphasis on challenges of wind turbine gearbox lubrication systems, including gear protection, fine filtration and demanding oil cleanliness targets, high oil circulation rates without an oil sump, and oil temperature, pressure and level sensors, which can be affected by oil-related deposits. This paper will also discuss practices that have been used successfully for oil changes and oil conversions, addressing safety concerns, removal and disposal of used oil, cleaning of key gear oil system components, preparation of new oil and delivery to the gearbox.

11 - 11:30 am
Optimizing a Wind Turbine Oil Condition Monitoring Program by Understanding the Mode of Lubricant Degradation

The first step in establishing an effective condition monitoring program for wind turbines is understanding how the fluid degrades in service. We have analyzed oils from several operating wind turbines of different ages. Several tests were performed to understand the depletion of additive chemistries, including AO measurement through linear sweep voltammetry, EP additives through P31 NMR and other additive components through FTIR. Fluid degradation products were observed by looking at Membrane Patch Colorimetry and analyzing the deposits by FTIR. Several other oil analysis tests were also employed to adequately profile the condition of the fluid and understand its mode of degradation. The results of this study allows us to better design condition monitoring programs by analyzing the key components that predict lubricant failure. Wind turbine reliability is critical to achieve forecasted ROI. Condition Monitoring programs that take into account the mode of lubricant failure contribute significantly in improving gearbox reliability and improving asset ROI.

11:30 - Noon
Wind Turbine Tribology
D. Brake, NextEra Energy, Hobe Sound, FL

The importance of clean, dry oil is well understood based on studies in the paper mill industry and the Navy. Cleanliness studies on wind turbines and, most importantly, oil change guidelines are lacking in wind. Areas of discussion include gearbox oil, grease, hydraulic fluids, and associated testing methods.
The Influence of Speed and Load Spectra on the Friction of Rolling Bearings
T. Stahl, S. Tremmel, H. Meerkamm, S. Wartzack, Chair of Engineering Design, Erlangen, Germany

Speed and load spectra do not only influence the lifetime of rolling bearings, but also friction and so the power loss of bearings. The article describes the influence of non-stationary operating conditions on the frictional behaviour of rolling bearings and introduces a theoretical model for the consideration of non-stationary operating conditions in the power loss calculation. The model is based on established calculation models, but extends them by the possibility to include speed and load spectra in the power loss calculation. Furthermore, the article describes a test rig, which permits the validation of this theoretical model by experimental tests. The test rig enables to test the bearings with speed spectra as well as with radial and axial load spectra. Finally, first test results and a comparison between the theoretical model and the experimental results are presented.

Numerical Investigation of Thermal Behavior of a Hybrid High-Speed Bearing
J. Wang, SKF, Nieuwegein, Netherlands, F. Greco, SKF, Villar Perosa, Italy

Thermal related problems are the main cause of bearing failures in high-speed applications such as in high-speed machine tool spindles. The development of reliable high-speed bearings with an increased speed limit demands better understanding of bearing thermal behavior. This study numerically investigates the operating temperatures of a hybrid angular contact ball bearing with oil-air lubrication. The heat generations on the raceways and cage are determined by the advanced bearing simulation tools Orpheus and BEAST respectively. To accurately analyze the convective heat transfer on bearing surfaces with an air flow, a CFD model was developed to analyze fluid flow and conjugated heat transfer simultaneously. The influences of the heat generation due to frictional losses, air-bearing interaction and external cooling have been investigated. In addition to better understanding of thermal behavior, the developed CFD model combined with the Orpheus and BEAST tools provides an opportunity to predict bearing thermal performance for specific bearing design and application.

Parametric Testing of 133mm Bore Ball Bearings with Metal Rolling Elements
N. Forster, G. Givan, K. Thompson, Air Force Research Laboratory, Wright Patterson AFB, OH, D. Gerardi, UES Inc, Dayton, OH

133 mm bore ball bearings with metal rolling elements were tested at following conditions: speeds from 1.5 to 2.6 MDN; thrust loads form 13.34 to 53.38 kN; oil delivery temperatures from 86 to 121°C; and oil flow rates from 5.7 to 9.5 liter/min. The resulting bearing outer race temperature, oil exit temperature, power loss determined from shaft torque, and power loss determined from oil temperature rise are reported. The data are fitted to polynomial equations using linear regression analysis.

Parametric Testing of 133mm Bore Ball Bearings with Silicon Nitride Rolling Elements
N. Forster, G. Givan, K. Thompson, Air Force Research Laboratory, Wright Patterson AFB, OH, D. Gerardi, UES Inc., Dayton, OH

133 mm bore ball bearings with silicon nitride rolling elements were tested at following conditions: speeds from 1.5 to 2.6 MDN; thrust loads form 13.34 to 53.38 kN; oil delivery temperatures from 86 to 121°C; and oil flow rates from 5.7 to 9.5 liter/min. The resulting bearing outer race temperature, oil exit temperature, power loss determined from shaft torque, and power loss determined from oil temperature rise are reported. The data are fitted to polynomial equations using linear regression analysis. Results are compared to the same bearings fitted with metal rolling elements.

Power Losses Predictions in High Speed Rolling Elements Bearing Using Thermal Network Method
F. Pouly, Turbomeca, B. Darnien, Groupe Safran, Pau, France, C. Changenet, ECAM Lyon, Université de Lyon, Lyon, France, F. Ville, P. Velex, LaMCoS - INSA Lyon, Université de Lyon, Villeurbanne, France

The understanding of the power loss and heat generation mechanisms is a major issue especially for high speeds rolling element bearings. In a previous study, authors estimated the temperature distribution into a high speed thrust ball bearing using the thermal network method and a model to predict power losses distribution. Different schools of thought exist taking into account or not hydrodynamic rolling traction losses and/or drag ones. Moreover the drag loss intensity is controlled by the oil fraction in the air and the drag coefficient. As a consequence, different models can be used to estimate power losses and the question was to determine which one was relevant. A thermal network allowing unsteady state resolution is presented, extended to its surroundings (housing, shaft) and coupled to a power loss model. It is shown that, numerical simulations fit with experimental data (temperature, friction torque ...) for some of the power losses hypothesis.

Parametric Study of Rolling Element Bearings under Faults
M. Nakhaeinejad, M. Bryant, The University of Texas at Austin, Austin, TX

Dynamics of rolling element bearings (REB) are studied to determine the influence of load, clearance, fault severity and rotational speed on the response of bearings under faults. Model-based diagnostics of REBs requires detailed modeling, parametric study, and parameter tuning. A detailed model of REB with direct correspondence between parameters of the model and physical components was developed in form of vector bondgraphs. Radial and rotational responses of REBs in the presence of localized faults were obtained under various radial loads, rotational speeds and bearing clearances. Results were presented in time- and frequency-domains. Also, the effect of fault severity on the REB response was investigated. Results provide model-based diagnostics a physics-based knowledge of REBs behavior under faults.

The Composition of Reaction Layers on Bearings Lubricated with Gear Oils and its Correlation with Bearing Performance
R. Pasaribu, P. Lugt, SKF Engineering and Research Center, Nieuwegein, Netherlands

Various commercially available gear oils with similar viscosity were subjected to bearing life tests under identical test conditions. It was found that bearing performance can significantly be reduced by some gear oils due to unfavorable additives reactions with bearing steel. Surface analysis with SNMS techniques revealed a relation between the compositions of the reaction layer on the bearing inner ring and the bearing performance. The tests showed that bearing performance was reduced in the case that the reaction layers contained significant concentration of sulfur and phosphor in combination with a low concentration of oxygen. The good performing gear oils generated reaction layers with a high concentration of oxygen (indicating the presence of a passivating iron oxide layer) and hardly any traces of phosphor and sulfur. In addition, some tribological tests were conducted with the same lubricants to identify the parameters that control the formation of the reaction layers. This has lead to a physical explanation for the correlation between the composition of the reaction layer on the inner ring of bearings due to additives in gear oils and its effect on bearing life.
The goal of this research is to investigate the influence of macroscopic wear on friction in lubricated sliding line contacts. In case of lubricated contact three zones are distinguished: inlet, the hydrodynamic lubrication theory [1] and implemented in a mixed lubrication friction model [2] which is able to predict friction and the transitions between the different lubrication regimes represented in the so-called Stribeck curve. Experimental and theoretical results show that with increasing wear resulting in a decreased contact pressure hydrodynamic effects are facilitated (increase of the separation) which leads to a change in friction and lubrication regime [3].

Frictional Behavior in Worn Lubricated Sliding Line Contacts

M. Adams, Case Western Reserve University, Cleveland, OH

Significantly uneven radial wear patterns on several commutator copper surfaces of 10 KW DC starter-generator units of Auxiliary Power Units (APU) of a specific commutator jet necessitated an intensive engineering investigation to identify the root cause and thereby cure this wear problem. A brush dynamics-wear model identified imposed vibration from the driving 60,000 rpm gas turbine as the root cause. Accordingly, the commutator wear problem was eliminated when the turbine OEM changed the material for the turbine rotor axial retaining bolt to eliminate a severe bolt material creep phenomenon that had allowed the turbine rotor to become loose in operation.

8:30 - 9 am
Effect of Oil Aging Due to Bio-fuels on Wear of Piston Ring and Cylinder Liner System


Engine oil aging in a passenger car combustion engine can be related to shear stress, temperature, corrosion, incorporation of and reaction with water, air, fuel and especially blow by gases. The interactions of these impact parameters are as multiple as there are auto brands and engines. Nevertheless, the engine oil has to be composed to fulfill all appropriate needs and to perform excellent lubrication. With respect to the damaging mechanisms engines are exposed to, the engine oil should prevent severe damage of the components and reduce their wear rate. Still, the wearing behaviour of the engine parts is hardly understood, especially taking oil aging mainly due to bio-fuels into account. The effects of artificially aged oils on the wear behaviour of the system piston ring and cylinder liner are investigated using a novel wear measurement method based on online and continuous detection of radioactive isotopes as wear tracers. These investigations are carried out in a tribometer environment in order to distinguish between single impacting parameters, such as selected bio-fuel components, as well as in an engine bench test to cope with the multiple impacting parameters of the real application.

9:00 - 9:30 am
Comparative Evaluation of Scuffing Mechanisms in Carbon Steel and Cast Iron

R. Zhang, J. Han, G. Barber, Q. Zou, Oakland University, Rochester, MI, O. Ajayi, Argonne National Laboratory, Argonne, IL

Scuffing, described as a sudden catastrophic failure of lubricated sliding contact interface, is one of the least understood failure mechanisms in tribological components and systems. Its occurrence is usually characterized by a sudden and large increase in friction, noise/vibration and temperature. Because of its implications for component reliability, scuffing performance of many materials has been studied for many decades. Although the detailed mechanisms of scuffing are still poorly understood, several empirical approaches to scuffing prevention have been developed over the years. This paper presents our comparative assessment of the mechanisms of scuffing in two commonly used tribological materials, viz: gray cast iron and high carbon steel (AISI 1080). Using a reciprocating ball-on-flat contact configuration, scuffing tests were conducted with step load and step speed increase. Although, sudden transition in friction (scuffing) was observed in tests with both the cast iron and steel materials, the mechanism responsible for this transition was different. In cast iron, the sudden friction increase coincided with sudden increase in wear rate, while the friction transition in steel was due to occurrence of severe plastic deformation but minimal wear.

9:30 - 10 am
Effect of Particle Size on Erosive Wear Performance of Pump Casing Material in Solid Liquid Mixture

S. Jain, Institute of Engineering & Science, Indore, India

Wear is defined as the progressive volume loss of material from a surface due to abrasion, erosion and corrosion. The volume loss due to corrosion is caused by chemical reactions, which can be prevented by adopting suitable measures, whereas abrasion and erosion wear can be minimized by controlling the affecting parameters. Abrasion wear is the loss of material due to passage of hard particles over the surface, where as erosion wear is caused by the impact of liquid/solid particles on the solid surface. The aim of the present study is to analyze the parametric dependence of erosion wear of Pump Casing Material in sand-water suspension. The effect of various parameters namely, impact angle, particle size and solid concentration on erosion wear of Pump casing Material has been analyzed. This has been achieved by conducting experiments in a pot tester to generate the data at an accelerated rate.

10:00 - 10:30 am - BREAK

10:30 - 11 am
A State-of-the-Art Report on Fretting: Is There Uniqueness in the Fretting Measurements?

D. Nellas, J. Rigal, INSA-LYON, LYON, France, J. Nobrega de Medeiros, UFRN - Federal University of Rio Grande do Norte, Natal, Brazil

The probabilistic nature of fretting and inherent processes of energy dissipation and recovery have been generally investigated under deterministic approaches that use a set of simplifying hypothesis to reduce time and costs - always a contemporary constraint. Is fretting an intrinsically chaotic phenomenon, as had idealized Poincaré more than a Century ago about a set of periodic motions of the nature? This is a good question to start the present discussion. Based on this hypothesis, the aims of this paper is (a) present an approach composed by a new conception for a coupled experimental and theoretical test rig for fretting; (b) discuss the complexities associated to the responses of a material concerning fretting. There is a set of possible implications from fretting motion on each contacting material. The cracks that nucleate and propagate themselves during the phenomenon are examples of this, as well the debris that are developed, conformed or not, and remain or are expelled from the contact zone between solids. These damage entities have a trigger function for nonlinear responses of the contact and the transition zones until the unaffected material's bulk according to (a) point contact; (b) linear contact; (c) elliptical contact, that is generally considered as the most general case of contact between two solids.

11:00 - 11:30 am
Frictional Behavior in Worn Lubricated Sliding Line Contacts

I. Crăciunaru, D. Schipper, Twente University, Enschede, Netherlands

Depending on the operating conditions lubricated systems can operate in one of the following lubrication regimes: boundary BL, mixed ML and (elasto) hydrodynamic (EH) lubrication. In time tribosystem components are subjected to wear that take place between the opposing surfaces when operating in the ML and/or BL regime. Wear starts at asperity level and continues in changing the macroscopic geometry of the components and as a result the components no longer fulfill the functional specifications for which they have been designed. The goal of this research is to investigate the influence of macroscopic wear on friction in lubricated sliding line contacts. In case of lubricated contact three zones are distinguished: inlet, contact and outlet zone. When wear is present even with small amounts, the geometry of the inlet zone is changing, leading to a modification of the contact pressure distribution and separation between rubbing surfaces as a function of the operational parameters (load, velocity, lubricant, temperature, etc.). Changes in separation due to wear are calculated based on the hydrodynamic lubrication theory [1] and implemented in a mixed lubrication friction model [2] which is able to predict friction and the transitions between the different lubrication regimes represented in the so-called Stribeck curve. Experimental and theoretical results show that with increasing wear resulting in a decreased contact pressure hydrodynamic effects are facilitated (increase of the separation) which leads to a change in friction and lubrication regime [3].

11:30 - Noon
Studies on Friction and Transfer Layer Formation when Super Purity Al Pins Slid at Various Numbers of Cycles on Steel Plates of Different Surface Texture

S. Kailas, K. Kishore, Indian Institute of Science, Bangalore, India, P. Menezes, M. Lovell University of Wisconsin-Milwaukee, Milwaukee, WI
In the present investigation, unidirectional, 8-ground, and random surface textures were attained on the steel plates. Using an inclined pin-on-plate testing system, super purity Al pins were then slid against the steel plates at various numbers of cycles. In the experiments, it was observed that the coefficient of friction and formation of transfer layer during the first few cycles depend on the surface textures under both dry and lubricated conditions. The coefficient of friction decreases for unidirectional and 8-ground surfaces while for random surfaces it increases with number of cycles. A stick-slip phenomenon was observed only under lubricated conditions when pins slid perpendicular to the unidirectional texture. The amplitude of vibration induced by the stick-slip phenomenon increased with increasing number of cycles. The variation in the coefficient of friction is attributed to the change in texture of surfaces during sliding. The change in texture is found to vary based on the initial texture of the plate.

### Session 5J

**Commercial Marketing Forum V**

**Session Chair:** TBD

**8:30 - 9 am**

Rohm and Haas Company

9 - 9:30 am

**Development of Optimized AO-packages for Ester-based Hydraulic Fluids Using DOE-Techniques**

N. Broekhof, L. Herrendorf and P. Skoog, Quaker Chemical Corp., The Netherlands

The anti-oxidant (AO-) package is one of the key building blocks of ester-based hydraulic fluids. This package should prevent oxidation of the esters resulting in an increase of the lifetime of the hydraulic fluid during practical usage.

Numerous AO’s are available on the market today. Product development usually involves time-consuming trial-and-error, also because interactions of anti-oxidants – either synergistic or antagonistic - are usually unknown.

Quaker decided to opt for the following approach in designing state-of-the-art optimized AO-packages:

- The key screening methods used were the Dry-TOST test (ASTM D 943) and the RPVOT test (ASTM D 2272).
- Screening has been executed in Rapeseed oil, while the most promising results were confirmed in polyol esters.

Theoretical considerations, approach and results will be discussed during the presentation.

**Session Chair:** L. Rudnick, Ultrachem, Inc., New Castle, DE

**10 - 10:30 am**

**Open**

11 - 11:30 am

**Polartech Additives, Inc.**

### Session 6A

**Synthetics & Hydraulics II**

**Session Chair:** L. Rudnick, Ultrachem, Inc., New Castle, DE

1:30 - 2 pm

**Boundary Lubrication and Fluid Thermal Property Effects in Low-Speed High-Torque Motors**

M. Devlin, P. Michael, K. Burgess, E. Radle, T. Wanke, Milwaukee School of Engineering, Milwaukee, WI, K. Hux, Afton Chemical, Richmond, VA

This paper presents an investigation of the fluid properties that affect starting and low-speed efficiency in hydraulic motors. Low speed motor efficiency is important because it often determines pump displacement and operating pressure requirements of mobile hydraulic equipment. The viscosity, heat capacity, thermal conductivity and boundary/mixed lubrication properties of prototype fluids have been characterized.

These hydraulic fluids have been evaluated in a full-scale hydraulic motor dynamometer. Geroler, axial piston and radial piston motors have been evaluated. Low-speed (1 RPM) testing was performed under constant pressure conditions in accordance with the ISO 4392-1 standard test method. Startability testing was performed under constant load conditions in accordance with ISO 4392-2. In startability and 1 RPM testing, the axial piston motor exhibited a significant efficiency improvement when using a high viscosity index hydraulic fluid. Efficiency improvements were seen in the radial piston and geroler motors when using a fluid that reduced boundary layer friction. The results of this investigation reveal that energy efficient fluids can increase the torque output of hydraulic motors under starting and low-speed high-torque conditions.

2 - 2:30 pm

**Documenting Lubricant Related Hydraulic Efficiency in Controlled Field Trials**

J. Hannon, ExxonMobil Lubricants & Specialities, Fairfax, VA

Hydraulic efficiency differences resulting from lubricant selection are expected based on theory. However, the measurement of these effects in practice require tightly controlled conditions.
experiments in laboratory test rigs and careful attention to detail. Testing to determine if one lubricant delivers an energy efficiency benefit versus another can be challenging because energy efficiency is often a modest difference between two large energy consumption values. Taking these experiments from the controlled conditions of the laboratory rigs and attempting to measure hydraulic efficiency differences under real-world conditions introduces several challenges. Successful field demonstrations of this type require detailed test protocols, proper control of key variables and the monitoring of potential factors which may skew the results. Finally, conclusive energy efficiency measurement often requires collection of data over a significant time period, testing in multiple pieces of equipment and the rigorous statistical data evaluation to ensure the veracity of the test conclusions. This discussion addresses key elements to be considered in field hydraulic efficiency demonstrations in industrial and mobile equipment applications and suggests standards for the conduct and reporting of energy efficiency measurements for hydraulic fluids.

2:30 - 3 pm
Inhibition of Copper/Zinc Exchange in a Hydraulic System Utilizing Advanced, Triboelectric Charging Resistant (TCR) Filter Elements
C. Bauer, Pall Corporation, Port Washington, NY, L. Kerley, ExxonMobil Lubricants & Specialties, Fairfax, VA

Over the past several years, high levels of Copper were found in periodic oil analyses of zinc-containing hydraulic fluids of plastic injection molding machines. Research by the authors indicated that the ZnDDP additive is reacting with Copper to make CuDDP. While the fluid itself is not compromised, high levels of copper in used oils raises cause customer concern. Historical data from a clipper hydraulic system at a plywood mill showed that the hydraulic fluid copper levels increased from a baseline of 5-10 ppm to approximately 100 ppm after six months, and to approximately 300 ppm after 12 months. On average, Copper levels increased by 30-35 ppm/mo. It was suspected, that the generation of an electric charge in the fluid facilitated the Copper/Zinc exchange. Since conventional glass-fiber filter elements are known to cause triboelectric charging, the original glass-fiber-based media were replaced with advanced, triboelectric charging resistant (TCR) filter elements. The fluid in the system was changed out and baseline Copper levels were determined. Copper levels did not change for six months, remaining stable at the baseline level of 50-60 ppm. The original filtration was then re-installed, and Copper levels started to rise again, at a rate of approximately 25-30 ppm/mo. After three months the Copper levels in the fluid have reached 100 ppm. This work demonstrates the suitability of utilizing advanced, triboelectric charging resistant (TCR) filtration to inhibit Copper/Zinc ion exchange in systems with Copper surfaces and fluids containing ZnDDP additives.

3 - 3:30 pm - BREAK

3 pm – Synthetics & Hydraulics Business Meeting
wear and low friction (<0.05) when slid in H2. Ball-on-disk sliding tests were performed at temperatures up to 400°C, to assess the suitability of DLC for use in high-temperature applications. The research presented elaborates on the proposed mechanism of vapor phase lubrication of high temperature metallic and ceramic sliding contacts. Friction data was acquired from a pin-on-disk tribometer using a silicon nitride ball and Nickel-Aluminum superalloy counterface at 650°C surface temperature, 2N normal load, and 50 mm/s sliding speed in a controlled inert gas environment with acetylene (C2H2) admixtures. A 20x reduction in friction coefficient was observed in experiments with the inclusion of admixtures, in contrast to experimental data using an inert cover gas only. Steady-state friction coefficients as low as 0.02 were observed. Focused ion-beam milling was implemented to extract representative cross-sectional liftouts for high resolution transmission electron microscopy (HRTEM) analysis. Confocal Raman spectroscopy of the worn and unworn surfaces and HRTEM of the worn subsurface revealed that frictional contact in dry nitrogen induced amorphous to crystalline transformation in the subsurface regions of the wear surface with 2H-MoS2 basal (0002) planes parallel to the sliding. In humid air, wear surface was enriched with Au. In both environments, the transfer films exhibited (0002)-orientated cross-sectional transmission electron microscopy (XTEM) revealed that frictional contact in dry nitrogen induced amorphous to crystalline transformation in the subsurface regions of the wear surface with 2H-MoS2 basal (0002) planes parallel to the sliding. In humid air, wear surface was enriched with Au. In both environments, the transfer films exhibited (0002)-orientated basalt planes along their entire section resulting in predominantly self-mated ‘basal-on-basal’ interfacial sliding in dry environments and basal planes of solid lubricant sliding on Au enriched wear surface in humid air.

3:30 - 3 pm - BREAK

3:30 - 4 pm
Effects of Reactive Nano-Fillers in PTFE
B. Krick, J. Vail, K. Marchman, W. Sawyer, University of Florida, Gainesville, FL
PTFE has historically been a popular solid lubricant due to its advantageous properties including low friction coefficient and chemical inertness; however poor wear resistance limits its use. Previous studies have shown that the wear resistance of PTFE can be increased by orders of magnitude with the inclusion of fillers. Predominately, these nano-fillers have been oxidized metals such as alumina, titania, and zirconia. This work explores the use of metallic nano-particles such as nickel nano-strands to investigate the ability to blend properties such as electrical conductivity with increased wear resistance. Other nano-fillers, such as iron powder and fumed silica, were used to study the influence of reactivity on the performance of PTFE.
PTFE. Wear rates and friction coefficients of varying reactive filler loading and material are compared with more traditional non-reactive filler materials. Transfer film and samples were characterized using spectral analysis techniques and optimal volume fractions were determined for each filler.

4 - 4:30 pm
Heavy Duty Gear Lubricants for Wind Turbines: Nanotech Lube Additives for CleanTech Energy
N. Fleischer, M. Genut, M. Zarbuv, O. Ovadia, N. Feuerstein, NanoMaterials, Nes Ziona, Israel
Research has led to the discovery of a new class of inorganic nanostructures with a closed cage structure termed inorganic fullerene-like nanoparticles (IF). IF nanoparticles have a similar geometry to the hollow C60 carbon fullerenes but instead are made from inorganic compounds such as WS2 and MoS2 while maintaining a spherical multi-walled, onion-like structure. These nanoparticles, due to their nanosize, shape, chemistry, and structure have unique lubricating properties superior to other solid additives. Recent efforts by our company has led to the successful scale-up of production of IF in ton quantities which are now being supplied commercially as concentrates and pastes under the trade mark NanoLub® for enhancing lubricating oils and greases. Tribological and field testing of lubricants additivated with NanoLub clearly show that these special nanoparticles reduce friction and wear significantly better than other solid lubricant additives including conventional platelet materials like molybdenum and tungsten disulphide, graphite, and PTFE. Their greatest relative advantage is realized under high load conditions.

4:30 - 5 pm
Tribological Mechanism of Amorphous Hydrogenated Fullerene Like Carbon Films
J. Zhang, Z. Wang, B. Zhang, State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, China
We present a passivation process of amorphous hydrogenated fullerene like carbon (FLC) films in air condition. Time-of-Flight Second Ions Mass Spectra were conducted before and after the tribological tests. The results showed that the fragments of FLC films were complicate before tribotest due to its amorphous nature and the fragments were composed of complicated hydrogen carbonate forms (such as: C2H2X-, C3H3X-, X=1, 3, 5). However, after the tribotest, the results gave ordered structure information and the fragments were composed of smaller groups (such as: C2H5- groups) due to their more stable characteristic in tribological tests. We confirm the low friction and wear of amorphous hydrogenated FLC films are attributed to the transformation of surface structure from diversiform bonding configurations to ordered passivated structures. This transformation forms a passivation hydrogen carbonate surface and thus induces extremely low friction force during sliding process.

5 - 5:30 pm
Intermolecular Forces, Adhesion, and the Elastic Foundation
W. Sawyer, D. Dickrell, University of Florida, Gainesville, FL
A theory for the elastic contact adhesion between a rigid sphere and an elastic foundation is developed through a process that involves integrating the intermolecular forces. The theory gives an adhesion force of F=3*π*R*Rg, and provides completely closed form algebra relationships for penetration, contact area, and force.

5:30 pm - Solid Lubricants Business Meeting
elastic solids. The theory gives an adhesion force of \( F_{adh} = 7nR\Delta y \).

4 - 4:30 pm
Quantitative Study of Atomic-scale Stick-slip Friction: Experiment
Q. Li, R. Carpick, University of Pennsylvania, Philadelphia, PA; Y. Dong, A. Martini, Purdue University, West Lafayette, IN
Despite its persistent occurrence in nanoscale sliding and its crucial role in friction at small scales, atomic-level stick-slip is still not well understood. The stick-slip behavior of a well-defined system composed of a platinum tip sliding over a gold (111) surface is quantitatively studied both experimentally and through accelerated molecular dynamics simulation where the velocities are matched. In the experiment, the stick-slip behavior is measured using an atomic force microscope under dry nitrogen environment. We observe clear stick-slip behavior with the periodicity of the Au(111) lattice and are able to slide without damaging the surface. Proper preparation of the surface is essential for the experiments. The effects of sliding velocity, crystal orientation, and defects on the stick-slip behavior between these two noble metals are investigated. A logarithmic dependence of the energy dissipation on velocity is observed. We will discuss the correlation between experiment and simulation in order to understand the nature of how energy is dissipated in this system.

4:30 - 5 pm
Quantitative Study of Atomic-scale Stick-slip Friction: Theory and Modeling
Y. Dong, A. Martini, Purdue University, West Lafayette, IN; D. Perez, A. Voter, Los Alamos National Laboratory, Los Alamos, NM; Q. Li, R. Carpick, University of Pennsylvania, Philadelphia, PA
Atomic-scale stick-slip friction of platinum on gold (111) surfaces is studied at low scanning velocities using accelerated molecular dynamic simulation. The Parallel Replica Dynamic Method (ParRep) is used to accelerate the simulation so scan velocities can be decreased to scales approaching those used in atomic force microscope experiments. The effects of conditions including velocity, temperature, and load are studied. ParRep simulation results are evaluated in terms of both analytical model predictions and trends observed experimentally. We focus specifically on the correlation between simulation and experiment with the ultimate goal of using the two in conjunction to be able to both predict and fundamentally understand atomic stick-slip friction and the associated energy dissipation mechanisms.

5 - 5:30 pm
Nano-Scale Displacement of a Rough Spherical Shell Loaded Against a Rigid Flat
L. Li, Harbin Institute of Technology, Harbin, China; A. Ovcharenko, University of California, San Diego, La Jolla, CA; I. Etsion, Technion-Israel Institute of Technology, Haifa, Israel; F. Talke, University of California, San Diego, La Jolla, CA
The nano-scale load-displacement characteristics of a rough spherical shell in contact with a smooth sapphire flat are investigated. The surface roughness parameters and the corresponding plasticity index are determined from AFM and optical profilometer measurements. A modified model for elastic-plastic spherical contact of rough surfaces is used to simulate the load-displacement relationship. Good agreement is found to exist between experimental and theoretical results for a range of relevant plasticity index values. It is shown that both capacitance and ultrasonic measurements can detect particles as small as 1 mil (25 μm) in diameter. While measured capacitance increases linearly with the increase of the debris particle size while the ultrasonic wave amplitude decreases linearly with the increase of debris particle size. While measurable differences can be detected by the capacitance measurements between the ferrous and the non-ferrous particles, systematic differences between the ferrous and non-ferrous particles cannot be developed using the ultrasonic approach. In addition, the existence of nonconductive particles cannot be readily detected using the capacitance measurements but their existence can be observed by the ultrasonic approach. Oil viscosity measurements were also performed using both ultrasonic and capacitance approaches and results are compared for both accuracy and range of detection. Oil Debris and Viscosity Monitoring Using Ultrasonic and Capacitance Measurements
M. Appleby, F. Choy, University of Akron, Akron, OH
This paper aims at the development of a comprehensive procedure for detecting oil debris and viscosity change using ultrasonic and/or capacitance sensing approaches. Laboratory work has been conducted using a network analyzer to detect change in capacitance for oil debris contents and results are compared to those obtained using an ultrasonic device. It was found that both capacitance and ultrasonic measurements can detect particles as small as 1 mil (25 μm) in diameter. Based on the comparison of experimental results, it can be shown that the measured capacitance increases linearly with the increase of the debris particle size while the ultrasonic wave amplitude decreases linearly with the increase of debris particle size. While measurable differences can be detected by the capacitance measurements between the ferrous and the non-ferrous particles, systematic differences between the ferrous and non-ferrous particles cannot be developed using the ultrasonic approach. In addition, the existence of nonconductive particles cannot be readily detected using the capacitance measurements but their existence can be observed by the ultrasonic measurements. Oil viscosity measurements were also performed using both ultrasonic and capacitance approaches and results are compared for both accuracy and range of detection.

6 pm – Nanotribology Business Meeting

Session 6E

Session Chair: K. Malik, Ontario Power Generation, Pickering, ON, Canada

1:30 - 2 pm
Oil Debris and Viscosity Monitoring Using Ultrasonic and Capacitance Measurements
M. Appleby, F. Choy, University of Akron, Akron, OH
This paper aims at the development of a comprehensive procedure for detecting oil debris and viscosity change using ultrasonic and/or capacitance sensing approaches. Laboratory work has been conducted using a network analyzer to detect change in capacitance for oil debris contents and results are compared to those obtained using an ultrasonic device. It was found that both capacitance and ultrasonic measurements can detect particles as small as 1 mil (25 μm) in diameter. Based on the comparison of experimental results, it can be shown that the measured capacitance increases linearly with the increase of the debris particle size while the ultrasonic wave amplitude decreases linearly with the increase of debris particle size. While measurable differences can be detected by the capacitance measurements between the ferrous and the non-ferrous particles, systematic differences between the ferrous and non-ferrous particles cannot be developed using the ultrasonic approach. In addition, the existence of nonconductive particles cannot be readily detected using the capacitance measurements but their existence can be observed by the ultrasonic measurements. Oil viscosity measurements were also performed using both ultrasonic and capacitance approaches and results are compared for both accuracy and range of detection.

2 - 2:30 pm
Ion Exchange Treatment of Phosphate Esters in Industrial Hydraulic Systems; Lessons Learned from Power Generation Applications
J. Duchowski, HYDAC Filtertechnik GmbH, Sulzbach, Germany
Phosphate esters are widely used in a variety of hydraulic and lubricating systems in industrial applications because they exhibit excellent lubricity and oxidative stability. However, in presence of water these fluids hydrolyze and form acidic partial phosphates. This aging process is well recognized in Power Generation Industry, where fluid condition is strictly regulated. In contrast, in Steel and Aluminum industries, the fluid is often left untreated which can result in detrimental effect on system components and reduced fluid service life. However, the general lack of fluid specifications has thus far not prompted the operators to seek new fluid treatment methods in these important industries with few notable exceptions. One such important exception - the first application of a combined ion exchange / vacuum dehydration treatment at a major Canadian steel mill - will be discussed in the course of this presentation.

2:30 – 3pm
reported. As machine size increases, however, one of the critical technical challenges of AFB is wear on the top foil and rotor during starts/stops due to relatively heavy rotor weight located on the bearing walls. A modified form of the compressible Reynolds equation for active lubrication is derived. By solving this equation, stiffness and damping coefficients can be determined.

The demand for reduced on-site commissioning time has resulted in "cleanliness" specifications being placed on certain components of hydraulic and lubricating systems. Such "on-delivery" cleanliness specifications are becoming increasingly applicable not only to smaller sub-components, such as valves, but also to components as large as heavy-duty industrial coolers. These specifications might include the first-time flush results targeted to specific contaminant levels designated by the ISO 4406:1999 Range Codes, for example 17/15/12. The challenge then lies in the design of specialized test stands, selecting appropriate fluids and tailoring flushing procedures to rapidly achieve the desired cleanliness levels without introducing undue hardship on production and assembly personnel. In this paper, we describe how such a flushing process was designed and optimized to achieve these purposes and present the particle count data demonstrating the effectiveness of the procedure.

4 – 4:30 pm
Diagnosis of Contaminant Ingression and Distribution of a Heavy-Duty Hydraulic Press
J. Duchowski, HYDAC Filtertechnik GmbH, Sulzbach, Germany, R. Hinterberger, HYDAC International, Pasching, Austria
A detailed investigation of contaminant distribution carried out on a large, heavy-duty industrial hydraulic press is described. The multi-part investigation included an on-site analysis of oil samples collected at various points of the hydraulic system by both optical microscopic as well as on-line automatic particle counting methods. As a result of this investigation, the migration of particulate contaminants throughout the press hydraulic system was elucidated and several most probable sources of contaminant ingestion were indentified and eliminated. In addition, monitoring of filter element differential pressure, which correlated relatively well with the observed contaminant levels, has allowed for selection of the media grade most suitable for the application and led to the optimization of filter element service life.

4:30 – 5 pm
The Detecting Asphaltene Contamination Test (DAC)
A. Suan, ExxonMobil Lubricants & Specialties, Fairfax, VA
DAC, awarded a patent in 2008, is helping ship operators respond to a problem that’s increasingly common and potentially costly: contamination of medium-speed engine lubricants with partially burned and unburned residual fuel. Residual fuel contamination can accelerate the formation of piston undercrown deposits and lead to piston crown burning. Monitoring lubricants for residual fuel contamination can help ship operators avoid downtime and save as much as $30,000 per cylinder on component replacement and maintenance. Other available asphaltene measurement tests are time consuming and costly. Asphaltenes are major components in marine residual fuel. They pose one of the greatest threats to a ship’s engine, potentially causing excessive deposits in the hot piston undercrown area and sludge in the cooler parts of the engine. Currently, the Central European Coordinating Council (CEC) for the development of tests for lubricants and fuels is near standardizing a method that measures asphaltenes in used marine engine oils with good accuracy. While draft method CEC L-94 is a significant step forward, it’s costly to perform and does not lend itself to automation. To solve the problem, ExxonMobil researchers invented the “Detecting Asphaltene Contamination” (DAC) test. DAC is an automated test that uses ultraviolet-visible spectroscopy and a sophisticated mathematical model to analyze spectra of used medium-speed engine lubricants, measuring asphaltenes levels in under two minutes. DAC test results correlate well with the CEC method.

5 pm - Condition Monitoring Business Meeting

Session 6G

Fluid Film Bearings IV

Session Chair: W. Dmochowski, National Research Council Canada, Ottawa, ON, Canada

1:30 - 2 pm
On the Modeling of Active Gas Journal Bearings
S. Morosi, I. Santos, DTU, Technical University of Denmark, Kgs. Lyngby, Denmark
Gas journal bearing have been increasingly adopted in modern turbo-machinery applications, as they meet the demands of operation at higher rotational speeds, in clean environment and great efficiency. Due to the fact that gaseous lubricants, typically air, have much lower viscosity than more conventional oil bearings, carrying capacity and dynamic characteristics of passive systems are generally poorer. In order to enhance these characteristics, one solution is to employ active control strategies. The present contribution presents a detailed mathematical modeling for test lubricants and fuels is near standardizing a method that measures asphaltenes in used marine engine oils with good accuracy. While draft method CEC L-94 is a significant step forward, it’s costly to perform and does not lend itself to automation. To solve the problem, ExxonMobil researchers invented the “Detecting Asphaltene Contamination” (DAC) test. DAC is an automated test that uses ultraviolet-visible spectroscopy and a sophisticated mathematical model to analyze spectra of used medium-speed engine lubricants, measuring asphaltenes levels in under two minutes. DAC test results correlate well with the CEC method.

2 – 3:30 pm
Design Study of 4" Diameter Hybrid Air Foil and Experimental Studies on Static Performance
D. Kim, D. Lee, University of Texas at Arlington, Arlington, TX
Air foil bearings (AFBs) have been explored for various micro- to mid-sized turbomachinery for decades, and many successful applications of the AFB to small turbomachinery were also reported. As machine size increases, however, one of the critical technical challenges of AFB is wear on the top foil and rotor during starts/stops due to relatively heavy rotor weight compared to the load capacity of the bearing. The hybrid air foil bearing (HAFB) which combines hydrodynamic pressure with hydrostatic lift can help to minimize/eliminate the wear problem during the start/stops. This paper reports design and preliminary test results of preloaded three-pads HAFB aimed for mid-sized air-born applications. Static stiffness at the zero running speed was measured to investigate load capacity at zero running speed. The measured static stiffness at zero running speed showed good agreement with simulation data. Preliminary results on load capacity of the bearing will be also presented.

2:30 – 3 pm
Experimental Investigation of the Performance of Herringbone Grooved Journal Bearings
I. Oggnjanovic, A. Schröderet, J. Giovanola, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
Although many analytical/numerical methods, including Narrow Groove Theory, Finite Difference Models, and Finite Element Models, have been developed to calculate stiffness and load carrying capacity of Herringbone Grooved Journal Bearings (HGJB), few well qualified experimental results are available to validate model predictions. This paper presents an experimental study performed on air lubricated HGJB. For these experiments a novel four DOF piezo-actuated loading system has been developed. Measurements performed during the experiments allow determining the load carrying capacity and stiffness of a journal bearing as a function of compressibility number. By measuring bearing reaction forces in two perpendicular planes bearing attitude angle at different levels of eccentricity ratio have also been determined. Different grooving configurations have been tested. Pressure distribution experimental study performed on air lubricated HGJB. For these experiments a novel four DOF piezo-actuated loading system has been developed. Measurements performed during the journal bearings. Load capacity and gas film stiffness of EP journal bearings with three types of inlet restrictors for varying supply pressures and air flow rates are investigated pockets offers better stiffness but these can lead to instability known as pneumatic hammer even under static condition. In the present work, investigation is carried out to find the effects of three inlet supply configurations (restrictors) a) orifice type, b) orifice with circular pocket and c) orifice with circumferential pocket on the performance of externally pressurized gas journal bearings. Load capacity and gas film stiffness of EP journal bearings with three types of inlet restrictors for varying supply pressures and air flow rates are investigated experimentally and reported in the paper.

3 - 3:30 pm - BREAK

3:30 - 4 pm
A Novel Thermal Management Approach for Radial Foil Air Bearings
K. Radil, ARL-VTD, Cleveland, OH, Z. Balto, United States Military Academy, West Point, NY
Tests were conducted to evaluate a novel thermal management technique for radial foil air bearings based on injecting air directly into the circulating fluid-film to reduce bulk temperatures and axial thermal gradients. The tests were performed on a single top foil, Generation III, radial foil bearing instrumented with three thermocouples to monitor internal temperatures. A hole extending through the shell was placed in the gap between the top foil’s fixed and free ends to provide entry for the injection air. The tests were conducted at room temperature with the bearing operating at speeds from 20 to 50krpm while supporting 222N. Two different levels of air injection were used during each test, 0.014m3/min and 0.042m3/min. Test results suggest that the air injection approach is a viable and implementable thermal management technique that is capable of reducing radial foil bearing bulk temperatures and axial thermal gradients.

4 - 4:30 pm
Investigation on Externally Pressurized Gas Journal Bearings with Different Inlet Restrictors
N. Murmu, Central Mechanical Engineering Research Institute, Durgapur, India
The design of an externally pressurized (EP) gas bearing is complex in the sense that it involves the solution of nonlinear partial differential equation satisfying multiple boundary conditions due to multiple supply ports. The distribution of gas film pressure depends on the location, type of the feeding system and intensity of the supply flow. Gas supplied with pockets offers better stiffness but these can lead to instability known as pneumatic hammer even under static condition. In the present work, investigation is carried out to find the effects of three inlet supply configurations (restrictors) a) orifice type, b) orifice with circular pocket and c) orifice with circumferential pocket on the performance of externally pressurized gas journal bearings. Load capacity and gas film stiffness of EP journal bearings with three types of inlet restrictors for varying supply pressures and air flow rates are investigated experimentally and reported in the paper.

4:30 pm – Fluid Film Bearings Business Meeting

Session 8H
Wind Turbine Tribology II Panel - Condition Monitoring and Fluid Maintenance of “Gearbox” Lubricants for Wind Turbines: Issues and Opportunities

Session Chair: K. Harrington, ExxonMobil Lubricants & Specialties, Fairfax, VA
1:30 - 5 pm
Panelists:
Paul Hetherington, Fluid Life Corporation
Dan Brake, NextEra Energy
Kevin G. McKenna, ExxonMobil Lubricants & Specialties
Kevin Dinwiddle, Amsoil Inc.

Session 8I
Rolling Element Bearings II

Session Chair: A. Ashtekar, Purdue University, West Lafayette, IN
Session Vice Chair: M. Nakhaeinejad, The University of Texas at Austin, Austin, TX
1:30 - 2 pm
Effect of Internal Clearance on Life of Radially-Loaded Ball & Roller Bearings
F. Oswald, E. Zaretsky, NASA Glenn Research Center, Cleveland, OH, J. Poplawski, J.V. Poplawski & Associates, Bethlehem, PA
The effect of internal clearance on deep-groove ball and cylindrical roller bearing fatigue life was determined for four clearance groups defined in ABMA-Std-20-1996. A modified Stribeck Equation is presented that relates maximum rolling-element load to internal clearance. The analysis was extended to negative clearance conditions to produce a curve of life factor vs. internal clearance. A relationship is derived between bearing life and internal clearance as a function of ball or roller diameter. Results are presented as life factors for bearings with light, moderate and heavy loads. For a deep groove ball bearing, a Group N (normal) fit produces a life factor ranging from 0.75 - 0.46 for a light load on a 1910-size bearing and 0.98 - 0.90 for a heavy load on a 310-size bearing. Bearing life is a maximum for a small negative clearance but then declines rapidly with increasing internal interference.

2 - 2:30 pm
Investigation of the Performance of Highly Loaded Structured Surfaces Part 1: Theory and Quasi Static Results
M. Pausch, V. Bakolas, A. Liebel, Schaeffler KG, Herzogenaurach, Germany, H. Meerkamm, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
The use of structured surfaces in highly loaded bearings’ and gears’ applications has been a topic of discussion for the past decade. It has been proven that structured surfaces can have a positive effect on other applications mainly acting as lubricant deposits. Therefore one expects the same positive effects in the aforementioned areas. However, a clear picture has yet
to emerge both from simulations as well as experiments. Some early experimental results point to a degradation of the lubricating performance, although the results are far from conclusive. A theoretical model as well as its solution algorithm will be presented in this paper. With the aid of this model a variety of surface features has been investigated under quasi-static conditions and the effect of their main geometrical parameters was evaluated. These results serve as a first benchmark of the operating performance of these features before their behavior under transient conditions will be investigated.

2:30 - 3 pm
Investigation of the Performance of Highly Loaded Structured Surfaces Part 2: Transient Results
M. Pausch, V. Bakolas, A. Liebel, Schaeffler KG, Herzogenaurach, Germany, H. Meerkamm, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
The use of structured surfaces in highly loaded bearings and gears’ applications has been a topic of discussion for the past decade. It has been proven that structured surfaces can have a positive effect on other applications acting as lubricant deposits. Therefore one expects the same positive effects in the aforementioned areas. However, a clear picture has yet to emerge both from simulations as well as experiments. Some early experimental results point to a degradation of the lubricating performance, although the results are far from conclusive. Based on the results of the quasi static calculations that were performed in the first part of this paper, a series of transient calculations was carried out in order to investigate the performance of selected surface features under conditions of both sliding and pure rolling. In order to validate the model once again, some contacts found in the literature were also investigated. The results of these calculations agree qualitatively as well as quantitatively to those mentioned in literature. The results of various surface features are finally presented and compared to each other and conclusions regarding the main influence factors are discussed.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Monotonic Stress-Strain Response of Case Hardened Bearing Steels, Part I: Determination of hardness profiles and plastic properties
G. Subhash, N. Arakere, M. Klecka, N. Branch, University of Florida, Gainesville, FL
Previously published experimental rolling-element fatigue test Weibull parameters for VIM-VAR, AISI M-50, EFR 18-4-1, and VAR 18-4-1 were used to construct a Monte Carlo simulation of rolling-element bearing fatigue. The simulation results were compared with those obtained from experiments and found to be in good agreement. The simulation results were also used to predict the fatigue life of a rolling-element bearing under a given load and speed.

4 - 4:30 pm
Monotonic Stress-Strain Response of Case Hardened Bearing Steels, Part II: Elastic-Plastic Finite Element Analysis
N. Arakere, G. Subhash, N. Branch, M. Klecka, University of Florida, Gainesville, FL
Case hardened bearing steels with plastically graded surfaces (PGSs) have broad applications in high-performance bearings and gears. The plastic properties of case hardened surfaces do not vary with depth while the plastic properties at intermediate depths vary widely and are graded monotonically with depth. In our investigation, we have developed a two-part method, (i) a coordinated experimental investigation that utilizes micro indentations to obtain the hardness profile of the virgin material as a function of depth and a macro indentation spanning the graded region of the PGS that induces large plastic deformation through the case layer, and (ii) an elastic-plastic finite element analysis for determining the monotonic constitutive response of case hardened PGSs. This part II paper utilizes the experimental data in a computational model of the macro indentation process along with the stress-strain response of the homogeneous materials of case and the core materials. A power-law model is fit to the stress-strain responses of the case and core materials. The exponents of the two materials provide a map of the flow stress reached along the stress-strain curves at each depth of the PGS. From the above results, we are currently developing empirical models to identify the surface hardness trends for given gradation in the subsurface regions.

4:30 - 5 pm
Comparison of Rolling Element Bearing Fatigue Lives Using Johnson-Weibull Monte Carlo Simulations
B. Vlcek, N. Murray, Georgia Southern University, Statesboro, GA, R. Hendricks, E. Zaretsky, NASA Glenn Research Center, Cleveland, OH
Previously published experimental rolling-element fatigue test Weibull parameters for VIM-VAR, AISI M-50, EFR 18-4-1, and VAR 18-4-1 were used to construct a Monte Carlo simulation of rolling-element bearing fatigue. Confidence numbers were determined by (1) simulating groups of 100 fatigue failures for each bearing type, (2) comparing pairs of simulated groups, and (3) determining for each pair how many L10 and mean lives of bearing type A were greater than those of type B. These simulated confidence numbers were compared to confidence numbers determined by traditional graphically methods based on the limited series of figures published by Leonard Johnson, and by using linear algebraic approximations derived from curve fits of the original Johnson figures. There was reasonable agreement between each of the three methods. In addition, the algebraic approximations eliminated the cumbersome need to graphically interpolate between Johnson's original figures.

5 - 5:30 pm
Elastic Field of Inhomogeneities Embedded in a Half Space Under Contact Loading
K. Zhou, L. Keer, Q. Wang, Northwestern University, Evanston, IL
Inhomogeneities which have different elastic moduli than the host material or matrix are ubiquitous in solid materials. In materials subjected to cyclic contact loading (e.g., bearings and gears), the presence of inhomogeneities near the contacting surface disturbs the subsurface stress field surrounding them and is often detrimental to material performance and life. Many experimental studies have demonstrated that stress concentrations caused by inhomogeneities can lead to subsurface cracking and yielding, which may result in failure. In this study, we develop an elastic solution for multiple inhomogeneities in an isotropic half space under contact loading. The solution takes into account the interactions between all the inhomogeneities as well as the interaction between the inhomogeneities and the loading indenter. Using this solution, we study a single inhomogeneity embedded in a half space subjected to indentation and a stringer of inhomogeneities in an indented half-space to reveal the mechanisms of failure caused by inhomogeneities.

5:30 - 6 pm
Advanced Analysis Methods Aid Optimizing Bearing Geometries For Vertical Roller Mill Pulverizer Journal Anti-Friction Rolling Element Bearings, Used in Coal (Thermal) Power Generation and Cement Processing Industries
S. Kuppuru, J. Rhodes, T. Baker, Timken Corporation, Canton, OH
Vertical roller mills (VRMs) are used in coal and cement pulverizing applications for power generation and cement manufacturing respectively. The advantages offered by vertical roller mills are reduced energy consumption as well as flexibility in manufacturing. The availability of high calorific value anthracite coal deposits around the globe is decreasing, thereby requiring coal power plants to operate with lower calorific value coals, such as brown coal, powder river basin (PRB) coals in the USA, and lignite among others. Due to this reason, existing vertical roller mills for pulverizing coal will need to deal with additional tonnage of coal to fire the same boilers, mostly without increasing the footprint of the vertical roller mills. Under such circumstances any modifications to the existing vertical roller mills, that would allow for additional coal processing rates, would be an added plus for the coal power stations.

New bearing system analysis methods and technical/manufacturing capabilities available within the Timken Company allow for modifications to internal geometries of bearings, allowing for increased bearing performance such as, throughput increases within an existing journal/pulverizing roller design, increased tolerance of bearing system to misalignments encountered in the housing/shaft geometries and the like.

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Y. Lee, H. Jeon, Sungkyunkwan University, Suwon, Republic of Korea, S. Cho, Samsung Electronics, Suwon, Republic of Korea

The Prediction of Wear Life for Parts of a Rotary Compressor with Carbon Dioxide as a Refrigerant

Y. Lee, H. Jeon, Sungkyunkwan University, Suwon, Republic of Korea, S. Cho, Samsung Electronics, Suwon, Republic of Korea

Carbon dioxide (CO2) was investigated as an alternative refrigerant to replace the HFCs (hydrofluorocarbons) refrigerant in an air-conditioning system due to the environmental concerns.

The substitution of the refrigerant requires to operate the system under high pressure, which results in an increase of the contact pressure among compressor parts. The effect of this increased pressure on the surfaces of the parts in contact must be investigated. In this study, actual parts from the compressor were tested in a customized tester, which was designed to mimic the motion of the parts during compression under load, to improve reliability of the compressor with carbon dioxide as refrigerant. The wear life of the compressor parts was predicted by evaluating wear volume and wear rate during experiments. The results from this experiment were compared with the parts from the actual compressor, which was operated for 3000 hours in the air-conditioning system.

The Prediction of Friction and Wear Behavior of A6061-SiCp (Ni-P coated) Composites

R. Chinnakurli Suryanarayana, S. Komandur Sudarshan, C. B Hudedagaddi, K. Ramaiah, PES Institute of Technology, Bangalore, India

A6061 are currently the most sought after matrix alloy to develop light alloy composites in aerospace, automotive, defence and space applications. A6061 based composites do posses higher specific strength, higher specific modulus and better wear resistance when compared with matrix alloy. There exists abundant literature as regards the processing of light alloy composites and their tribological characterization. The experimental data as regards the tribological behavior of the composites is a vital one in judging its suitability as regards its applications. However, the experimental data generation is quite expensive and time consuming. To overcome this, tribological researchers are currently focusing on developing theoretical models to predict the friction and wear behavior of metal matrix composites. However, meager information is available as regards the prediction of tribological behavior of A6061-SiCp (Ni-P coated) composites. A rule of mixture model will be discussed to predict both coefficient of friction and wear rates of the developed A6061-SiCp (Ni-P coated) composites. Archard’s and Yang models to predict the wear rates of developed composites at different loads and speeds will be discussed. The experimental verification of the theoretical prediction of coefficient of friction and wear rates has been carried out using a pin-on-disc wear testing machine. The predicted values are in close agreement with the experimental values.

Electron Microscopy Characterization of Copper Sliding Electrical Contacts

G. Bourne, D. McIntyre, J. Keith, N. Argibay, W. Sawyer, University of Florida, Gainesville, FL

The rates of wear in sliding metallic contacts have recently been found to be closely related to the rates of oxidation at the surface. Wear rates have shown an order of magnitude difference between the anode and cathode in contacts designed to simulate direct current motors. Electric motors are emerging as a predominant and efficient means for energy to motion conversion. It is critically important to evaluate these surfaces and the subsurface deformations that arise from sliding metallic contacts in order to gain further fundamental understanding of the chemical, physical, and morphological processes that govern wear. This presentation reports on characterization of surface and subsurface microstructure and deformation using focused ion beam scanning electron microscopy (FIB/SEM) and transmission electron microscopy (TEM) on samples obtained from a newly developed rotating pin-on-disk tribometer that can perform experiments on a single metal fiber.

Tribological Improvement of Using Ionic Liquids and Nanoparticles as Oil Additives

R. Gonzalez, J. Viesca, A. Hernández Battez, University of Oviedo, Gijón, Spain, A. Torres, G. García-Atance, Bournemouth University, Bournemouth, United Kingdom

Friction, wear and surface damage in lubricated mechanical contacts can be reduced by applying adequate additives to common lubrication oils. In this respect, nanoparticles used as oil additives have been investigated recently. Results show that they can be deposited on the rubbing surface and improve the tribological properties of the base oil. Likewise ionic liquids used as base oil have exhibited a good tribological performance with a low friction coefficient. However, the utilization of the ionic liquids as neat lubricants is not feasible from the economical point of view. Therefore, they would be more likely used as additives in the lubricant industry. This paper compares the friction and wear behavior of a steel/steel contact lubricated with a mineral base oil added with CuO nanoparticles and a imidazoliunm ionic liquid respectively. Test was made using a block-on-ring tribometer set for pure sliding contact. A reduction in the friction and wear was observed in the tests with both additives compared with the pure mineral base oil.

A Study on Characteristics of Cu-based Powder Metallurgy Brake Materials

G. Gilmah, D. Chen, P. Huang, South China University of Technology, Guangzhou, China

The characteristics of Cu-based brake materials which are widely and successfully used for train were studied. The characteristics of worn surface of Cu-based powder metallurgy brake materials for train after undergoing working condition were studied. Three forms of wear mechanisms were observed during the dry sliding process, namely;

1. delamination wear,
2. plowing wear and
3. abrasive wear
The abrasive wear resulted in flake or break-away debris and these wear mechanisms were found to be responsible for high wear rate on samples sintered at 850oC and 900oC. The materials demonstrated excellent braking performance and wear resistance. The values of friction coefficient under excessive pressure (3.13MPa) dry conditions were 0.336, 0.343, and 0.404, at 850oC, 900oC and 950oC respectively. The results show that the main components of worn surface are graphite, SO2, Fe, Cu and oxides of Fe and Cu (Fe2O3 and CuO) and AlFe. The worn surfaces were divided into three sections: destructive wear section, medium wear section and low wear section. These wear mechanism were examined by using SEM, XRD and TALYSURF CLI 1000.

5 - 5:30 pm
Wear Behaviour of Cold Rolled Commercial Grade Pure Aluminium-Carbon Fibre Metal Matrix Composite
S. Sudarshan, PES Institute of Technology, Bangalore, India, M. Krishnamurthy, U.V.C.E, Bangalore, India, V. Basalalli, Sir M.V.I.T, Bangalore, India
This paper focuses on the wear behaviour of cold rolled commercial grade pure aluminium and copper coated carbon fibre composite. Carbon fibres were coated with copper by electrodess deposition technique. These coated fibres were dispersed in molten aluminium in the discontinuous form by conventional stir casting method. Further, these cast composites were subjected to cold rolling using a two high rolling mill. Adhesive wear tests were conducted on the cold rolled composites of different weight fractions of carbon fibres using a pin on disc machine at different loads and sliding velocities. Increase in carbon fibres in the composites from 0.5 to 2.5 Wt% resulted in a noticeable decrease in the wear resistance of the cold rolled composites. However, cold rolled composites do exhibit better wear resistance when compared with the cast ones under identical test conditions.

5:30 pm – Wear Business Meeting
interfaces to be designed that will yield a slow release of lubricant into a wearing interfaces to enable self-healing surfaces.

9:30 - 10 am

Tribology of Nanoconfined Water
M. Chandross, Sandia National Laboratories, Albuquerque, NM, C. Lorenz, King's College London, London, United Kingdom, J. Lane, G. Grest, Sandia National Laboratories, Albuquerque, NM

We report the results of large-scale Molecular Dynamics (MD) simulations of water confined to sub-nanometer thicknesses. We vary the amount of water and the applied pressure to examine the effects on the structure and dynamics of the confined water. Calculations of two dimensional diffusion constants indicate that the water remains liquid-like in all cases. The water is subjected to shear to measure the viscosity and microscopic friction. We find that while the viscosity increases by as much as a factor of six for low coverage and high loads, there is still no evidence of ice-like layers being formed. Friction coefficients can only be calculated at high shear velocities due to the low viscosity of the water and are found to decrease with increasing amounts of water, similar to experimental results.

10 - 10:30 am - BREAK

10:30 - 11:15 am

Contact and Friction of Nano-Asperities
M. Robbins, S. Cheng, Johns Hopkins University, Baltimore, MD, B. Luan, IBM, Yorktown Heights, NY

Scanning probe methods allow measurement of the behavior of single asperity contacts at the nanometer scale. However analysis of the results is complicated because of questions about the applicability of continuum mechanics results such in small contacts. This paper will present molecular dynamics studies of the effect of tip geometry, loading, sliding conditions and the presence of adsorbed monolayers on the substrate. The results are compared to continuum theory to determine the accuracy to which different material parameters may be inferred from continuum theory. Results for bare substrates vary strongly with atomic scale changes in tip geometry. Adsorbed monolayers reduce this variation and lead to a friction that rises linearly with load. Different methods for defining the real area of contact at molecular scales and analyzing its relation to friction will be discussed.

11:15 am - Noon

Microscale Tribology of Nanostructured Coatings
K. Wahl, Naval Research Laboratory, Washingon, DC

Novel nanostructured architectures are being explored for a wide range of applications including mimicking bioadhesive pads on insects and geckos, RF-microelectronics switches with carbon nanotube films, and energy harvesting from friction of piezoelectric fibers. Understanding how nanostructured materials behave requires experimental approaches at micron length scales. Examination of the mechanics and tribology of materials in this intermediate regime can be influenced by macroscale phenomena (such as wear and interfacial transfer film formation during sliding) as well as phenomena more often associated with nanoscale contacts (such as adhesion contributions). In this talk, I will present tribological and mechanical analysis of columnar nanostructured poly-(p-xylylene) thin films. The PPX films are structurally anisotropic, consisting of nanowires oriented at various angles with respect to the surface normal. Sliding friction experiments performed at discrete angles with respect to the nanowire orientation resulted in relatively uniform friction behavior but significant differences in deformation response of the films. Sliding ‘with’ and ‘against the column tilt axis resulted in measurable friction anisotropy as well as depth hysteresis. A simple mechanical model is proposed to explain the observed depth anisotropy. The value of monitoring both friction and contact depth simultaneously will be discussed and evaluated in context of nanostructured coatings.

Lubrication Fundamentals V

Session Chair: C. Kajdas, Institute for Fuels & Renewable Energy, Warsaw, Poland

8 - 8:30 am

A Preliminary Study on Tribo-Photoemission from Sliding Surfaces
G. Molina, K. Hiratsuka, Chiba Institute of Technology, Chiba, GA, C. Kajdas, Warsaw University of Technology, Institute of Chemistry, Warsaw and Plock, Poland

The authors have carried out extensive research on the triboemission of electrons and charged particles from sliding contacts under high vacuum, and more recently on photon emission from alumina and palladium, which was measured using a twin-ring sliding/rolling test rig installed in a chemiluminescence detector. They also have started preliminary research on triboemitted photon-counting by a solid-state device inside a vacuum chamber. Measurements will be carried out for materials from which electron emission were previously detected. This work also includes a review of most relevant literature, and advantages and disadvantages of the techniques are discussed.

8:30 - 9 am

Tribological and Rheological Behaviour of a Heavy Naphthenic Oil and Polyisobutenes: A Comparative Study
L. Bastardo-Zambrano, M. Fathi-Najafi, Nynas AB, Nynashamn, Sweden

Recent developments in the base oil industry have resulted in shortages of high viscosity base oils in the market. The shortage of these types of base oils (known as bright stocks), has prompted lubricant and grease manufacturers to look for alternative products to substitute them. Heavy naphthenic oils and polymers (especially polyisobutenes) are among the alternatives to bright stocks present in the market at the moment. Previous work done at Nynas has compared heavy naphthenic oils and polyisobutenes (PIBs) in terms of properties such as tackiness, film strength and shear stability, among others. In this work, the behaviour of two different PIBs and a heavy naphthenic oil is studied at different temperatures by means of different tribological and rheological techniques with the aim to understand the different mechanisms with which these different substances affect the friction coefficient between surfaces.

9 - 9:30 am

The Pressure and Foot Print of a Viscoelastic Dry Point Contact Under Dynamic Conditions: Comparison Between the Contact Model Predictions and Experimental Observations
M. Organisciak, A. Felix Quinonez, A. Naveira Suarez, P. Ehret, SKF Engineering & Research Centre, Nieuwegein, Netherlands

Elastomers are commonly used in many applications such as tires, wind shield blades and reciprocation and rotating lip seals. The dynamic behavior of a contact between an elastomeric body and a hard surface is directly dependent on the mechanical behavior of elastomers, characterized by their viscoelasticity: the stiffness depends on the temperature and frequency of excitation of the material. In this paper, a new formulation of the viscoelastic dry contact is proposed. It is based on a multi-relaxation material model and a modified half space formulation. This formulation allows the implementation of a fast numerical solver based on multigrid relaxation techniques. The model is applied to a ball on disk contact to investigate the dependency of the contact size, shape and pressure to the rotating speed. The contact size as well as the contact pressure distribution change drastically with sliding speed. Numerical results are correlated in terms of contact foot print to ball on disk observations and measurements.

9:30 - 10 am

Session Chair: C. Kajdas, Institute for Fuels & Renewable Energy, Warsaw, Poland

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Wear experiments on nickel surfaces show that stable, nanocrystalline tribofilms can form under certain conditions, even on single crystals. The presence of these nanocrystalline layers is qualitatively dependent on the crystallography of the surface and wear orientations, and are responsible for a marked reduction in friction. For example, when a 1 N normal load and 3.75 mm/s tangential speed are applied to a 1/8" diameter Si3N4 ball in contact with electropolished single crystal nickel in a dry nitrogen environment, the measured friction coefficient is usually in the range 0.6 to 0.8. However, when the nickel surface is {110} and the sliding direction is <211>, the friction coefficient abruptly drops to 0.3 after about 500 cycles, where it remains indefinitely. Modeling of this phenomenon, based on crystal plasticity, microstructure formation, and grain boundary sliding, suggests that the self-lubrication is due to the ability of ultra-fine-grained microstructures to support grain rotation. Wear experiments on bulk nanocrystalline nickel deposits support this hypothesis by demonstrating low friction coefficients (around 0.3) and virtually no wear-in under low loads and sliding speeds, and higher friction (around 0.6) under high loads and speeds. We will provide an overview of the experiments and modeling of nanocrystalline film formation on single crystal nickel, detail the results from friction experiments on bulk nanocrystalline nickel, and discuss model validation of the phenomenon's strain rate sensitivity.

10 - 10:30 am - BREAK

10:30 - 11 am
Thermodynamic Approach to Coulomb Friction, Wear, and Self-lubrication
M. Nosonovsky, University of Wisconsin-Milwaukee, Milwaukee, WI

Friction and wear are often described by linear empirical laws, such as the Coulomb-Amontons law and Archard's law. These laws are valid in a very diverse range of situations (various material combinations and friction mechanisms, as well as loads ranging from nano- to thousands of tons). However, there is apparently no general explanation of their striking universality. In physics, such linear empirical laws are often seen as the consequence of the Osnager linear relationships between the generalized thermodynamic forces and flows. However, there is a number of difficulties in deducing the Coulomb-Amontons law from the Osnager relationships. We show that by assuming that the normal degree of freedom plays a significant role in friction and by an asymptotic transition from the 3D bulk body to the 2D frictional interface, the Coulomb-Amontons law can be obtained from the Osnager formalism. Furthermore, the approach provides a convenient general framework to describe wear (Archard's law) and self-lubrication/self-healing. The relation of the model to the novel self-lubricating/healing materials is discussed.

11 - 11:30 am
Reciprocating Friction and Wear Studies of Bovine Cartilage Sliding Against Cartilage, Polyurethane, Polyethylene, and CoCr Alloy
R. Erck, O. Ajayi Argonne National Laboratories, Argonne, IL, J. Gil, Loyola University, Maywood, IL, S. Chudik, Hinsdale Orthopedic Assoc, Hinsdale, IL

We report the friction and wear results of a reciprocating tribological study using bovine cartilage specimens sliding against tibial plateau cartilage, polyurethane (PU), ultrahigh molecular weight polyethylene (UHMWPE), and CoCr alloy specimens. Dissected condyles, lubricated with lactated Ringer's solution and bovine serum at 37°C, were slid using 250 N load, 2 Hz reciprocation, with stroke lengths up to 2.5 cm, for a period of one hour, and repeated seven times. Contact pressure was ascertained using indicating film as a nominal 2.3 MPa. Wear debris was collected and weighed using a siring filter membrane technique. Cartilage wear rates were in a ratio approximately 4:2:1 for sliding against CoCr, PE, and PU, respectively. Worn surfaces were examined using white light interferometric profilometry. Cartilage/cartilage sliding produced relatively constant coefficients of friction between 0.01 and 0.02 with no visible wear. The coefficient of friction for cartilage against CrCo was steadily increasing as a function of time up to approximately 0.15, with an excellent fit to \( \mu = m(1 - \exp(-bt)) \). A polyurethane counterface produced generally lower and constant coefficient of friction and a UHMWPE counterface produces generally decreasing frictional behavior (to 0.05), with sample-to-sample variation that may be associated with differences in surface machining topography. Work supported by U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Vehicle Technologies, under contract DE-AC02-06CH11357.

11:30 - Noon
Investigation on Viscoelasticity Property of Ultra Thin Film of PFPE by UHV Non-contact Atomic Force Microscopy
Z. Xiangjun, Z. Xiaohao, W. Shizhu, State Key Laboratory of Tribology (SKLT), Tsinghua University, Beijing, China

In this paper, we present a quantitative method to investigate the viscoelastic property of ultra-thin film based on the ultra high vacuum (UHV) non-contact AFM technique. Maxwell model is used to introduce the elastic modulus and damping factor of the thin film and response signal of AFM tip is simulated by SimuLink. A mixed intermittent contact model is introduced to take both the van der Waals force and contact force of the thin film into consideration, which makes the method more suitable to describe the contact steps and meanwhile measure the property of ultra-thin films. Contact force between the AFM tip and the thin film is analyzed by finite element modeling instead of Hertz model to increase the precision of the results. From our result, analog signal and the test curves are in good agreement in tendency. The model founded in this paper enable the application of non-contact AFM to investigate the mechanical properties of ultra-thin films.
In this work, we present and discuss the preliminary results of an ongoing research program aiming at the development of new bulk self lubricating materials having low friction coefficient combined with high mechanical strength and wear resistance. A new processing route to obtain a homogeneous dispersion of discrete particles of solid lubricant in the volume of sintered steels produced by metal injection molding is presented. This was achieved by in situ formation of graphite nodules due to the dissociation of precursor (silicon carbide SiC particles) mixed with the metallic matrix powders during the feedstock preparation. Nodules of graphite (size ≤ 20µm) presenting a nanostructured stacking of graphite foils with thickness of the order of a few nanometers were obtained. The friction coefficient decreases and the durability increases drastically due to the amount of graphite formed, producing sintered steels that combine high mechanical strength and low friction coefficient, thus presenting better wear resistance.

9:30 - 10 am
Tribological Properties of Fluorinated Carbon Nano/micro Particles
P. Thomas, J. Mansot, Université des Antilles et de la Guyane, Pointe a Pitre, France, W. Zhang, M. Dubois, K. Guérin, A. Harmi, Université Blaise Pascal, Aubiere, France

Graphite fluorides are well known to present good lubricating properties [1]. In this paper, the friction behaviour of various nano fluorinated carbons, respectively carbon nanofibres, amorphous and graphitized carbon nanofibres and nanocubes fluorinated at temperatures ranging between 280°C and 520°C in F2 atmosphere[2], are investigated under air. The friction properties of the compounds are investigated on burnished films using a ball-on-plane tribometer. The tribofilm structure at the end of the test is investigated using Raman spectroscopy and electron microscopy and compared to the initial nano particles structure. In all cases, fluorinated nano compounds present better friction properties than pristine ones. The Raman investigations of the films structure allowed us to point out that the friction process induces a partial defluorination and an increase of disorder as already observed with graphite fluorides. However, the tribologic properties of nanofibres and graphitized nanodiscs and nanocones remain better than fluorinated graphite ones. An action mechanism is proposed.

Acknowledgements
The authors acknowledge the Conseil Régional de la Guadeloupe, the European Regional Development Fund and the European Social Fund for their financial supports.

10 - 10:30 am - BREAK

10:30 - 11 am
Lubricating Performances of Room Temperature Highly Fluorinated Graphite Heat-treated Under Fluorine Atmosphere
P. Bilas, P. Thomas, J. Mansot, L. Romana, T. Césaire, Université Antilles Guyane, Pointe à Pitre, France, C. Delabarre, M. Dubois, A. Harmi, Université Blaise Pascal de Clermont Ferrand, Aubière, France

Tribological properties of new graphite fluorides are investigated. These compounds are obtained at room temperature by the reaction of graphite with a gaseous mixture of HF and F2 in the presence of mineral fluorides (IF5, BF3 or ClFx) as catalysts and then post-treated under fluorine atmosphere at temperatures ranging from 100°C to 600°C (TFPT). Whatever were the catalysts used for the fluorination processes, the tribologic tests indicate that the best results are obtained for the materials in which the planar shape of the carbon layer (carbon atoms in sp2 hybridization) is maintained, the C-F bonds are mainly of semi-ionic nature and intercalated MFn species are still present in the van der Waals gap. The authors acknowledge the Conseil Régional de la Guadeloupe, the European Regional Development Fund and the European Social Fund for their financial supports.
vibration systems commonly integrated with oil analysis and ultrasonic detection technologies as part of a well-rounded predictive maintenance program. By implementing multiple technologies and integrating condition monitoring data maintenance practitioners are unlocking the maximum potential of plant-wide predictive diagnostic solutions to create complete pictures of machinery health, which serve as a foundation for machinery management. Topics will include an introduction to vibration theory, time and frequency domain, amplitude units, vibration severity, application of theory to identify equipment and component deficiencies, ultrasonic and laser alignment. Live demonstrations by industry experts in the field of vibration analysis will be presented.

10 - 10:30 am - BREAK

10:30 - Noon - Infrared Thermography
T. Faulkner, FLIR Systems, Inc., Las Vegas, NV
This segment within the "Alternative" Condition Monitoring Mini-Session will focus on the use of infrared thermography techniques commonly used in mature predictive maintenance, or condition monitoring programs. Topics will include an introductory presentation on IR thermography basics and how basic principles are used in conjunction with popular infrared cameras and software to perform equipment condition surveillance, in order to improve equipment reliability by identifying deficiencies prior to catastrophic loss of assets or optimizing performance within the operating context of the equipment. Live demonstrations by industry experts in the field of infrared thermography will be presented.

Session 7E
Fluid Film Bearings V 

Session Chair: M. Conlon, National Research Council Canada, Ottawa, ON, Canada

8 - 8:30 am
An Analytical Model for the Basic Design Calculations of Journal Bearings
R. Naffin, L. Chang, Penn State University, University Park, PA
An analytical model is developed in this paper for the basic design calculations of journal bearings. Analytical equations are derived making use of simple theories of journal-bearing lubrication and heat transfer in conjunction with published design tables of numerical solutions. The analytical equations can be programmed into a computer to yield continuous solutions in the design space of length-to-diameter ratio of the bearing and the bearing eccentricity ratio. The model effectively replaces the discrete design charts and tables and eliminates the need for manual iterations and interpolations in the solution process. The analytical model may be integrated into a computer-aided-design environment for more advanced design and analysis of journal-bearing systems.

8:30 - 9 am
An Original Double Conical Hybrid Bearing: From its Design to its Experimental Use
P. Jolly, O. Bonneau, J. Freau, Université de Poitiers, Poitiers, France
The test rig BALAFRE is dedicated to the characterization of dynamic coefficients of thin fluid film components (bearings, seals). The major piece of the rig is a double hydrostatic bearing that is performed by a double conical fluid thrust bearing fed with water. It allows the shaft to be guided in rotation with a high stiffness (axial, radial, and angular) in order to transmit dynamic excitations to the rotor of the tested article. Following a brief description of the test rig, the major steps of design (geometrical dimensions, number of cavities) and qualifying of the double conical bearing are detailed. This includes both numerical and experimental tests. A comparison of the results is proposed for various functioning parameters: inlet pressure, working temperature, axial load, axial gap and rotation speed.

9 - 9:30 am
A Transient Based, Numerical Analysis of Flow and Pressure Fields inside a Variable Depth Rayleigh Step Hydrodynamic Porous Thrust Bearing
F. Horvat, M. Braun, The University of Akron, Akron, OH
This paper presents the numerical solution for the development of flow patterns and pressure profiles for a Variable Depth Rayleigh Step thrust bearing (VDRS) fed through a porous, smooth bottom plate. This self-acting hydrodynamic bearing is hybrid in nature, resulting from the combination of two classical geometries, the slider and the Rayleigh step with a distributed lubricating fluid feed method. The parameters used are: (i) geometric (number of circumferential steps, the depth and angle of the recess, and the bottom plate porosity and permeability) and (ii) operational (the VDRS and smooth plate angular velocity/es), and the porous plate fluid supply pressure. The isothermal solution is obtained using the commercially available software package CFD-ACE+. The package uses the full Navier-Stokes equations modified to accept the Darcy and Forchheimer terms. The resulting velocity and streamline maps, pressure patterns as well as stiffness and damping are presented on a parametric basis.

9:30 - 10 am
Hydrodynamic Lubrication Evaluation of Trust Bearings
L. Vieira, K. Cavaclca, P. Nomura, Unicamp - University of Campinas, Campinas, Brazil
The pressure generation within the lubricant fluid present in the clearance between a thrust bearing and the collar attached to the shaft has a fundamental importance to avoid contact between solid parts with axial relative motion. Any existing contact can lead to friction, wear and, as a consequence, failure of elements on a rotating machine. Therefore, in order to design an effective bearing, it is important to know how the pressure is generated in the oil film and the load capacity transmitted from the collar to the bearing throughout the fluid. Thus, it is necessary to solve the Reynolds' Equation to obtain the pressure distribution on the sections under Hydrodynamic Lubrication. Then several operation parameters can be obtained, such as, the total load capacity, lubricant fluid flow, position of the maximum pressure and so on. In order to evaluate the proposed hydrodynamic lubrication problem, a numerical solution model using the Finite Volume Method in polar co-ordinates was applied. This method allows the analysis of the bearing pads and the grooves which have a very important role on the lubrication of the system. Operation characteristics of several thrust bearings with different geometry were evaluated. The analysis allowed the comparison amongst the effects caused by the set of parameters involved, such as rotating speed, oil viscosity, film thickness and sector radii, on the results of pressure distribution and the calculated load capacity, and also the evaluation of the optimum dimensions for bearings and its influence on the component efficiency.

10 - 10:30 am - BREAK

10:30 - 11 am
The Impact of the Cavitation Model in the Analysis of Microtextured Lubricated Journal Bearings Considering Static and Dynamical Situations
M. Jai, Insa de Lyon, Villeurbanne, France, G. Buscaglia, Universidade de Sao Paulo, Sao Carlos, Brazil
In this work, we analyze the impact of the cavitation model on the numerical assessment of lubricated journal bearings. We compare results using the classical Reynolds model and the so-called p-theta model proposed by Elrod and Adams [1974, "A Computer Program for Cavitation and Saturation Problems," Proceedings of the First LEEDS-LYON Symposium on Cavitation and Related Phenomena in Lubrication, Leeds, UK] to fix the lack
of mass conservation of Reynolds’ model. Both models are known to give quite similar predictions of load-carrying capacity and friction torque in nonstarved conditions, making Reynolds’ model the preferred model for its better numerical behavior. Here, we report on numerical comparisons of both models in the presence of microtextured bearing surfaces. We show that in the microtextured situation, Reynolds’ model largely underestimates the cavitated area, leading to inaccuracies in the estimation of several variables, such as the friction torque. This dictates that only mass-conserving models should be used when dealing with microtextured bearings.

11 - 11:30 am
Behavior of Infinitely Long Radial Journal Bearing Under n-film Cavitation Model

M. Ricci, Brazilian Institute for Space Research (INPE), São José dos Campos, Brazil
In the mechanical engineering moving system’s field the radial journal bearing is one of the great interest. It consists of a circular inner cylinder (the rotor) that turns inside a hollow cylinder of slightly larger radius (the stator). The cavity between he cylinders is filled with a lubricant and any load carried by the rotor must be supported by the fluid forces exerted by the lubricant on the rotor. The system can be described by a set of four first order’s nonlinear ordinary differential equations which the fluid forces are approximate solution of a partial differential equations and shows a great richness of behavior same at simplest case of cavitation model, autonomous, unforced and balanced-mass rotor system. Rigorous geometrical constraints are imposed to the movement of the rotor’s center about the stator’s center to avoid the contact between them. Otherwise, the contact could well result in bearing failure. Starting from the Reynolds approximation for the long bearing the paper uses of numerical methods for bifurcation problems to calculate Hopf bifurcation points and to obtain branching of a periodic orbits that emanate from stationary solutions. The paper also shows the amplitude ad frequency of periodic solutions as a function of rotor’s angular velocity for the low, medium and high loads.

11:30 - Noon
Thermohyrodynamic Aspects in Lubrication of Sliding Contacts with Textured Surfaces

S. Glavatskih, S. Cupillard, M. Cervantes, Lulea University of Technology, Lulea, Sweden
There are experimental indications that textured surfaces, composed by a repetition of well defined identical patterns, can improve hydrodynamic performance. Therefore, there is a need to understand and explain the effects of textured surfaces on hydrodynamic contact performance. A Computational Fluid Dynamics (CFD) analysis of the flow field can provide such an understanding. The full Navier-Stokes equations are solved with a CFD code for both slider and journal bearings. Thermal and cavitation effects are considered. Numerical techniques deforming the computational grid in time are used to recalculate the film gap and to simulate a texture pattern located on a moving surface.

Session Chair: J. Levert, Maritime College, State University of New York, Bronx, NY
Session Vice Chair: F. Gao, Texas A&M University, College Station, TX

8 - 8:30 am
UHMWPE/Chitosan/Hydroxyapatite Composites and Wear Characteristics

C. Korach, K. Nelson, H. Mubareg, G. Halada, State University of New York at Stony Brook, Stony Brook, NY
Ultra high molecular weight polyethylene (UHMWPE) is currently used as a material for the cups of total hip and other joint replacement surgeries. However, a major obstacle that reduces the effectiveness is the polymer wear characteristics that lead to a short duration in active use. Previous research has utilized UHMWPE/Hydroxyapatite (HA) composites to increase the polymer wear life, however, the composites were found to lack strong filler-matrix bonding. Here, strengthening the interfacial bonds between the HA particles and the UHMWPE by introducing an interlayer of chitosan (Ch) coating the HA particles is considered. Chitosan, a natural biopolymer, is one of the most ubiquitous materials found in nature and is non-invasive to humans. The wear characteristics of UHMWPE, UHMWPE/HA, and UHMWPE/Ch/HA will be compared, showing an improvement in wear rates for the Ch/HA filler composite.

8:30 - 9 am
Effect of Crystallinity and Thickness on Hardness in ZrC Thin Films

J. Zhang, G. Bourne, V. Craciun, University of Florida, Gainesville, FL, D. Craciun, G. Socol, G. Dorcioman, N. Stefan, Institute for Laser, Plasma, and Radiation Physics, Bucharest, Romania
Single and multilayer thin films of zirconium carbide were grown on a Si substrate through pulsed laser deposition with the goal of creating ultra-hard films. Such films have applications in various fields such as wear-resistant coatings and electronic devices. The films included single and mixed layers of zirconium carbide, zirconium nitride, and titanium nitride. The films density was estimated from x-ray reflectivity measurements and their crystalline structure from symmetrical and grazing incidence x-ray diffraction. Hardness results were obtained through nano-indentation with a diamond cube-corner tip on a Hysitron TribolIndenter. Using a focused ion beam scanning electron microscope (FIB/SEM), cross sections of the films were cut out for analysis by transmission electron microscopy (TEM). Nanomechanical testing and electron microscopy results are presented.

9 - 9:30 am
Fretting Damage to Composite Implant Materials - In-vitro Test Strategy

D. Drees, S. Achanta, Falex Tribology NV - Falex Corporation Group, Rotselaar, Belgium, J. Juhasz, S. Best, Cambridge Centre for Medical Materials Department of Materials Science & Metallurgy, Cambridge, United Kingdom, R. Brooks, N. Rushton, Orthopaedic Research Unit, University of Cambridge, Cambridge, United Kingdom
A composite material, well established in dentistry, is adapted for load bearing implants in the human body (intramedulary nail and compression plate). The implants undergo small sliding due to impact, fretting, and could release wear particles in the body. An important part of the risk analysis when introducing these materials as bone implants, is the characterisation of wear particles and the wear rate, and the biological response of cultures on these particles. In this work, it is shown how an in-vitro simulation test generates wear particles that can be used for inflammation studies. Furthermore, the influence of the simulation frequency was studied, showing that the wear rate and particle characteristics are not influenced by accelerating the test. This makes accelerated testing of these materials possible.

9:30 - 10 am
A Study on Surface Finish of Laser Sintered Iron-SiC Composites

R. Chinnakurti Suryanarayana, PES Institute of Technology, Bangalore, India, S. Cheekur Krishnamurthy, R. Vr, Central Manufacturing Technology Institute, Bangalore, India, K. Ramaiah, PES Institute of Technology, Bangalore, India
Development of MMCs(Metal Matrix Composites) by laser sintering is currently gaining wide spread importance in industries, owing to its several unique advantages, such as building up of complex and intricate parts in a short period of time. At present the focus is mainly on processing of MMCs by laser sintering. However, meagre information is available as regards the evaluation of surface finish of MMCs produced by laser sintering. It is the surface finish of RP sintered parts that mainly dictates the mechanical properties and also the geometric...
Aluminium-carbon fiber composites have attractive properties for a variety of automotive and aerospace applications. Particular attention has been paid to the unidirectional carbon fibers reinforced metal matrix composites (MMCs) due to their high mechanical properties, low thermal expansion coefficient in the fiber direction, good electrical and thermal conductivity and potential of high damping capacity. However, the widespread acceptance of carbon fiber-reinforced aluminum composite has been limited due to the various problems encountered during the fabrication of the composites. It has been reported that carbon fibers are difficult to be wetted by molten aluminum and its alloys. By applying suitable fiber coatings, the wetting characteristics of the fiber with the metal matrix can be improved. In this investigation, carbon fibers coated with copper and cut to size have been used as reinforcements to develop their composite with aluminum. Further, the composite developed has been subjected to a wire drawing operation. The electrical conductivity of as cast and wire drawn composites were determined. Experimental results have indicated an improvement in electrical conductivity of as cast and wire drawn composites as compared with base aluminum metal.

11:30 am

A Quantitative Metric for Nanocomposite Dispersion Analysis

H. Khare, D. Burris, University of Delaware, Newark, DE

The materials science community has identified particle dispersion as a primary challenge area for the advancement of polymer nanocomposites technology. The stochastic complexities of these systems have motivated the use of qualitative TEM images assessments as the ‘gold standard’. While numerous quantitative dispersion analyses have been proposed, they have proven cumbersome, system specific and unreflective of the proposed benefits of nanoparticles reinforcement. No single quantitative method has been adopted by the community to date and inferences about processing and dispersion effects require significant subjectivity. This paper presents a quantitative analysis of particle dispersion which (1) makes use of typical TEM dispersion images, (2) directly reflects proposed nano-reinforcement mechanisms and (3) outputs a single intuitive performance metric. By quantitatively isolating dispersion effects, this technique may help link disparate studies while providing defensible quantitative insights into nanoscale reinforcement mechanisms.

11:30 - Noon

Lubrication of Ti3SiC2/Si3N4 Tribo-Couple: From Water to Ethanol

J. Lu, S. Ren, J. Meng, S. Yang, State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, China

Ethanol is a renewable fuel because it is available by fermenting and distilling the biomasses. Low friction of self-mated Si-based ceramics, e.g. Si3N4, lubricated by ethanol and water was reported. Ti3SiC2 is a promising material applied in many fields because of its combined merits of metal and ceramic including machinability, electrical and thermal conductors, stiffness and relative softness, resistance to thermal shock, oxidation and corrosion. It was reported that Ti3SiC2/SiC composite experienced low friction and wear in ethanol. In this paper, the tribological behaviors of Ti3SiC2/Si3N4 tribo-couple in pure water, pure ethanol and their mixtures were investigated. The tribo-couple exhibited good tribological performance in pure ethanol but poor tribological behavior in water. In mixtures, low friction was only available in 1% water solution. The dependences of wear rates of Ti3SiC2 and Si3N4 on water fraction were a little bit more complex. Finally, the possible tribochemistry was discussed.

Session 7G

Rolling Element Bearings III

Session Vice Chair: B. Jalalahmadi, Purdue University, West Lafayette, IN
Session Chair: M. Kotzalas, The Timken Company, Canton, OH

8 - 8:30 am

Fatigue Life Performance of Lubricated Hybrid Rolling Contact Bearing Elements

Z. Khan, Bournemouth University, Poole, United Kingdom

Experimental results of the rolling contact hybrid ceramic/steel contact with refrigerant lubrication and their failure mechanisms due to various induced defects are presented in this paper. Fatigue life performance of ceramic bearing elements in relation to indents and radial cracks and their location, position within the Hertzian contact and geometry are discussed. Rolling contact fatigue test programme is provided. The fatigue life performance of the rolling elements with respect to various artificially induced surface defects is studied and the results are discussed and presented in this paper. Surface profiles of the failed specimens, using various techniques were obtained during this research and are presented.

8:30 - 9 am

Stick-slip Contact of Dissimilar Elastic Materials

D. Nélia, INSIA Lyon, Villeurbanne, France

The stick-slip phenomenon results in a complex distribution of surface and subsurface stress, which also varies during the fretting cycle. Some analytical solutions are given in the literature for circular and line contacts when the contacting bodies have identical elastic properties. When the materials are different and when the contacting bodies are neither cylindrical nor spherical, a numerical approach is usually required. This paper presents the result of a numerical investigation performed to describe the pressure distribution in a stick-slip contact between i) an ellipsoid and a flat of identical elastic properties but for various ellipticity ratio ranging from 1/30 to 30, and ii) a sphere and a flat with various Young modulus ratio ranging from 1 to 8. For similar elastic properties it is confirmed numerically that the sliding along the transverse direction has negligible effects on the surface shear stress distribution for non nil Poison’s ratio. For elastically dissimilar bodies and circular point contact it is found that the coupling between normal and tangential effects can not be neglected anymore since it strongly affects the surface pressure distributions. The analytical solution which neglects the coupling effects is then no more valid.

9 - 9:30 am

Fundamental Study on the Use of the Timken Roller Bearing Fatigue Tester to Differentiate Driveline Lubricant Additive Performance. Part 1/2: Statistical Analysis of Test Results


The impact of driveline lubricants on rolling element bearing fatigue has been an important concern for many years. The recent emphasis on improved drivetrain efficiency, resulting in the use of lower viscosity transmission and axle fluids, has further heightened interest in the impact of lubricants on bearing life. A number of laboratory roller bearing test machines have been used to qualify lubricants for automotive applications. Included in these is the Timken roller bearing fatigue tester. In order to better understand the impact of lubricant additive chemistry in the Timken test, an experimental matrix of ZDDP and ashless phosphate additives, along with a commercial fluid, was evaluated. In Part 1 we describe the test procedure.
and present a statistical analysis of the fatigue life results.

9:30 - 10 am
Fundamental Study on the Use of the Timken Roller Bearing Fatigue Tester to Differentiate Driveline Lubricant Additive Performance. Part 2: Surface Analysis
The impact of driveline lubricants on rolling element bearing fatigue has been an important concern for many years. The recent emphasis on improved drivetrain efficiency, resulting in the use of lower viscosity transmission and axle fluids, has further heightened interest in the impact of lubricants on bearing life. A number of laboratory roller bearing test machines have been used to qualify lubricants for automotive applications. Included in these is the Timken roller bearing fatigue tester. In order to better understand the impact of lubricant additive chemistry in the Timken test, an experimental matrix of ZDDP and ashless phosphate additives was evaluated in a model lubricant. In Part 2 we explore the tribochemical mechanisms governing additive performance in light of data from Auger sputter-depth profiles and transmission electron microscopy on the end-of-test bearings.

10 - 10:30 am - BREAK

10:30 - 11 am
Effect of Imbalance and Surface Defects on Flexible Rotor System Dynamics
A. Ashktekar, F. Sadeghi, Purdue University, West Lafayette, IN
In order to accurately simulate bearing dynamics and predict life, interaction of a bearing with rotor system needs to be considered. Forces acting on a bearing, supporting flexible rotors, are considerably different from the forces calculated with rigid rotor assumption. Further, the cage undergoes flexing during operation which severely affects the bearing performance and life. The effects of flexible components are amplified with presence of imbalance in the rotor and/or surface defects on race surface. Current work presents a new model incorporating flexible rotor system and flexible cage with a dynamic bearing model. The model uses component mode synthesis approach for rotor flexibility and explicit finite element modeling for cage flexibility. Surface defects are incorporated into the model using a novel method based on the principle of superposition. An experimental setup has also been designed and manufactured to corroborate the model and study effects of imbalance and defects on bearing performance, forces, motion and operating temperatures.

11 - 11:30 am
CAGEDYN: A Contribution to Roller Bearing Dynamic Calculations; Part III: Experimental Validation
L. Houpert, Timken Europe, Colmar, France
Many models used in Cagedyn and described in part I and II have been validated by comparing calculated and measured values of the impact force of a ball falling on a beam, the hydrodynamic rolling force, the sliding traction force in an EHL contact, bearing cage impact forces and bearing cage slip. A description of the bearing test rig used for measuring cage impact force and cage slip is made. The correlation obtained is satisfactory, especially when looking at trends. The impact force increases when increasing the roller - cage pocket clearance, increasing the bearing end play (which causes a reduction of the load zone) and increasing the shaft speed. At very light radial load, impact force increases with the radial load for reaching a maximum value and then decreases as the radial load continues to increase. Cage slip increases as the radial load decreases and the shaft speed increases. Past cage failures and cage solutions to recent cage problems in real field applications have been explained by using Cagedyn and comparing the maximum calculated cage stress to the cage material endurance limit.

11:30 - Noon
Influence of Material Inclusions on Rolling Contact Fatigue Life
B. Jalalahmadi, F. Sadeghi, Purdue University, West Lafayette, IN, V. Bakolas, Schaeffler KG, Herzogenaurach, Germany
An implicit Voronoi finite element model was developed to simulate the randomness and topology of microstructure of bearing steels and its effects on rolling contact fatigue (RCF) life of bearing elements. In this investigation, material inclusions and their effects, which were not considered in the previous work, on RCF lives of bearing elements are studied. A parametric study was undertaken to determine the effects of size, shape, and number of inclusions on RCF. It is found that both softer and harder inclusions reduce lives and increase the scatter. Increasing the number of inclusions reduces fatigue lives approaching to a minimum life. Also, inclusions which are closer to the contact surface are more detrimental than the deeper ones. Based on the results obtained through the simulations, a life equation including the influence of inclusions is developed for rolling contact fatigue.

Session Chair: V. Wong, MIT, Cambridge, MA
Session Vice Chair: P. Lee, Univ of Leeds, Leeds, United Kingdom

8 - 8:30 am
Influence of Gear Oil Formulation on Fuel Economy of Passenger Cars
W. Bartz, Technische Akademie Eslingen, Ostfildern, Germany, D. Wienecke, Volkswagen AG, Wolfsburg, Germany
Energy savings by tribological measures means the reduction of the friction and wear caused losses by optimized design and material selection, surface engineering as well as lubrication engineering. Minimizing the fuel consumption of engines requires the reduction of energy losses within the complete driving system of a vehicle. Gear losses and gear efficiency depend on the transmitted power, the speed, the lubrication regime, the material and surface conditions, the geometry and especially on the lubricant itself. Via the friction losses the lubricant influences the power losses and the temperatures of the gear. Via the power losses and the temperatures the lubricant controls the fuel economy of he vehicle. It is the aim of this presentation to deal with the lubricants’ influence on friction resulting in the effect on fuel economy. Using the real automobile gear measurements on a test rig were performed using a set of test oils formulated with 9 base oils and 7 additives. With some selected gear oils fuel consumption measurements were performed using a Polo car on a dynamometer. The following results can be summarized:
- Synthetic base oils result in greater fuel economy improvements compared to mineral oils
- Viscosity reveals to be a main factor to control fuel consumption
- Certain AW/EP additives can contribute to fuel consumption reductions
- Depending on the base oil type, the additive and the viscosity fuel economy improvements by optimally formulated gear oils in a range between 0.33 and 1.98 % are realistic.

8:30 - 9 am
Impact of Bio-fuels on Engine Oil Ageing in Passenger Cars
C. Besser, N. Doerr, AC2T Research GmbH, Wr. Neustadt, Austria
In recent years there has been a growing interest in bio-fuels mainly due to the awareness of limited fossil fuels and global warming. In automobiles, biodiesel for diesel and ethanol for gasoline engines are used, respectively. The impact of biodiesel on the engine oil is well documented, but the effect of ethanol itself and of its combustion products on the lubrication system is still unclear. In this paper, the results of lab-based artificial ageing of fully formulated engine oils as well as model oils are presented. The conditions for the artificial ageing
The lubricant in an automotive engine caters to a number of vital requirements from which friction and wear reduction is of prime importance. In gasoline engines, 40-60% of mechanical energy are dissipated as frictional heat. The problems solving properties characterize the functional profile of polyglycols, even engine oils are technically and globally very complex. Polyglycol-based engine oils find an increasing OEM-interest base due to their manifold intrinsic properties in relation to an increasing number of new drivers loaded to the engine design department, as the engine oils have to evolve from multi-grade to multi-functional! The impact of the different backbones of polyglycols (PAG, PPG, PBG) in respected to the functional properties, like bio-no-tox properties, viscometrics, lubricity and wear protection will be illuminated. This paper illuminates the latest results from OEMs engine bench and road testing supporting the following functional benefits:

- **bio-no-tox**, b. **improvements of fuel economy**, even when compared with latest hydrocarbon-based prototype oils, c. **reduced wear**, d. **reduced engine friction**, e. **extended drains**, f. suited for bio-fuels, etc..

9:30 am

**Experiment Design, Instrumentation and Preliminary Camshaft Tribology Studies of an Ethanol Fuelled Otto Engine for Lawn Mower Application**

V. Soloiu, C. Hiliard, G. Molina, B. Vlcek, Georgia Southern University, Statesboro, GA

One important market that will use alternative fuels increasingly, namely ethanol is lawn mower engine application with millions of units built in US annually and using fossil fuels. During start-up and cold run, the bio-fuels condense on the cold cylinder walls and they are scrapped by the rings diluting the mineral oil in the oil pan. The author’s engine-based research is investigating the tribology of the contact surfaces in a lawn mower internal combustion engine while lubricated with mineral oil contaminated with different percentages of ethanol at various temperatures. The experimental engine is instrumented to measure resistive forces and torques and in order to achieve that, the camshaft is being instrumented with a full bridge reciprocating tribometer, running a loaded section of piston ring against a cylinder liner specimen, capable of providing comparative results is used to screen a variety of fuel/lubricant blends.

11:00 am

**No Ash and Bionotox Engine Oil Based on Polyglycols**

W. Mathias, BAM, Berlin, Germany

The problems solving properties characterize the functional profile of polyglycols, even engine oils are technically and globally very complex. Polyglycol-based engine oils find an increasing OEM-interest base due to their manifold intrinsic properties in relation to an increasing number of new drivers loaded to the engine design department, as the engine oils have to evolve from multi-grade to multi-functional! The impact of the different backbones of polyglycols (PAG, PPG, PBG) in respected to the functional properties, like bio-no-tox properties, viscometrics, lubricity and wear protection will be illuminated. This paper illuminates the latest results from OEMs engine bench and road testing supporting the following functional benefits:

- **bio-no-tox**, b. **improvements of fuel economy**, even when compared with latest hydrocarbon-based prototype oils, c. **reduced wear**, d. **reduced engine friction**, e. **extended drains**, f. suited for bio-fuels, etc..

Session 71

Silver Room

**Wear V - Biotribology**

Session Vice Chair: H. Gao, ConocoPhillips, Ponca City, OK
Session Chair: R. Cooper, Texas A & M University, College Station, TX
While CoCr alloys have been used in hip joints for decades, there is still debate over which parameters truly affect metal wear. Variables include metallurgy, heat-treatments, ball diameters, mismatch, finish, and lubrication, etc. We studied the wear performance of 38 and 60mm bearings of high-C, CoCr powder metallurgy. Controls were 38mm of low-C design. Our hypothesis was that high-C bearings would generate less wear than low-C types. All bearings successfully completed 5 million load cycles (5Mc). The HC38 produced 'gray serum' color episodes between 0.3-0.2Mc and 1.5-2Mc due to breakaway wear between 1 and 2Mc and roughness (Sa) increased from 5 to 30 nm. The worn 38mm low-C bearings showed heavy abrasion and plastic flow with overall wear averaging 1.1mm^3/Mc. The overall wear rates with HC38 and HC60 averaged lower at 0.63 and 0.31mm^3/Mc, respectively. These superior wear data provided additional support for the use of high-C MOM bearings.

8:30 - 9 am
How Do Retrieved 2-thoughenened Alumina Hip Bearings Compare to Wear Simulation Tests in the Lab?
I. Clarke, J. Personius, P. Williams, Loma Linda University, Loma Linda, CA
Ceramics represent the lowest wearing bearings for artificial hip joints. Alumina (ALX) has been used 40 years but now alumina-zirconia (AZX) is the high strength alternate. We studied wear of AZX and ALX in a hip simulator. Since lab studies cannot use the patient's natural lubricant, the simulator studies were run with blood serum as lubricant. The 1st wear study looked at off-the-shelf bearings; the 2nd used AZX bearings autoclave-aged 5 to 30hrs to challenge zirconia's known metastability and indentify any micro-changes in surface roughness and microcracks. All ceramic bearing combinations were run for 5 million cycles. The AZX-AZX averaged 6-fold wear improvement compared to ALX-ALX. Tetragonal to monoclinic phase transformations were detected in all AZX surfaces. The bearing wear, roughness transformations, microcracking etc were compared in implants retrieved after 3-7 years patient use. Such lab to clinical comparisons appear essential for understanding hip wear mechanisms in patients.

9:30 - 10 am
Retrieval Analysis of Large Ball Metal on Metal Hip Prosthesis
S. Gregorius, P. Williams, Loma Linda University Medical Center, Loma Linda, CA, J. Personius, Donaldson Arthritis Research Foundation, Colton, CA, T. Donaldson, Empire Specialty Orthopedic Center, Colton, CA, I. Clarke, LLL Peterson Tribology Lab, Loma Linda, CA
Large diameter metal on metal (L-MOM) bearings (>36mm balls) are a popular change in hip arthroplasty due to their low wear, small particle debris, and being highly stable. Despite these positive aspects, there are numerous reports of adverse tissue reactions due to metal ion release. This study examined a retrieved L-MOM hip bearing that failed after 5 ½ years due to pain and clicking. Radiographs showed the cup position at 47 degrees inclination and 40 degrees anteverision. Grossly an anterior polar stripe was seen near a highly polished zone on the head. Coordinated measuring machine analysis demonstrated a figure of 8 wear pattern on both sides of the bearing, which had not been previously seen. The wear rate was calculated at 20.5mm^3/yr compared to 1.26mm^3/yr seen in simulator studies. The stripe wear suggested anterior subluxation due to cup position. Cup position and specifically anteverision are crucial in L-MOM hip arthroplasty for low wear.

10:00 - 10:30 am
Wear of Large Diameter MOM Total Hip Arthroplasty Retrievals Compared to Small Diameter MOM Bearings
J. Personius, Donaldson Arthritis Research Foundation, Colton, CA, I. Clarke, LLL Peterson Tribology Lab, Loma Linda, CA, T. Donaldson, Empire Specialty Orthopedic Center, Colton, CA
The 28mm and 32mm diameter bearings have seen 10 years use in artificial hip joints of metal-on-metal designs (CoCr alloys). However, today’s practice permits much larger diameter (36, 42mm etc) bearings for more hip stability. However there is still an inadequate understanding of how these MOM bearings can produce abnormal wear in certain high risk patients. Our hypothesis was that some hips performed well but sub-optimal implant positioning triggered adverse wear modes in CoCr bearings. We documented the wear patterns for both small and large diameter MOM bearings in our retrieval programs and analyzed the implant positions by X-rays and CT-scans. We ran 3D wear analyses by CMM and determined wear by plate light interferometry (roughness assessment). The high wear modes evaluated were compared to those MOM retrievals we defined as normal. The results showed MOM wear rates 30-40 times higher than expected. This has not been previously reported.

11:00 - 11:30 am
Wear Mapping Analysis of 28mm CoCr-CoCr Hip Bearings Over the Decade
I. Clarke, Loma Linda University, Loma Linda, CA, K. Kubo, Tokyo Medical University, Tokyo, Japan
While contemporary metal-on-metal (MOM) hip joints have been used 15 years, there has been no detailed mapping of wear on retrieved CoCr bearings. This study presents a detailed analysis of 28 MOM bearings with 1-11 years follow-up. Main cause for revision was pain with progressive loosening around the hip cups. The retrieved bearings were mapped using reflected light, SEM/EDS and white-light interferometry. Eight femoral stems were recovered and all showed 5 also demonstrated severe damage to their polyethylene adaptors. On the CoCr balls, stripe wear was common and medial, equatorial and basal wear stripes were easily identified. Areas of multi-directional 3rd-body wear averaged roughness 50mm compared to new CoCr with Sa < 5nm. It was apparent that use of the 28mm CoCr balls added risks of impingement and adverse wear with CoCr cups.

11:30 - Noon
Blended Vitamin-E in Oxidation-Inhibition Mode can Severely Compromise the Primary Wear Mode of ‘Crosslinking’ in Artificial Hip Joints
I. Clarke, Loma Linda University, Loma Linda, CA, K. Kubo, Tokyo Medical University, Tokyo, Japan
It is well known that crosslinked UHMWPE offers superior wear resistance for artificial hip joints. It is also been shown that diffusing vitamin E into crosslinked UHMWPE beneath the melt matrix of tribological conditions that are used to describe the modes of friction, mechanics, and conditions to failure. Specific issues discussed will be the role of applied shear and contact pressures in the physiological responses to friction, as well as cell layer properties. Cell layers are assessed pre- and post-testing with optical microscopy and colored assays. This study uses a custom-instrumented micro-tribometer in order to resolve forces on the order of ~10 μN and biologically-relevant contact pressures < 100 kPa.

12:30 - 1:30 pm
The Eyes Have It
A. Dunn, D. Dickrell, W. Sawyer, University of Florida, Gainesville, FL
The tribology of the human corneal epithelium, from dry eye irritation to contact lens comfort, affects millions of people on a daily basis. Recent work has determined the experimental methods for measuring contacting friction and related properties on commercially available HCE-T corneal epithelial cells of characteristic individual size ~10 μm. This study presents a matrix of tribological conditions that are used to describe the modes of friction, mechanics, and conditions to failure. Specific issues discussed will be the role of applied shear and contact pressures in the physiological responses to friction, as well as cell layer properties. Cell layers are assessed pre- and post-testing with optical microscopy and colored assays. This study uses a custom-instrumented micro-tribometer in order to resolve forces on the order of ~10 μN and biologically-relevant contact pressures < 100 kPa.

12:30 - 1:30 pm
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The model lubricants are chosen to investigate effects of chain length and branching. The influence of film thickness is also characterized in terms of deviation from bulk fluid behavior. All self-assembled monolayers (SAMs) are common model systems for fundamental investigations of tribological properties at the molecular level and for the ultrathin lubricating films needed to protect the contacting surfaces in MEMS/NEMS. We have used atomic force microscopy (AFM) to study the friction of aromatic and polyaromatic SAMs in single-asperity contacts where the strength of adhesion was altered by immersing the contact in dry N2 gas or in ethanol. At low loads, low adhesion (in ethanol) resulted in a linear dependence of the friction force on load, whereas high adhesion (in N2) gave an apparent area-dependence of the friction force. The Thin-Coating Contact Mechanics model, describing a compliant thin film confined between rigid substrates, was used to calculate contact areas that were compared to the functional form of the friction data obtained in N2. Systematic changes were found in the friction coefficient (obtained in ethanol) and the critical shear stress (obtained in N2) with the packing density of the monolayers. The investigation has also been extended to thin films of polystyrene with and without stretching-induced orientation to study the dependence of friction on the polymer chain orientation.

2 - 2:30 pm
Self-healing and Wear prevention of Boundary Lubricant Film on Silicon Oxide Surface
E. Hsiao, S. Kim, The Pennsylvania State University, University Park, PA
The boundary film formation and lubrication effects of low molecular weight silicone lubricant molecules with catonic side groups were studied. Poly-(N,N,N-trimethylamine-3-propylmethyloxysiloxane-co-dimethylsiloxane) iodide was deposited on silicon oxide surfaces to form a bound- and mobile lubricant film. The ionically bound layer and mobile multilayers were investigated. Both nano-scale and macro-scale tribological tests of these films revealed advantages over the polydimethylsiloxane control sample. Self-healing capability was quantified by measuring the lateral diffusion coefficient at both nano-scale and macro-scale. In the macro-scale the effect of ionic content, environmental condition, and advantage of the bound layer on self-healing is discussed. In the nano-scale, disjoining pressure and viscosity measurements quantify the lateral diffusion of the mobile layer. The multilayer films exhibited characteristic topographic features due to ionic interactions within the polymeric film. The interconnectivity of these features allows for the mobile film to flow and self-heal. The diffusion coefficients were on the order of 10^{-9} m^2/s.

2:30 - 3 pm
Effect of Molecular Structure on Tribological Properties of Free Fatty Acids
H. Gylfadottir, A. Martini, Purdue University, West Lafayette, IN
Free fatty acids (FFA) are the fundamental elements of food fats and oils and therefore significantly influence texture, mouth feel and flavor of food products. To better understand how the molecular structure of FFAs affect food perception, molecular dynamic simulation is applied. Models of FFAs with naturally occurring variations in molecular structure, such as chain length and degree of saturation, have been developed. Then, equilibrium and non-equilibrium molecular dynamics simulation is used to characterize nanoscale clusters of these model FFAs in terms of their material properties and tribological behavior. Molecular model predictions are evaluated by comparison to detection thresholds obtained from human taste panel studies. By correlating frictional behavior with taste perception the effect of molecular structure can be linked to taste. This knowledge is critical for functional food design and may play a critical role in enabling manufacturers to control the taste of their products.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Molecular Structure and Film Thickness Effects on TFL Compressibility Using Atomistic Simulation
A. Vadiakapti, A. Martini, Purdue University, West Lafayette, IN
Previous studies using molecular dynamics simulations of 5 nm n-hexadecane films indicated that the confined fluid compressibility may differ from that predicted by traditional bulk compressibility models. Here, we report a significant extension of that study in which we evaluate the compressibility of multiple model lubricants over a range of film thickness values. The model lubricants are chosen to investigate effects of chain length and branching. The influence of film thickness is also characterized in terms of deviation from bulk fluid behavior. All studies are performed over a wide range of loads, corresponding to pressures from kPa to GPa. Other properties/phenomena such as glass transition, molecular relaxation, and confinement-induced layering are also investigated. This work provides not only detailed characterization of ultra thin film lubricant compressibility, but also insight that can enable application-specific lubricant design.

4 - 4:30 pm
Bionanomanufacturing of Solid Lubricant Nanoparticles of Molybdenum Sulfide Using Fungal Cells
D. Demydov, W. Zhang, A. Malshe, I. Pinto, University of Arkansas, Fayetteville, AR
The objective of this research was to study ability of biological cell, to be used for controlled synthesis of sustainable nanoparticles. Investigators examined programmable synthesis of nanoparticles inside as well as outside cells, for localized and large scale production of nanoparticles that can be used as solid lubricant additives for base oils. The biomass of cells was suspended in an aqueous solution of molybdenum salts and incubated under standard conditions to let molybdenum cations interact with sulfide anions produced by biological cells to form molybdenum sulfide nanoparticles. The synthesized samples were analyzed by HRTEM on nanoparticles-cell interface for nanostructural analysis and EDX to reveal elemental composition. The received TEM results confirmed that layered lamellar structure of molybdenum sulfide nanoparticles were produced, HRTEM/EDX pattern confirmed the molybdenum sulfide chemical composition, and diffraction pattern showed high crystalline structure of these nanoparticles. The tribological performance of MoS_{2} nanoparticles was also evaluated.

4:30 - 5 pm
Tribological Performance of Boron-MoS_{2} Nanoparticulate Hybrid System
W. Zhang, D. Demydov, A. Malshe, University of Arkansas, Fayetteville, AR, K. Misty, A. Erdemir, Argonne National Laboratory, Argonne, IL
Nanoparticles of MoS_{2} and boron based materials (ex. Boric acid [1]) have shown excellent tribological properties. To study if there is a synergistic effect, authors have used chemomechanical synthesis route for synthesis of boric acid-MoS_{2} nanoparticles (NPs). The tribological performance of this hybrid systems were investigated through coefficient of friction and tribofilm analysis. Different samples of MoS_{2} NPs, Boric acid NPs, and the combination of them in different ratios were studied and compared. EDS, TEM, XRD, and particle size analysis techniques were implemented to examine structural properties, compositions, particle size, and particle size distribution. Friction and wear properties were observed by pin-on-
disc tribometer, and tribofilms were characterized by optical microscope, SEM, and EDS analysis. DSC and TGA techniques were used to study the thermal properties of this hybrid system.

5 - 5:30 pm

Tribological Properties of Nanoparticles of Lamellar Solid in the Presence of Organic Molecules

E. Ezugwu, Air Force Institute of Technology, Kaduna, Nigeria, J. Bonney, M. Abu Bakar, London South Bank University, London, United Kingdom

This work is concerned with the tribologic effect of organic liquids when associated to nano particles of lamellar compounds (graphite, boron nitride, nickel thiophosphate). The tribologic properties are investigated by means of alternative sphere on plane tribometer. The nanoparticles are deposited on the plane in the form of a thin film using a burnishing method. Whereas friction coefficients measured under argon are high (graphite $\mu=0.25$, BN $\mu=0.45$, NiPS3 $\mu=0.25$) the introduction of pure dodecane on the films induces an immediate and drastic decrease of the friction coefficient down to $0.05<\mu<0.07$. Transmission Electron Microscopy and Raman micro-spectrometry investigations of tribologic films obtained under air and in the presence of dodecane do not reveal significant differences in composition and structure. Complementary characterization (X rays diffraction, nano indentation) allowed us to eliminate hypotheses such as intercalation of organic molecules in the lamellar compounds. Tribologic experiments using various organic compounds show that the improvement of friction properties of the studied nano particles is mainly due to the presence of the organic liquid in the sliding interface.

Acknowledgements

The authors acknowledge the Conseil Régional de la Guadeloupe, the European Regional Development Fund and the European Social Fund for their financial supports.

Session 8B

Lubrication Fundamentals VI

Session Chair: K. Naithani, Indian Oil Corporation Ltd., Faridabad, India

1:30 - 2 pm

Effect of Coolant Grades on the Machining Ti-6Al-4V Alloy with Uncoated Carbide Tools Using High Pressure Coolant Supplies

E. Ezugwu, Air Force Institute of Technology, Kaduna, Nigeria, J. Bonney, M. Abu Bakar, London South Bank University, London, United Kingdom

Application of cutting fluids has significant influence on the machining Ti-6Al-4V alloy because of extreme heat generated. An ideal cutting fluid should perform lubrication and cooling functions as well as chip transportation away from the cutting zone. This work presents the evaluation of commercially available coolant grades, an alkanolamine based coolant, a triethanolamine based coolant and an ester based coolant when machining Ti-6Al-4V alloy with high pressure coolant (up to 20.3 MPa) delivery. The evaluation were based on cutting performance, measured by tool life, cutting forces, analyses of tool failure mode(s), wear mechanisms, surface integrity and chips formation. The cutting speeds varied from 110 m/min to 130 m/min with constant depth of cut and feed rate of 0.5 mm and 0.15 mm/rev respectively. The alkanolamine based coolant grade gave the best cutting performance at 110 m/min speed and 20.3 MPa coolant pressure. The triethanolamine based coolant however outperformed the alkanolamine based coolant at 110 m/min cutting speed and 11 MPa coolant pressure. Flank and nose wears were the dominant failure modes in all cutting conditions investigated. Surfaces generated when machining with all coolant grades were generally acceptable with negligible physical damage.

2 - 2:30 pm

Squeeze Film Characteristics Between a Sphere and a Rough Porous Flat Plate with Micro-polar Fluids

A. Elsharkawy, K. Al-Fadhalah, Kuwait University, Safat, Kuwait

The effects of surface roughness on the squeeze film characteristics between a sphere and flat plate covered with a thin porous layer are investigated in this paper. The sphere and the plate are separated with a non-Newtonian lubricant of a micropolar fluid. The well-established Christensen stochastic theory of hydrodynamic lubrication of rough surfaces is used to incorporate the effects of surface roughness into the Reynolds equation. The film pressure distribution is solved and other squeeze film characteristics, such as the load-carrying capacity, and time-height relationship, are obtained. The results indicate that lubrication by a micropolar fluid will increase the load-carrying capacity and lengthen the squeeze film time, regardless to the surface rough and porosity of the flat plate. It is also found that excessive permeability of the porous layer causes a significant drop in the squeeze film characteristics and minimizes the effect of surface roughness. For the case of limited or no permeability, the azimuthal roughness is found to increase the load-carrying capacity and squeeze time, whereas the reverse results are obtained for the case of radial roughness.

2:30 - 3 pm

The Influence of Bonded Coatings on the Stick-slip Behaviour and Breakaway Forces in a Tribological Contact with Elastomers

J. Züele, Klüber Lubrication, Munich, Germany

Elastomers, which run in a tribological contact against solid compounds like glass, steel or plastic, can lead to stick-slip and breakaway forces. With the help of theoretical explanations the occurrence of Stick-Slip and breakaway forces in dependency of the downtime of a loaded contact, can be described. These theories are proved with a stick-slip testrig under different parameters like temperature, humidity, load and velocity. The results are interpreted with a vibration analysis Data acquisition. To get a correlation to real applications it is shown, how these findings can help in the design of coatings for elastomers, which are used in automotive door profiles.

Session 8D

Condition Monitoring IV

Session Chair: K. Malik, Ontario Power Generation, Pickering, ON, Canada

1:30 - 2 pm

Site-Direct Oil Analysis: Virtual Machine Diagnostics

J. Poley, CMI, Miami, FL

Today’s technology allows a highly comprehensive approach to Oil Analysis Data Evaluation, as well as other forms of NDT (Non-Destructive Testing, e.g., vibration sensor data). This presentation addresses the use of such technology to achieve ‘Virtual Machine Diagnostics’ (VMD), focusing on real-time machine condition with all the attendant benefits. VMD involves employment of sensors, data streaming, offline oil analysis data, and an automated NDT Intelligent Agent to collate and automatically evaluate all the data for real-time, in-depth and solidly consistent machine condition evaluation and assessment. Maintenance Advisories, pertinent supporting information and data can be continually and globally available, presented on GUI (Graphical User Interface) dashboards, simultaneously
Oil condition monitoring is a vital part of integrated asset health management. With an increasing impetus towards real-time decision making, delays incurred in offline laboratory oil analysis are unacceptable. Kittiwake Developments is pursuing an active R&D programme to develop robust, cost effective sensors for continuous monitoring. This paper presents recent developments in three key areas; Metallic Wear Debris, Total Water Content and Viscosity. Quite different technological solutions have been adopted for these oil parameters. Metallic Wear Debris: improvements in the sensitivity of inductive particle counters have enabled the detection of individual ferrous particles down to 40µm diameter and to 135µm for non-ferrous metals. Independent validation on test rigs employing loaded case hardened straight cut gears show very good correlation with the observed progression of damage on the gear flanks. Total Water Content: a sophisticated sensor utilising Infrared transmission measurements has been developed. The sensor has been designed primarily for marine diesel engine applications. The maximum water content measurable is 2%. A correction methodology, correlating to an accepted DIN standard, has been developed to increase the accuracy of the measurements in oils contaminated by soot. Viscosity: a cost effective device employing a low amplitude vibrating sensor element is the most recent development. Key features include accurate measurement over a very wide viscosity range and an operating range which covers combustion engine oil temperatures and pressures.

2:30 - 3 pm
An Intelligent Agent for Automated Oil Analysis Evaluation
M. Murpy, CMI, Miami, FL
A unique software application for automated Oil Analysis Evaluation is described, providing the most important part of the oil analysis process: The Evaluation. Most reports come back to Customers with a lot of data but not much advice, and even when that advice is included, it is often sketchy and of little use or help.

The system is characterized by the following:
- A multi-layered hierarchical system that correctly isolates Components for meaningful Data Rating and Comments
- Sophisticated data rating algorithms that include preferential aggressiveness by account
- Nuanced rules that can isolate specific situations with extremely fine granularity, also account-specifiable
- Precisely tuned commentary to fit the Customer: Terminology, Sequencing, Language, etc.

A means to create Work Orders and capture maintenance findings, translation: a potent ROI tool
Open-ended architecture for enhancements

3 - 3:30 pm - BREAK

3:30 - 4 pm
Single and Multiple Bearing Fault Recognition Using New Sensor-technology and Advanced Processing Techniques
A. Dadouche, M. Conlon, W. Dmuchowski, National Research Council, Ottawa, ON, Canada
Despite the large body of literature dealing with bearing defect diagnosis, there is still a need and room to implement newer technologies in terms of sensing and processing for early and better fault identification. For decades, vibration measurements and oil debris monitoring have been used and led to a good understanding of bearing failure modes, however, vibration measurements can be very challenging and signals tend to distort when access to the machine components is restricted. On the other hand, oil debris analysis may be considered very limited in terms of bearing and faulty component identification in multiple-bearing machinery. In this investigation, a suite of sensor technology along with tailored post-processing methods are being studied for early, single- and multiple-fault signature recognition. Seeded faults have been implemented on the bearing components and tests have been performed on a laboratory test rig at different speed and load combinations.

4 - 4:30 pm
Use of the Advanced 'Dry-Bath' RPVOT Techniques to Precisely Chose Lubricants and Extend Their Service Life by Direct Measurement of Initial and Cumulative Oxidation Level
T. Seiby, R. Deignan, Savant, Inc., Midland, MI
The well-known and highly informative Rotating Pressure Vessel Oxidation Test (RPVOT-formerly RBOT) has provided it many users with the most direct path of condition monitoring. That is, by the direct measurement of the combined effects of the base oil and the anti-oxidation additives. This is in contract to other, particularly titrimetric, approaches which only measure the initial and remaining status of the anti-oxidant. A drawback to the RPVOT approach has been the need to use a large liquid bath difficult to maintain and service at its continued operating temperature of 150 degrees Centigrade as well as forming a large presence in the laboratory requiring a special hood. Very recently, an advanced 'dry-bath' RPVOT approach to maintaining sample temperature and also if desired permitting access to the sample under test to follow the oxidation process, has been developed. With no dependence on a liquid bath, the instrument requires little laboratory space and no placement in a hood. This paper will represent some interesting studies using this 'dry-bath'-based RPVOT instrument.

4:30 - 5 pm
Vibration Pattern Recognitions on Damages in Gears and Rolling Element Bearings
F. Choy, C. Shen, J. Wen, P. Arunyanat, University of Akron, Akron, OH
The main objective of this paper is to identify possible damages in gear teeth and rolling element bearings in a gearbox based on pattern recognition of vibration signals. Vibration signatures of different damage cases are experimentally generated using different gear sets and rolling element bearings with controllable damages on a 75 HP experimental test rig. Cases with no damage, gear tooth damage only, damage in rolling element bearing only, and damages in both gear tooth and bearing system are being investigated. In order to provide more detailed damage identifications of the vibration signatures, vibration signals are analyzed in time domain, frequency domain and joint time-frequency domain. Special vibration pattern features for each type of component damage are extracted from the 3-dimensional time-frequency display generated from both Wigner-Ville Distributions and Continuous Wavelet Transform. Indicative parameters are developed to recognize the pattern for each type of damage as well as to quantify the damage levels. Based on results of this comparative study, general conclusions are drawn concerning identification between gear teeth damage and faults at the rolling element bearings in a gear transmission system.

5 - 5:30 pm
Qualifying Greases and Lubricants for Suitability in the Nuclear Industry
G. Pereira, Kinekinetics Inc., Toronto, ON, Canada; G. Staniewski, Ontario Power Generation, Pickering, ON, Canada; D. Finora, Bruce Power, Kinkardine, ON, Canada
Physical and chemical tests were carried out on virgin, artificially aged and irradiated samples (after aging) of lithium complex soap greases. Reformulations of these commercially available products were studied to determine their suitability and compatibility for environmentally qualified applications in nuclear stations. This paper discusses the protocol involved in qualifying the greases for use in power generation applications. The greases were subjected to a sequence of stresses to emulate a worst-case, in-service scenario determined as 5 years of thermal aging and significant exposure to gamma radiation. Thermal aging of 5 years was mimicked by heating the greases at 120 °C for 1344 hours in a forced air convection oven with periodic mixing. Aged and irradiated greases showed decreased performance compared to the virgin samples. Although, no individual laboratory test can predetermine the
service performance of greases, the combined results of many tests can assist with a prediction. Based on the findings of this comparative study, the new formulations of these lithium complex soap greases were found to be favorable greases for nuclear applications. This presentation will discuss physical results and discuss the long term implications for nuclear stations.

**Session 8F**  
**Palace 3**  
**Ceramics & Composites II**

**Session Chair:** F. Gao, Texas A&M University  
**Session Chair:** A. Rocha, Texas A&M University

1:30 - 2 pm  
The True Contact Area for Friction in Chemical Mechanical Polishing  
J. Levert, SUNY Maritime College, Bronx, NY, C. Korach, Stony Brook University, Stony Brook, NY

Friction from Chemical Mechanical Polishing (CMP) during integrated circuit (IC) fabrication can damage the IC surface which motivated experiments to understand it. Friction was measured using a pin-on-disk tribometer with fused silica samples as the disk. Various polymeric CMP pad materials were formed to a spherical surface serving as the pin while slurries of silica nanoparticles flooded the contact. Friction varied with pad materials and the slurry nanoparticle concentration. Data analysis estimated the friction contribution of: 1) bare pad asperity tip contacts 2) nanoparticle contacts on the pad asperity tip, and 3) a proposed pad asperity edge contact where particles adhere to both asperity and substrate. The results suggested that 75% of the pad asperity tip contact area was bare (no particles) and that the asperity edge contacts were 65% of the asperity tip area. This implies that substantial CMP
In this paper the authors compare numerical solutions for the lubricated crack problem under elasto-hydrodynamic lubrication (EHL) conditions with experimental observations for a.

The importance of coupling the solid and fluid domains as well as including the influence of the fluid film at the surface (Balcombe, et al.). The granular microstructure topology is modeled by randomly generated Voronoi tessellations.

Friction and wear significantly decreased when sliding occurred in dry inert gas environments. The friction coefficient, initially 0.25 in ambient humid air, decreased to 0.05 by introducing dry nitrogen into the chamber. Micron thick tribo-layers composed of wear particles of polymer and carbon fibers were observed on PEEK-CF worn surfaces after sliding tests both in humid air and dry nitrogen. However, the surface of the tribo-layer became smoother, wear particles became smaller, and carbon content became richer after sliding in dry nitrogen. Also, Raman spectroscopy analysis indicated formation of a graphite layer on top of the tribo-layer when sliding occurred in dry nitrogen.

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Friction plays an important role when abrasive particles are embedded or trapped between polishing pads and substrates. In addition to contributing to the material removal, severe surface damage to components in the form of delamination or distortion of surfaces due to scratch defects can occur. In this work, lateral force microscopy (LFM) in an electrolyte environment (NH4OH) was performed with silica-coated AFM probes as an analog to nanoscale abrasive particles in oxide CMP. Silica probes were used to measure the two-body friction contribution of the particle analog in contact with a silica substrate and a polyurethane CMP pad for load and pH variations. Friction forces were found to be lower contacting silica than the pad material and pad surface deformations showed plowing friction was the dominant cause. Silica friction was lower for elevated pH (>10) and was found to have a decrease in adhesion.

The Influence of Multiwalled Carbon Nanotubes on Mechanical and Tribological Properties of Polyamide6 Nano-composites

Multiwalled-carbon-nanotubes (MWCNT) are known for their reinforcing properties. However, their efficient dispersion in polymer matrix is still a challenge and the performance properties are highly dependent on this. Various parameters are to be optimized to ensure better dispersion. In this paper MWCNT-Polyamide 6 system was selected and processing parameters were optimized using rheology as a tool to determine the dispersion of nanotubes. Various nano-composites (with variation in amount of MWCNT- 0.25, 0.5, 1.0, 2.0, 5.0 %) were developed (extrusion followed by injection molding) based on commercially viable master-batch dilution process. These were then characterized for physical, mechanical and tribological properties. MWCNT inclusion led to significant enhancement in mechanical properties. Adhesive wear studies confirmed appreciable improvement in tribo-performance which varied with the amount of MWCNT. 2 % was observed to be optimum for best combination of performance properties. SEM was used to understand wear mechanisms.

Effect of Barriers on Friction Behaviors and Tribo-layer Formations of PEEK/Carbon Fiber Composites

We investigated the tribological behaviors and tribo-layer characteristics of polyetheretherketone (PEEK) containing carbon fibers (CF) sliding against stainless steel in terms of their dependence on gas environments. Block-on-ring sliding tests in a gas chamber were conducted, followed by detailed observations and analysis of the worn surfaces. Friction and wear significantly decreased when sliding occurred in dry inert gas environments. The friction coefficient, initially 0.25 in ambient humid air, decreased to 0.05 by introducing dry nitrogen into the chamber. Micron thick tribo-layers composed of wear particles of polymer and carbon fibers were observed on PEEK-CF worn surfaces after sliding tests both in humid air and dry nitrogen. However, the surface of the tribo-layer became smoother, wear particles became smaller, and carbon content became richer after sliding in dry nitrogen. Also, Raman spectroscopy analysis indicated formation of a graphite layer on top of the tribo-layer when sliding occurred in dry nitrogen.
Simultaneous Measurements of Pressure, Lubricant Film Thickness and Temperature Distributions in Lubricated Rolling Sliding Contacts Using High Spatial Resolution in Situ Raman Spectrometry

J. Mansot, D. Himmel, Y. Bercion, A. Sauldubois, Université Antilles Guyane, Pointe à Pitre, France, T. Lubrecht, INSA de Lyon, Villeurbanne, France

In situ quantitative Raman microscopy [1] is used to acquire high spatial resolution (10µm) spectroscopic images in the elasto-hydrodynamic lubricated (EHL) sphere/plane contacts. The lubricant used, SP4E, presents a strong Raman band near 1000 cm⁻¹ (trigonal breathing vibration mode of the aromatic rings) which allowed us to analyse film thicknesses down to 0.1 µm.[2,3]. The quantitative analyses of the intensity, energy shift and Raman Stoke/anti Stoke band ratio of the 1000 cm⁻¹ Raman band of SP4E allowed us to deduce the local lubricant film thickness, pressure and temperature and then to establish simultaneous distribution of these parameters in the rolling sliding contact with a high spatial resolution [1-4]. The experimentally measured distributions of the three contacts parameters in the case of pure rolling contacts are in good agreement with theoretical ones. The significant increase of the temperature in a rolling sliding contact attributed to the shearing of the lubricant film in the contact area explains the variation of the lubricant film thickness distribution experimentally observed.

Acknowledgements
The authors acknowledge the CNRS, the Conseil Régional de la Guadeloupe, the Fond Social Européen (FSE) and Fonds Européens de Développement Régional (FEDER) for their financial support.

3 - 3:30 pm - BREAK

Numerical Modeling of Surface Defects in Heavily Loaded EHL Line Contacts

A. Warhadpande, B. Jalalahmadi, F. Sadeghi, Purdue University, West Lafayette, IN

Surface initiated fatigue caused by surface defects is one of the most dominant failure modes for bearing contacts. In this investigation a damage mechanics based voronoi finite element model (VFEM) is developed to investigate the effects of surface defects (such as dents, fretting wear etc.) in elasto-hydrodynamic lubricated (EHL) line contacts. A line contact EHL model is used to calculate the pressure distributions acting over the surface defects which are then employed by VFEM to calculate sub-surface stresses and strains. Continuum damage mechanics approach is used to incorporate cyclic damage accumulation and progressive degradation of material properties with rolling contact cycling. The model also takes into account the residual stresses generated during the denting process as well as during the overrolling of dents in EHL contacts. Using this methodology, the model simulates micro-crack initiation, coalescence and propagation stages and eventually forms a fatigue spall. The locations and patterns of dent initiated spalls are found to be consistent with experimental observations. The fatigue model is used to study the effects of dent sharpness, load, speed and material properties on RCF life and Weibull slopes.

4 - 4:30 pm

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4:30 pm – Rolling Element Bearings Business Meeting
Lubricants are under ever increasing demands. They are required to withstand longer drain intervals in engines at the same time as current lubricant viscosities and chemical composition is under constant review to meet both legislation and desired improved fuel economy. To enable educated design of these lubricants an understanding of the effect of engine and lubricant parameters on the temperatures experienced by the lubricant in the engine is essential; in particular in the piston assembly where the highest temperatures are experienced. A piston and liner has been instrumented to permit the study of operating temperatures in a single cylinder research engine. This presentation will briefly describe the experimental set up prior to presenting results obtained from running the engine with different loads and speeds. The implications of the results will be discussed.

3 - 3:30 pm - BREAK

3:30 - 4 pm
Measured Piston and Liner Temperatures in a Gasoline Engine Part Two: Effects of Engine Load and Speed
P. Lee, University of Leeds, Leeds, United Kingdom

Lubricants are under ever increasing demands. They are required to withstand longer drain intervals in engines at the same time as current lubricant viscosities and chemical composition is under constant review to meet both legislation and desired improved fuel economy. To enable educated design of these lubricants an understanding of the effect of engine and lubricant parameters on the temperatures experienced by the lubricant in the engine is essential; in particular in the piston assembly where the highest temperatures are experienced. A piston and liner has been instrumented to permit the study of operating temperatures in a single cylinder research engine. This presentation will briefly describe the experimental set up prior to presenting the results obtained from running the engine with different loads and speeds. The implications of the results will be discussed.

4 - 4:30 pm
Lubricating Oil Influence on Exhaust Hydrocarbon Emissions From a Gasoline Fuelled Engine
J. Sodré, P. Albuquerque, V. Vieira, Pontifical Catholic University of Minas Gerais, Belo Horizonte, Brazil

The engine exhaust concentration of unburned hydrocarbons has been investigated for different lubricating oils, using gasoline as fuel. The investigation is based on the theory of unburned hydrocarbon formation due to fuel absorption/desorption in the engine cylinder lubricating oil film. Six samples of lubricants have been tested: two synthetic oils, classification SAE 5W30 and SAE 5W40, two semi-synthetic oils, classification SAE 15W40 and SAE 20W50, and two mineral oils, classification SAE 15W40 and SAE 20W50. Experiments were carried out in a production engine mounted in a bench test dynamometer, varying engine load and speed in the range from 1500 to 6000 rev/min. The results demonstrate the existence of a strong correlation between hydrocarbon emissions and lubricant viscosity. The synthetic oils showed the lowest hydrocarbon emission levels, especially in the low engine speed range.

4:30 - 5 pm
Comparison Between Mass Conserving Cavitation Algorithm and Mobility Method in a Study of an Engine Main Crankshaft Bearing
B. Vessalpour, S. Jazzayeri, Khaje Nasir Toosi University of Technology, Tehran, Iran, Republic of Islamic

The main purpose of the present work is to compare the results produced by the mass conserving cavitation algorithm and the mobility method, while both are applied for the analysis of a dynamically loaded engine crankshaft main bearing. The basic approach is the same algorithm used by Elrod. Reynolds equation discretized using finite difference method. Mass Conserving Algorithm results are compared with the results produced by well known mobility method of Bloorke. The performance characteristics such as pressure distribution, minimum oil film thickness, flow rate and power loss are obtained using two mentioned methods. It is found that the mobility method overestimates minimum oil film thickness and underestimates lubricant flow rate and power loss. It is also found that mobility method generates reasonable and reliable estimation in the bearing design process as a rapid approach. It is also shown that, the maximum cycle averaged deviation predicted by these totally different methods is less than 20%.

5 - 5:30 pm
The Mechanisms of Wet Clutch Friction
M. Ingram, H. Spikes, Imperial College, London, United Kingdom, J. Noles, R. Watts, Infinium USA, L.P., Linden, NJ

Wet clutches are used in automatic transmissions for gear shifting, and to decrease power loss in the torque converter. For satisfactory operation the wet clutch must show desirable friction characteristics whereby (i) friction remains high over a wide range of sliding speeds and (ii) friction increases with sliding speed. A positive friction versus speed curve gradient is obtained by appropriate automatic transmission fluid (ATF) formulation combined with informed design of the friction surfaces. In this paper, the friction generated in wet clutches has been studied using a specially developed friction screener to measure the friction/speed behaviour of a range of model lubricant additives. The results, coupled with in-contact visualisation of real areas of contact, suggest that the wet clutch remains in the boundary lubrication regime, up to high sliding speeds, and the observed friction characteristics can be explained by the influence of surface active additives on boundary friction.

5:30 pm – Engine & Drivetrain Business Meeting

Session 8I

Wear VI

Session Chair: X. Lu, Varel International, Carrollton, TX
Session Vice Chair: P. Wang, Caterpillar Inc., Dunlap, IL

1:30 - 2 pm
The Role and Influence of Carbides in the Tribology of Metal-on-Metal Bearings in Total Hip Replacements
P. Williams, I. Clarke, Loma Linda University, Loma Linda, CA, T. Donaldson, Empire Orthopaedics, Colton, CA

Metal-on-metal (MOM) total hip replacements (THR) have demonstrated low wear in comparison to metal or ceramic on polyethylene. With high-carbon (HC) CoCrMo alloys the formation and morphology of carbides (chromium and molybdenum) can influence the tribology and lubrication of MOM THR. The objective of this work was to quantitatively characterize the surface morphology of carbide formations in MOM bearing couples. HC CoCrMo specimens were obtained from a series of tribology experiments with MOM THR devices. SEM images were obtained with backscatter mode for identifying and measuring carbides. Energy dispersive spectroscopy was employed to identify the types of carbides. Areas inside and outside of the wear zone were examined to establish relations to the tribology and lubrication. Differences were found between different manufacturers most likely as a result of the fabrication and machining processes utilized. Chromium carbides appeared to result in a factor of ten less wear for the run-in phase.

2 - 2:30 pm
Understanding Polyethylene Tribology of Total Joint Replacements from the Quantitative Analysis of Wear Debris Morphology
P. Williams, I. Clarke, Loma Linda University, Loma Linda, CA

Bioreactivity of polyethylene wear debris from artificial hip joints can result in considerable bone loss and eventual replacement of the prosthesis. Even with four decades of study a better understanding of the tribology and lubricant of these devices is needed. A better understanding of wear debris generation in relationship to the tribological processes and lubrication...
conditions could aid in better evaluation of long-term performance. We have been engaged in developing a methodology of mathematically modelling size distributions for polyethylene (PE) wear debris from hip simulator models. A mixture distribution model best represented the size distributions for both number and volume fractions. Therefore, it has been demonstrated that wear debris data is more complex than it appears. Debris morphology data represents several tribological processes and a factor such as crosslinking PE or changing the counterface surface roughness may be reflected only in a small proportion of the total dataset.

2:30 - 3 pm

Tribological Studies on Polyetherimide Composites Based on Gamma Irradiated Carbon Fabric
S. Tiwari, J. Bijwe, Indian Institute of Technology, New Delhi, India, S. Panier, Ecole des mines de Douai, Douai, France

Interfacial adhesion between matrix and fiber plays a crucial role in controlling performance properties of the composites. Carbon fibers have major constraint of chemical inertiess with the matrix and need surface treatments. In this work, gamma irradiation technique with varying dozes (100 to 300 KGY) was employed to carbon fabric (CF) to develop composites with Polyetherimide (PEI) matrix based on impregnation method followed by compression molding. Composited were characterized for interlaminar shear strength (ILSS) and adhesive wear studies against mild steel disc under various loads. Improvement in friction and wear properties was correlated with improvement in ILSS as a result of CF treatment. Fourier transform infrared spectroscopy (FTIR) indicated inclusion of functional groups (mainly carboxyl) which were responsible for improvement in adhesion between matrix and fiber. To observe effect of treatment SEM, fiber tension test, Raman spectroscopy and Thermogravimetric analysis of CF were also performed.

3 - 3:30 pm - BREAK

3:30 - 4 pm

The Influence of Plasma Treated Carbon Fabric on the Tribological Properties of PEEK Composites
M. Sharma, J. Bijwe, Tribology Research Institute, Traction Power State Key Laboratory, Southwest Jiao tong University, Chengdu, China

Polyetheretherketone (PEEK) and carbon fabric (CF) is the most favoured combination for developing high performance bi-directionally (BD) reinforced composites. CF, however, is also known for its inertiess towards the matrix and various treatments to improve CF-matrix adhesion are reported. In this paper cold remote nitrogen oxygen plasma (CRNOP) was used for surface treatment of chemically inert CF to enhance its reactivity towards matrix. Two composites with treated and untreated fabrics (~50 vol %) were developed by compression molding and assessed for mechanical properties. The erosive wear performance of these composites was evaluated using silica particle erodent at an impingement angle of 30°. The treatment improved mechanical properties of the composites and decreased the wear rate almost by 2 times. SEM studies were done to understand wear mechanisms. Inclusion of reactive functional groups on CF leading to more adhesion to matrix was confirmed to be responsible for the same.

4 - 4:30 pm

Study on Rotational Fretting Tribological Properties of L50 Steel by Low Temperature Ion Sulfuration
Z. Minhao, L. Jun, W. Yundong, M. Jiliang, Tribology Research Institute, Traction Power State Key Laboratory, Southwest Jiao tong University, Chengdu, China

The sulfide layer on the surface of L50 (0.50%C) carbon steel was prepared by low temperature ion sulfuration process and its characterizations were detected by using Vickers hardness tester, profilometer, scanning electric microscope (SEM), optical microscope (OM) and X-ray diffraction (XRD). Rotational fretting is one of basic running modes in contact configuration of ball-on-flat, to which was paid little attention. The rotational fretting wear behaviors of the sulfide layer and its substrate steel were comparatively studied in dry condition under varied angular displacement amplitudes (θ) in range of 0.125°-1°, imposed normal load (Fn) of 20 N and a constant rotational speed of 0.2°/s. The experimental results showed that the sulfide layer presented rough and porous surface was mainly consist of FeS and FeS2 phases. Compared with the substrate steel, the sulfide layer had a significant effect on reducing the friction coefficient and improving the fretting wear resistance, though the sulfide layer almost didn’t change the fretting running regimes of the substrate steel. The friction coefficients of the sulfide layer were lower than that of the substrate in the initial stage maybe due to the lubricating effect. The rotational fretting wear mechanism of the sulfide layer in the slip regime was mainly identified as abrasive wear, oxidative wear and delamination. As a result, the sulfide layer presented a better capability for alleviating rotational fretting wear.

4:30 - 5 pm

Effect of Various Types of Chills on Mechanical Properties and Fracture Toughness of Hypoeutectic Cast Iron
C. Vijayakumar, Sri Siddhartha Institute of Technology, Tumkur, India, J. Hemanth, Akshaya Institute of Technology, Tumkur, India

Hypo-eutectic cast iron specimens were cast using chills that were sub zero water-cooled, water-cooled, mild steel and silicon carbide end chills. The solidification behavior, number of eutectic cells, grain size and the effects of these on the mechanical properties like strength and fracture toughness were recorded and analyzed and compared with specimens of the same chemical composition which were sand cast without chill. It is revealed from the above investigation that sub-zero and water cool chilled cast irons exhibit severe under-cooling compared to normal sand cast iron. Thus, it is concluded from the investigation that nucleation conditions are completely altered during solidification but growth conditions prevail as usual. Therefore, under-cooling during solidification is considered to be responsible for the water-cooled variation in eutectic cell size, grain size, and microstructure and hence, the mechanical properties of the cast iron.
understanding of this phenomenon, this work presents a semi-analytical approach that enables us to explore the frictional interfacial behaviour of this type of assemblies [2]. Specifically, the interfacial behaviour of a simplified two-dimensional contact model of a commonly used frictional joint has been investigated using a quadratic programming technique based on the distributed dislocation technique [3]. An energy criterion has been proposed to describe the shake-down behavior of elastic frictional systems and, finally, some preliminary design considerations will be discussed.

2:30 - 3 pm
Establishing a Performance Map for Gas Foil Journal Bearings
B. Puleo, NASA Glenn Research Center, Cleveland, OH
Gas Lubricated Foil Journal Bearings (GFB), are self-acting hydrodynamic bearings with the unique feature of being compliant. These bearings are currently being researched in the Ambient Pressure Research Facility at the NASA Glenn Research Center, to create a performance map. This performance map will be used to aid in the design of future bearings and also to determine analytical modeling approaches. Oil free bearings offer many advantages for a variety of Aerospace applications. Gas Foil Bearings are presently being tested in Air, Argon, Helium, and CO₂, environments in the Ambient Research Rig. The Ambient rig has provided data that has shown that GFB's operate very well in 22-500°C environments, in various gases, and at pressures ranging from 0.5 ATM to 2.5 ATM. These findings will help to establish a performance map to aid in the design of future oil-free journal bearings.

3 – 3:30 pm – Aerospace Business Meeting