2012
International Joint Tribology Conference

Preliminary Program Guide & Schedule
As of 8/17/12

Westin Downtown Denver, Colorado
October 8 - 10, 2012
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Preliminary Schedule at a Glance
as of 8-17-12

**SUNDAY, OCTOBER 07**

Registration
Noon – 7pm – Registration – Foyer

Meet & Greet Reception
6 – 8pm – Molly Brown

**MONDAY, OCTOBER 08**

Speakers Briefing/Breakfast
7 – 8 am – Continental C

Registration
6:30 am – 5 pm – Foyer

**Technical Sessions 8am - 12pm**
1A (2-1) - BIOTRIBOLOGY - Lawrence A
1B (3-1) - ENGINEERED SURFACES I - Molly Brown
1C (4-1) - BOUNDARY AND THIN FILMS I - Horace Tabor
1D (5-1) - FLUID FILM LUBRICATION I - Tabor Auditorium
1E (6-1) - MACHINE COMPONENTS TRIBOLOGY I - Continental B
1F (7-1) - CONTACT MECHANICS I - Continental A
1G (13-1) CTI SESSION I - Lawrence B

Noon – 1:30 pm – Lunch on your own

**Commercial Exhibits & Student Posters** - Foyer

**Technical Sessions 1:30pm - 5:30pm**
2A (2-2) - BIOTRIBOLOGY - Lawrence A
2B (3-2) - ENGINEERED SURFACES II - Molly Brown
2C (4-2) - BOUNDARY AND THIN FILMS LUBRICATION - Horace Tabor
2D (5-2) - FLUID FILM LUBRICATION II - Tabor Auditorium
2E (6-2) - MACHINE COMPONENTS TRIBOLOGY II - Continental B
2F (7-2) - CONTACT MECHANICS II - Continental A
2G (13-1) CTI SESSION II - Lawrence B

Welcome Reception – 6 – 9 pm

**TUESDAY, OCTOBER 09**

Speakers Briefing/Breakfast
7 – 8 am – Continental C

Registration
6:30 am – 5 pm – Foyer

**Technical Sessions 8am - 12pm**
3A (1-1) - NANOTRIBOLOGY I - Lawrence A
3B (3-3) - ENGINEERED SURFACES III - Molly Brown
3C (4-3) - BOUNDARY AND THIN FILMS IV - Horace Tabor
3D (5-3) - FLUID FILM LUBRICATION III - Tabor Auditorium
3E (10-1) - SYMPOSIUM ON BIOMIMETICS AND GREEN TRIBOLOGY I - Lawrence B

Award Luncheon and Keynote Address
Noon – 2:00 pm – Continental Ballroom

**Commercial Exhibits and Student Posters**
9:30 am – Noon and 2 – 4 pm - Foyer

**Technical Sessions 2 - 6:00pm**
4A (1-2) - NANOTRIBOLOGY II - Lawrence A
4B (4-4) - BOUNDARY AND THINK FILMS III - Horace Tabor
4C (5-4) - FLUID FILM LUBRICATION IV - Tabor Auditorium
4D (7-2) - CONTACT MECHANICS III - Concourse 1
4E (9-1) - WIND TURBINE TRIBOLOGY - Lawrence B

**WEDNESDAY, OCTOBER 10**

Speakers Briefing/Breakfast
7 – 8 am – Continental C

Registration
6:30 am – 5 pm – Foyer

**Technical Sessions 8am - 12pm**
5A (1-3) - NANOTRIBOLOGY III - Lawrence A
5B (4-5) - BOUNDARY AND THIN FILMS VI - Horace Tabor
5C (5-5) - FLUID FILM LUBRICATION - Tabor Auditorium
5D (6-3) - MACHINE COMPONENTS TRIBOLOGY III - Continental B
5E (7-3) - CONTACT MECHANICS III - Continental A
5F (8-1) - MAGNETIC STORAGE TRIBOLOGY I - Molly Brown
5G (11-1) - CONDITION-BASED MONITORING AND MAINTENANCE - Lawrence B

**Technical Sessions 1 - 5pm**
6A (4-6) - BOUNDARY AND THIN FILMS V - Horace Tabor
6A (5-6) - FLUID FILM LUBRICATION - Tabor Auditorium
6B (6-4) - MACHINE COMPONENTS TRIBOLOGY I - Continental B
6C (7-4) - CONTACT MECHANICS IV - Continental A
6D (8-2) - MAGNETIC STORAGE TRIBOLOGY II - Molly Brown

Beverage Breaks are scheduled at 10am and 3pm daily in the Foyer
-The articular cartilage function is to allow the bones in a joint to move without causing excess friction and damage. When this function becomes impaired, the supportive and lubricating mechanisms break down, leading to injuries which can be permanent or take extended periods of time for recovery. Because of its importance in general health and body mobility, the unique lubricating properties of cartilage have been studied for many decades. Many current theories exist to characterize the biphasic and triphasic nature of cartilage; however, an important reason that cartilage is so effective is its viscoelastic nature, which allows elastic and dissipative mechanisms to exist simultaneously. It is desired to derive the material properties of cartilage in order to better understand its mechanical effectiveness. Utilizing a CETR-UMT-3 Tribometer, stress relaxation experiments will be performed on freshly harvested equine cartilage plugs that remain hydrated in a fluid bath. Viscoelastic models, such as the Prony series and fractional derivative, are applied to the experimental data to determine the storage and loss moduli of the sample explants. The storage and loss information characterizes the mechanical response of cartilage, and provides insight into the effectiveness and longevity of biological joints. A comparison will be made between joints that experience similar loads, but undergo different relative motions, to determine if the mechanical properties of cartilage are tailored to joint function. Osteoarthritic cartilage will also be explored for deviations in viscoelastic behavior compared to healthy cartilage. Ultimately, it is hoped that a viscoelastic characterization of articular cartilage will lead to insight into the precursors of osteoarthritis, more advanced prosthetics, and biomimetic applications such as the integration of flexible surfaces in mechanical systems.
were recorded with a high-speed digital camera and evaluated with thin film colorimetric interferometry. Under pure rolling conditions it was observed that the central film thicknesses increased with time for all measurements. When the disc was slower than head then the measured central film thicknesses achieved values only about some few nanometres, whereas when the tests were realized with faster disc then measured central film thicknesses achieved significantly higher values up to 300 nm. Distribution of the film thickness within the contact zone is not homogeneous and two different film thickness regions can be found; thicker protein film and thinner base film that both show specific behaviour over time.

This study showed that protein formation plays an important role in the lubrication processes of artificial joints of the human. Due to challenging of this study the more complex research work is carried out at the present time.

9:30 - 10am
Superlubricity Mechanism of Brasenia Schreberi Muclage
Extended Abstract. IJ TC2012-61113
- J injin Li, J Ianbin Luo, Tsinghua university, Beijing, China
  
  An eatable aquatic plant, Brasenia schreberi, was found owning excellent lubrication properties with an ultra-low friction coefficient about 0.005 between its surface and a glass surface. The friction coefficient is closely related to the structure of muclage and the content of water in the muclage. Many nanosheets were found in the muclage surrounding the Brasenia schreberi. The lubrication mechanism is proposed due to forming hydration layer among these nanosheets with plenty of bond water molecules. The excellent lubrication property has obvious application for the fabrication of glossy pill coated by such kind of muclage, which would prevent pill lodging in peoples throat, especially for children.

10 - 10:30am - BREAK

10:30 - 11am
Influence Of Hydrodynamic Fluid Pressure And Shoe Tread Depth On Available Coefficient Of Friction
Extended Abstract. IJ TC2012-61173
- Gurjeet Singh, University of Wisconsin Milwaukee, Milwaukee, Wisconsin, United States, Kurt Beschorner, University of Wisconsin - Milwaukee, Milwaukee, WI, United States
  
  Slip and fall accidents are a major occupational health concern. Identifying the lubrication mechanisms affecting shoe-floor-contaminant friction under biofidelic (testing conditions that mimic human slipping) conditions is critical to identifying unsafe surfaces and designing a slip-resistant work environment. The purpose of this study is to measure the effects of varying tread design, tread depth and fluid viscosity on underfoot hydrodynamic pressure, the load supported by the fluid (i.e. load carrying capacity), and the coefficient of friction (COF) during a simulated slip. A single vinyl floor material and two shoe types (work shoe and sportswear shoe) with three different tread depths (no tread, half tread and full tread) were tested under two lubrication conditions: 1) 90% glycerol and 10% water (219 cP) and 2) 1.5% Detergent-98.5% (1.8cP) water solutions. Hydrodynamic pressures were measured with a fluid pressure sensor embedded in the floor and a forceplate was used to measure the friction and normal forces used to calculate coefficient of friction. The study showed that hydrodynamic pressure developed when high viscosity fluids were combined with no tread and resulted in a major reduction of COF (0.005). Peak hydrodynamic pressures and (load supported by the fluid) for the no tread-high viscous conditions were 234 kPa (200.5 N) and 87.63 kPa (113.3 N) for the work and sportswear shoe, respectively. Hydrodynamic pressures were negligible when at least half the tread was present or when a low viscosity fluid was used despite the fact that many of these conditions also resulted in dangerously low COF values. The study suggests that hydrodynamic lubrication is only relevant when high viscous fluids are combined with little or no tread and that other lubrication mechanisms besides hydrodynamic effects are relevant to slipping like boundary lubrication.

11 - 11:30am
Equine Articular Cartilage Stiffness Determination using Indentation Technical Presentation Only. IJ TC2012-61245
- Hyeon Lee, Robert L. Jackson, R. Reid Hanson, Auburn University, Auburn, AL, United States, Patrick A. Smyth, Georgia Institute of Technology, Atlanta, GA, United States, Itzhak Green, Georgia Inst Of Tech, Atlanta, GA, United States
  
  -The indentation test is the most popular method for obtaining the mechanical properties of cartilage because of its relative simplicity. In this study, indentation tests were performed on fresh equine articular cartilage obtained from the radio carpal, intercarpal and carpal metacarpal joints to observe the stiffness of cartilage. All samples used in the tests were obtained from horses within 12 hours of death. All cartilage samples were preserved in its synovial structure to within 15 minutes of testing. A flat-ended indenter and spherical one were employed in the tests, and these were compared with each other. These were also compared to the results from the compression test using cylindrical cartilage plug. The stiffness of the cartilage was obtained through the analysis of the force versus indentation depth curve obtained from tests. The visco-elastic nature of the cartilage due to its biphasic structure was also observed.

11:30am - Noon
Mechanical And Tribological Characterisation of Articular Cartilage and Tissue Engineered Materials Technical Presentation Only. IJ TC2012-61259
- Mario Alberto Accardi, Imperial College London, London, United Kingdom, Philippa Cann, Imperial College Tribology Sec, London, Sn72bx, United Kingdom, Daniele Dini, Imperial College London, London, United Kingdom
The 2D transient Reynolds equation has to be solved for this kind of surface. The statistical method using the Patir and Cheng [2] flow factors is widely used. This approach lumps the different components of the surface (grooves and plateaux) and does not consider the roughness directionality. Methods decoupling both components, like the homogenization method [3] are also used. Another alternative is to use a deterministic model on measured surfaces, but this is a hugely expensive approach. Multigrid methods [4] are used to drastically reduce the calculational cost. The aim of the current study is to facilitate the understanding of measured surface calculations. Hence, analytical surfaces are used. They allow a flexible handling of the cross-hatching parameters. The plateaux are perfectly smooth and the grooves are sinusoidally shaped. The top ring is modelled using a parabolic profile. Periodic boundary conditions are used in the orthoradial direction and zero pressure conditions (Dirichlet) in the axial direction.

To investigate the effect of different parameters, various imposed film thicknesses are applied and the mean load carrying capacity (LCC) over time is calculated. When representing the LCC corresponding to each parameter compared to the smooth LCC, as a function of the logarithm of the minimum film thickness, the curves are quite linear for small values of the film thickness and then for larger values they converge to 1.

8:30 – 9 am
Effect of Surface Microtexturing on Friction at Unidirectional Sliding Depending on Lubricant Viscosity
Extended Abstract. IJTC2012-61042
-Karl-Heinz Zum Gahr, Mario Mann, Karlsruhe Institute of Technology, Karlsruhe, Germany
-Trends to lubricants of lower viscosity or hermetically sealed sliding systems or downsizing of machinery for using benefits such as reduced energy consumption, smaller installation size as well as lower cost of manufacture or maintenance can cause tribological problems. Today many tribosystems run under mixed friction, at least temporarily, because it is very difficult to achieve a load bearing lubrication film at severe service conditions. As consequence, problems can occur in these systems with the load-carrying capacity, running-in and friction as well as wear behaviour. Hence, materials and design of the functional surfaces mated in the lubricated sliding contact need particular consideration. New materials such as advanced ceramics and methods of surface engineering offer an interesting potential to meet demands for tailoring the friction behaviour. Particularly, laser-assisted surface microtexturing represents a highly flexible method of surface engineering with respect to geometry of components, materials and texture pattern. Theoretical and experimental studies showed in literature that microtexturing of the mated functional surfaces of sliding systems can be very effective in improving friction and wear behaviour. However, the effectiveness differs substantially and in some cases microtexturing showed no significant or even a detrimental effect on friction coefficient, wear resistance and load carrying capacity depending on...
the mated materials, lubrication and operating conditions.

Hence, aim of the present studies was to achieve a deeper knowledge of the mechanisms and most important factors influencing friction behaviour of steel/ceramic pairs textured with microdimples and lubricated by liquids of far different viscosities.

The experimental studies were carried out on steel 100Cr6/sapphire pairs with polished or microtextured flat contact areas. Laser-assisted microtexturing was manufactured on the polished functional surfaces using an Ytterbium-fibre laser. Parameters of the deterministic microtexture pattern with a face centred structure of microdimples such as area coverage fraction, diameter and depth were systematically varied in different test series.

Tribological tests were carried out up to the sliding velocity of 0.30 m/s using a laboratory tribometer and liquids with different values of dynamic viscosity were fed by drip lubrication in front of the contact area. As liquid lubricants, mixtures of glycerine and distilled water ranging from 96% to 50% glycerine, distilled water and different mineral oils without additives were used for studying the effect of viscosity on effectiveness of microtexturing. Results have shown that influence of microtexturing on friction behaviour depended strongly on viscosity and wetting behaviour of the lubricants as well as texture parameters.

9 - 9:30am
Determination of Fundamental Parameters for the Cross-Hatched Cylinder Liner Micro-Geometry
Extended Abstract. IJ T.C 2012-61060
-Nans Biboulet, Universitè de Lyon, INSA-Lyon, LaMCos, CNRS UMR 5259, Villeurbanne,France, Philippe Sainsot, Universitè de Lyon, INSA de Lyon, LaMCos, CNRS UMR 5259, Villeurbanne,France, Antonius Lubrecht, Insa De Lyon, Villeurban 69621,France
-Current automotive industry objectives are oriented towards energy saving and reduction of polluting emissions. In this context, the cylinder-liner-piston-ring contact optimisation is of particular interest. The two goals, which are partially imposed by environmental norms, require an optimisation as a function of the operating conditions (load, speed, viscosity, ...), and a compromise between fuel consumption (power losses due to friction), lubricant consumption (leading to pollution emission) and cylinder liner life (especially wear and scuffing, Wilin).

The surface micro geometry is strongly influenced by the manufacturing process. A current trend to enhance vehicle performance is to optimize this surface micro-geometry. In most of the cylinder-liner-piston-ring contacts in automotive engines, classical surface finishes are cross-hatched micro-geometries. These helicoidal grooves may have a major influence on cylinder-liner-piston-ring contact performance.

Classical roughness measurement parameters (Abbott and Firestone) may no be able to correctly characterise these surfaces. Some specific parameters are used to describe these cross-hatched micro-geometries (Weidner et al.) Surface topographies with different number of fired cycles have been analysed.

The main points of this paper are:
- a presentation of the main parameters of grooved-plateau honed surfaces; a description of an automatic way to characterise these surfaces; a detailed statistical study, focusing on the statistical significance of cylinder surface measurements; a quantification of the micro-geometry evolution during the system life (Picken et al., Gara et al.)

9:30 – 10am
Non-Uniform Behavior of Lubricant Flow According To Surface Texturing Distribution
Extended Abstract. IJ T.C 2012-61100
-Alberto Higuera, Universidad de Oviedo, Gijon, Asturias,Spain, Chin-Pei Wang, Purdue University, West Lafayette, IN,United States, Ruben Gonzalez, University of Oviedo, Gijon, Asturias,Spain, Antolin Hernandez Battez, University of Oviedo, Gijon, Asturias, Spain,Spain, Farshid Sadeghi, Purdue University, West Lafayette, IN,United States
-This study presents and discusses how the lubricant film flows in and around the dimples of a textured surface. Currently some authors assume that the emptying of the dimples starts in their front edge (according to the lubricants flow), but several tests, with different texturing densities and distances, have showed that this behavior can only be seen in the first row of dimples or, if distance is long enough, in the following rows. However, in those cases where rows are closely distributed (high texturing densities) the emptying of the dimples shows two lateral fronts instead of a frontal one. 200 µm stainless steel TBI shims were textured, according to different densities and distances, with an Oxford Laser Micro-machining Work Station. The shape of the dimples was circular and its diameter was 500 µm. The shims were bonded to stainless steel pieces which were previously polished to achieve perfectly flat bottom surfaces for all the dimples. The adhesive was a high-performance two component epoxy-phenolic resin, M-Bond 610, with an estimated 5 µm thickness of the adhesive film. Specimens were tested in a Glass Disk Test Rig Optical Machine, rotational speed was 3.3 rpm and normal load was 0.98 N. The contact area was a circular one with 14 mm diameter and nine 500 µm diameter pockets placed on it, therefore the final contact area was 152.17 mm² with a contact pressure of 6.5 kPa. Surface roughness was Ra<0.05 µm. Silicone oil was used as lubricant fluid with a viscosity of 0.0005 m²s⁻¹ at 25°C and dynamic viscosity of 0.0048 Pa’s at 25°C. All tests were run with a 0.1 µl single drop placed on the contact surface. A single pocket textured surface was set as control test. The study led to the following conclusions: the way pockets are emptied depends on their distribution and position in the dimples’ array; frontal emptying phenomenon is only present at first row dimples or when distance between rows is long enough; when surrounding pockets modify how the lubricant reaches the dimple, the frontal emptying phenomenon becomes a bi-edged one, with two emptying fronts instead of one; as surface texturing requires a huge number of pockets at usually high texturing densities, it can be asserted that the frontal emptying phenomenon is not the most
common one even though it's the one that several authors use to study the emptying phenomenon.

10 - 10:30am - BREAK

10:30 - 11am
The Role of Laser Surface Textured Patterns on Friction in Reciprocating Contacts
Extended Abstract. IJ TC2012-61149
-Miguel De la Cruz, Michael Gore, Nicholas Morris, homer rahnejat, Loughborough University, Loughborough,United Kingdom
-The paper presents the development of a new reciprocating friction measurement test rig. Additionally, laser surface texturing (LST) techniques are introduced and a set of typical experimental results is presented. It is shown that the introduction of textured areas can result in significant reduction in lubricated conjunctional friction of a straight ring segment-to-a flat substrate.

11 - 11:30am
Tribological Properties of Tialsin Coatings: Effect of Si and Sputtering Conditions on Wear and Adhesion
Technical Presentation Only. IJ TC2012-61178
-David Phillipon, Laboratoire de Mécanique des Contacts et des Structures - INSA de Lyon, VILLEURBANNE,France, Vanda Godinho, Instituto de Ciencia de Materiales de Sevilla CSIC-US, Sevilla,Spain, Peter M Nagy, CRC-HAS, Department of Surface Modification and Nanostructures, Budapest,Hungary, Marie-Paule Delplancke - Ogletree, Université Libre de Bruxelles, Matières et matériaux, Bruxelles,Belgium, Asuncion Fernandez, Instituto de Ciencia de Materiales de Sevilla CSIC-US, Sevilla,Spain
-Industrial demands for hard and protective coatings applications have increased since the last decade. The superhardness properties of the Ti-Al-Si-N system, made it one of the best candidates. Such behaviour is mainly attributed to a nanoscaled heterostructure constituted by small crystals of a hard nitride (TiN) phase separated by a thin grain boundary region of a second amorphous material (a-Si3N4). The incorporation of Al into the TiN phase would lead to an improvement of the oxidation resistance at high temperature while maintaining the outstanding mechanical performance. Therefore TIALSIN appears as an interesting candidate for many industrial applications and accordingly the investigation of microstructure, mechanical properties as well as tribological behaviour is strongly required.

In this work, several series of TIALSIN nanocomposite thin films were deposited onto different substrates by reactive magnetron sputtering. TIALSIN coatings were sputtered from TiAl (75/25 at%) and pure Si (99.999 at%) targets under nitrogen atmosphere. The influence of the power applied to the TiAl targets (100 to 600W) as well as the pure Si target (250 and 400W), substrate temperature and bias on the tribological performance of durability of the coatings were investigated.

The mechanical properties of the coatings (hardness and reduced Young Modulus) were obtained by nanoindentation technique. Profilometry measurements were used to estimate the residual stress of the coatings calculated by Stoney's equation. The adhesion of the films was evaluated by scratch test. Dry sliding experiments were conducted using a ball-on-disk rotating tribometer with WC-Co ball as antagonist. The chemical composition, the structure and the thickness of the coating were investigated by various complementary techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), grazing incidence X-ray diffraction (GIXRD) and X-ray photoelectron spectroscopy (XPS). Coefficients of friction, wear rates and endurances were correlated with the composition, microstructure, mechanical properties, residual stress and adhesion of the coatings. The hardness and elastic modulus were found dependent not only on the composition but also on the residual stress induced by the deposition process (substrate temperature and polarization). Friction coefficient was found to be independent on Si content while the wear rate is strongly reduced for higher Si contents. The formation of a nanocomposite microstructure, the amount of amorphous Si-based phase and both, wear resistance and adhesion are shown as the critical factors to determine the endurance of the coating.

11:30am - Noon
Influence of Surface Roughness on Traction and Scuffing Performance of Lubricated Contacts for Aerospace and Automotive Gearing
Extended Abstract. IJ TC2012-61212
-Samuel Shon, Ahmet Kahrman, Ohio State University, Columbus, OH,United States, Kelsen LaBerge, US Army Research Laboratory, Cleveland, OH,United States, Brian Dykas, US Army Research Laboratory, Aberdeen Proving Ground, MD,United States, David Stringer, US Army Research Laboratory, Cleveland, OH,United States
-In this study, a two-disk test set-up was devised to investigate the impact of surface roughness on the performance of lubricated contacts. In order to simulate contacts from automotive transmissions and rotorcraft gearboxes, roller specimens made of a typical automotive gear steel (AISI 5120) and a common rotorcraft gear steel (AISI 9310) were paired with 80W90 and MIL-PRF23699 lubricants, respectively. The specimens were subjected to various operating conditions to measure traction and scuffing performance. Contact surfaces of specimens were engineered to represent three different conditions: (i) axially ground surfaces with Rq = 0.4-0.5 micrometers, (ii) chemically polished isotropic surfaces with Rq = 0.08-0.12 micrometers, and (iii) highly polished mirror-like surfaces with Rq = 0.01-0.03 micrometers. The experimental conditions and specimen conditions were chosen to determine the improvements in frictional losses and oil-off performance attainable through the use of commercially available super-finishing methods.
Two different sets of tests were performed to assess the influence of surface conditions. The first set of tests varied the slide-to-roll ratio from 0.1 to 1.0 at constant normal load, rolling velocity and oil inlet temperature conditions to establish traction coefficient curves within typical ranges of operating conditions. The second group of tests was designed to assess the scuffing performance as a function of surface conditions. This paper provides a detailed description of the test set-up, specimen, test matrices, and presents the traction and scuffing results in various formats to allow direct comparisons on the impact of surface effects under both automotive and aerospace conditions. At the end, the measured benefits of reducing surface roughness in terms of these contact performance metrics are discussed, and a list of practical recommendations are provided.

This cooperative research activity was conducted between The Ohio State University and the US Army Research Laboratory under sponsorship of Quick Reaction Fund #2009QRF0022 through the Assistant Secretary of Defense for Research and Engineering.

1C - TRACK 4 Boundary and Thin Film Lubrication
Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

4-1 - BOUNDARY AND THIN FILMS 1
8am - Noon - Horace Tabor
Session Chair: Kurt Beschorner, University of Wisconsin - Milwaukee, Milwaukee, WI, United States
Session Co-Chair: Ken Nakano, Yokohama National University, Yokohama, Kanagawa, Japan

8 - 8:30am
Transient Behaviour in Lubricated Compliant Contacts
Technical Presentation Only. IJ TC2012-61021
- Connor Myant, Mark Fowell, Imperial College London, London, United Kingdom
- Philippa Cann, Imperial College Tribology Sec, London S72bx, United Kingdom
- Soft/ compliant materials have many engineering and biological uses from polymer seals to contact lenses, condoms and biological analogues. When designing these products knowledge and understanding of the lubricant film thickness is essential for achieving optimal performance. Beginning in the 1960s optical interferometry was established as the primary technique for the study of lubricant film thickness in compliant contacts. However optical interferometry on compliant substrates is currently limited to monochromatic illumination systems which makes obtaining high resolution (in z direction) measurements difficult. In addition due to the loss of coherence lubricant film thickness above < 2 microns is also hard to measure. Contacts are restricted to simple uni directional sliding, very low load and entrainment. This is undesirable as many engineering and biological interfaces of interest under typical conditions will undergo transient loading cycles and complex kinematics. Contact film thickness is expected to range from nanometres to hundreds of microns. Therefore a more suited technique is required to investigate the film thickness. To this end the authors have built on the laser induced fluorescence (LIF) technique for film thickness measurement which has been widely reported in the literature. Fluorescence is an optical phenomenon the intensity of which is a function of the dye characteristics, the dye concentration, the exciting light intensity, and the scalar being measured. Once a particular dye and concentration are selected, the fluorescence dependence on these factors is constant. Fluorescence can be used to characterize any scalar that affects the fluorescence of the dye, including film thickness, temperature, and contact pressure. Intensity images can be converted to film thickness maps by applying a simple calibration. This produced a fast, repeatable and easy to use technique for obtaining film thickness maps over the entire contact of interest. In this paper we describe the formation and breakdown of elasto-hydrodynamic (EHL) lubricating films during start-up and stopping motion of a compliant point contact. Lubricant film thickness behavior is compared to acceleration. When motion starts a front is observed to pass through the contact as separation between the contacting bodies occurs. Once film thickness is stabilized the observed front halts at the rear of the contact becoming a recognizable hydrodynamic wedge. During halting motion a rapid reduction in film thickness is seen until a static contact is reformed. A bell of fluid is then trapped in central contact region, which is squeezed out over time.

8:30 - 9am
Development of Screening Test Method for Assessing the Wear Performance of Marine Cylinder Lubricants using Cylinder Liner and Piston Ring Tribo-Couple
Extended Abstract. IJ TC2012-61021
- Ramakumar SSV, IndianOil Corporation Limited, Fairdabad, Haryana, India, Bijwe J, Shekhar Kansara, IITD Industrial Tribology, Machine Dynamics & Maintenance Engineering (ITMMEC), New Delhi, Delhi, India, Neelim Agarwal, V. Martin, Ravinder Kumar Malhotra, IndianOil Corporation Limited, Fairdabad, Haryana, India
- Cylinder liner wear protection is one of the important performance attributes expected out of marine cylinder lubricants used for the lubrication of low speed, 2-stroke marine cross-head diesel engines. Piston ring and cylinder liner during the length of power stroke in these engines experience varying lubrication regimes - boundary conditions at top & bottom dead centers and hydrodynamic in the rest of the liner length. Known wear mechanisms of cylinder liner are abrasion, corrosion and scuffing. Since marine cylinder lubricants are not governed by any standard performance specifications, optimization of these lubricants towards wear resistance is a difficult proposition, especially in the absence of any well correlating laboratory screening test method. Need for such tests is all the more required now, as oil companies, the world over, are re-optimizing the marine cylinder lubricants commensurate with low sulphur, MARPOL...
emission regulation compliant bunker fuel quality. Simulation of real time conditions of a piston-cylinder liner operation in a laboratory test method seemed to be best possible in sliding reciprocatory motion of a pin on plate. Present paper describes the development of a quick and well correlating screening test method for assessing the relative wear resistance of various marine cylinder lubricants. A reciprocatory wear tester using the cut segments of actual ship liner & piston ring material as pin-on-plate assembly was used. Reciprocatory mode was selected with load, speed, stroke length and oil temperature-directionally representative of the real time conditions. Several marine lubricants of varying total base number, detergent chemistry and known field performance attributes were subjected to tribotesting in this newly fabricated wear tester for specific wear rate and coefficient of friction. The same studies were also carried out under accelerated conditions by adding 1 and 2 percent vol/vol of sulphuric acid in the lubricant samples to simulate the corrosive wear conditions. The studies were also repeated in a conventional tribometer (not using actual liner and ring material) and a standard four ball wear tester. The data generated on newly fabricated wear tester could accurately discriminate the high and low performance reference oils among the investigated marine lubricants. The field trial data on these oils also validated the findings. However, same kind of distinction and correlation was very poor in case of conventional tribometer and standard four ball wear tester. Surface analysis of post test ring specimens by scanning electron microscopy revealed the relative scuffing patterns yielded by several investigated oils.

9 - 9:30am
Friction Process Studies of Superlubricity
Extended Abstract. IJTC2012-61048
Jinjin Li, Tsinghua university, Beijing,China, Chenhui Zhang, Tsinghua Univ, Beijing 100084,China, Jianbin Luo, Tsinghua university, Beijing,China

In this work, the friction process of superlubricity (u=0.004) obtained by phosphoric acid solution has been investigated by a traditional tribometer. The evolution of friction coefficient with time indicates that the friction process of superlubricity is divided into three stages, i.e. friction reducing rapidly process, low friction process and superlubricity process. The relationship among these three stages is discussed according to several experiments. It is found that the first stage is a tribochemical reaction process between phosphoric acid solution and friction surfaces, which is a necessary process for superlubricity, and the second stage is associated with free water evaporating process, which is not a necessary process for superlubricity. The third stage is superlubricity state, which is the result of the first stage and the second stage. According to the feature of friction process in the first stage and the second stage, it is concluded that there is a three layer structure formed in the contact region between two friction surfaces, which is the origin of ultra-low friction. The present work provides evidence for understanding the superlubricity mechanism and reducing running-in period of superlubricity, which seems to be helpful for us to find out more kinds of water based superlubricity materials in future.

9:30 - 10am
Study Interfacial Interaction of Nanoscale Confined Liquid with Modified QCM-D
Technical Presentation Only. IJTC2012-61049
Xiaoxi Qiao, Tsinghua University, Beijing,China, Xiaoxi Qiao, Xiangjun Zhang, State Key Laboratory of Tribology, Tsinghua University, Beijing 100084, P. R. China
The interfacial properties of liquid confined between two solid surfaces in micro-nano scale have attracted much interest. Many researches have done many experiments about this by different techniques such as surface force apparatus (SFA) and atomic force microscope (AFM). The experimental results show that when the two solid surfaces approach a few molecular diameters, discontinuous theories often break down and an oscillatory solvation force appears arising from the layered structure of the confined liquids. Under the confinement of micro/nanobscale, both the structure and the rheology properties of liquid will change, in which the solid-liquid interface interaction play a significant role. However, the confined areas are small in both the AFM and SFA experiments, and the shear velocities of these two techniques in the tangential direction are small, which cannot use to measure confined liquid under high shear speed condition.

The quartz crystal microbalance with dissipation monitoring (QCM-D) as an potential device has been developed to measure and study the interface properties of liquid such as absorption/desorption kinetics, electrochemical reaction mechanisms and interfacial viscosity. The tangential vibration frequency of QCM-D can get several mega hertz resulting in a local mean shear rate as high as the order of 106. In this paper, a modified QCM-D device was developed to measure and study interfacial properties of liquid which can actively control the confinement thickness in nanometer scale by using a parallel confining structure. Then, we investigated the frequency change vs. confinement thickness curves, which was proved depending on the molecular structure of the measured liquid, the electrostatic interaction original from electric double layer (EDL) and boundary condition of interfacial layer. Finally, we compared several aqueous solutions with different ionic concentration to reveal the mechanism of interfacial interaction and different EDL Debye lengths.

10 - 10:30am - BREAK
10:30 - 11am
Anti-Vibration Tribometer using Viscous Damping Effect generated by Lateral Slip
Extended Abstract. IJTC2012-61194
Ken Nakano, Chiharu Tadokoro, Naohiro Kado, Yokohama National University, Yokohama, Kanagawa,Japan

This paper proposes a simple and novel principle for suppressing frictional vibration using viscous damping effect generated by lateral slip given to a typical sliding system. This principle was applied to the measurement of friction coefficient and an anti-vibration tribometer (AVT) was developed. The AVT suppressed frictional vibration caused by the
negative dependence of the friction coefficient on the relative velocity, and it enabled one to measure friction coefficient accurately in the force balance between the friction force and spring force. If using the mean value of oscillating spring force to calculate friction coefficient under frictional vibration, it was found that considerable errors (e.g., approximately 30%) appears.

11 - 11:30am
The Contribution of a Sliding Velocity to EHL Film Thickness Distribution
Extended Abstract. IJ TC2012-61133
-Milan Omasta, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

-In general contact conditions, the surface velocities are variously oriented, thus the entrainment and sliding velocity act at different directions. The effects of magnitude and direction of the sliding velocity in elastohydrodynamical lubrication (EHL) circular contact have been investigated. Film thickness distribution has been obtained using thin-film colorimetric interferometry. It has been found that direction of sliding velocity with respect to entrainment velocity play a role in film thickness distribution, particularly at high slide-to-roll ratios. A superposition of the effects of a pure rolling and of an opposite sliding has been considered. The pure rolling condition creates typical horse-shoe shaped film, whereas under the opposite sliding condition (i.e. zero entrainment velocity) conical depression in the central area of Hertzian contact called dimple has been observed.

11:30am - Noon
Experimental and Modeling Studies for Understanding Shoe-Floor-Contaminant Friction and Designing for Slip-Resistance
Extended Abstract. IJ TC2012-61191
-Kurt Beschorner, University of Wisconsin - Milwaukee, Milwaukee, WI, United States

-Insufficient friction at the shoe-floor interface causes a large number of slip and falling accidents each year. Developing solutions for enhancing shoe-floor-contaminant friction requires understanding the mechanisms that contribute to slippery surfaces. Over the past several years, our research group has conducted several experimental and modeling studies to reveal the critical tribological mechanisms contributing to shoe-floor-contaminant friction. This extended abstract will discuss the findings of these studies to: 1) determine the lubrication regime(s) that is/are most relevant to under-shoe conditions during slipping; 2) quantify how under-shoe conditions, shoes and floor roughness and shoe to floor hardness may be relevant for most other conditions. In boundary lubrication, the primary factors contributing to friction are adhesion and hysteresis. Experimental data and finite element models demonstrate that hysteresis friction increases with floor roughness and the ratio of shoe to floor hardness. Adhesion friction is dependent on real area of contact and the shear stress required to break junctions. Experimental data suggests that adhesion is dependent on the fluid lubricant, sliding speed, floor roughness and shoe material. Finite element models confirm that a reduction in the real area of contact occurs with increasing floor roughness and sliding speed, consistent with the experimental adhesion effects. Ensuring that the shoe-floor-fluid interface is operating in the boundary lubrication regime requires establishing minimum tread threshold for fluid lubricants that are likely to be found in a given environment. Designing a high hysteresis shoe-floor combination is preferred because it is relatively unaffected by fluid contaminants or under-shoe conditions (i.e. sliding speed). Therefore, ensuring a minimum tread depth is used along with increasing floor roughness and shoe to floor hardness may be effective in addition to minimum tread thresholds.

1D - TRACK 5 Fluid Film Lubrication
Track Chair: Daejong Kim, University of Texas at Arlington, Arlington, United States

5-1 -FLUID FILM LUBRICATION I
8am - Noon - Tabor Auditorium
Session Organizer: Mihai Arghir, Institut Pprime, Université de Poitiers, Futuroscope, France

8 - 8:30am
Influence of Couple Stress Lubricant on the Performance of Orifice Compensated Non-Recessed Hole-Entry Hydrostatic/Hybrid Journal Bearing
Extended Abstract. IJ TC2012-61013
-Satish C. Sharma, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India, Nathi Ram, Indira Gandhi Institute of Engineering & Technology (GGIPU) Delhi, Delhi, Delhi, India

-The lubricants are generally additized in order to enhance their lubricating properties. As a consequence of this, they exhibit nonlinear relationship between the shear stress and shear strain. One class of lubricants which has received considerable attention in recent years is the couple stress lubricants. The study of couple stress fluid flows has been the subject of increased interest owing to its widespread industrial and scientific applications such as synthetic fluids, polymer-thickened oils, liquid crystals and animal bloods. The present work is therefore aimed to study analytically the influence of couple stress lubricant on the performance of an orifice compensated non-
homogenized pressure.

The approach adopted in the present research work is based on the application of the homogenization concept to the turbulent Reynolds equation derived from the mean flow momentum equations by using the classical lubrication assumptions. The multi-scale expansion of the fluid pressure leads to a system of four partial differential equations governing two types (local and global) problems which solutions are the periodic functions and the homogenized pressure.

The numerical simulation are performed by considering isotropic roughness patterns periodically distributed over the entire stationary bush surface, and various values of the Taylor’s dimensionless damping coefficient is larger for hydrostatic journal bearing lubricated with couple stress lubricant.

8:30 - 9am
Homogenization of Laminar and Turbulent Reynolds Equations: An Application to the Analysis of Rough Hydrodynamic Journal Bearings
Technical Presentation Only. IJ TC 2012-61016
-Benyebka Bou-Said, INSA, Villeurbanne, France, Mustapha Lahmar, Guelma University, Guelma 24000, Algeria

The hydrodynamic lubrication theory founded by Osborne Reynolds in 1886 is based upon several assumptions among them the contact surfaces are perfectly smooth, and the flow regime of lubricant is laminar. However, it was shown that for the journal bearings of modern rotating machinery which operate under severe conditions, these hypotheses lose their validity. In these conditions the consideration of surface roughness and turbulence effects is then of a cardinal importance to accurately predict the performance characteristics of such journal bearings.

The approach adopted in the present research work is based on the application of the homogenization concept to the turbulent Reynolds equation derived from the mean flow momentum equations by using the classical lubrication assumptions. The multi-scale expansion of the fluid pressure leads to a system of four partial differential equations governing two types (local and global) problems which solutions are the periodic functions and the homogenized pressure.

The numerical simulation are performed by considering isotropic roughness patterns periodically distributed over the entire stationary bush surface, and various values of the Taylor’s dimensionless damping coefficient is larger for hydrostatic journal bearing lubricated with couple stress lubricant.

9:00 – 9:30am
Performance Analysis of Worn Misaligned 4-lobe Multirecess Hybrid Journal Bearing System Compensated With Orifice Restrictor
Extended Abstract. IJ TC 2012-61018
-Vikas Phalle, Veermata Jijabai Technological Institute (VJTI), Matunga, Mumbai, India, Satish C. Sharma, Indian Institute of Technology, Roorkee, Roorkee, India

-owing to the fast technological developments, the operating conditions of the machines are becoming very stringent, exact and more demanding. Various journal bearing designs have been developed to prevent the undesired effect of bearing whirl. An example of a successful design is the four-lobe multirecess journal bearing. The bearing which having four curved segments that referred to as four lobes is the four-lobe multirecess journal bearing. Further, as the 4-lobe journal bearing is expected to run over a number of cycles during its lifetime, it is subjected to several start/stop operations. These transient periods causes the bearing bush to wear out between the recesses and significantly affects the bearing performance. The modified Reynolds equation governing the flow of lubricant in the clearance space of bearing have been solved including the combined effects of three aspects, the worn effect, the misalignment angle and offset factors, using an iterative scheme based on FEM and Newton-Raphson method. The simulated results have been presented for a wide range of offset factor ?, wear depth parameter, journal misalignment factors (?,?) and external load. The simulated results suggests that it is an imperative to account for the effect of wear along with misalignment of journal in order to predict the performance of the bearing accurately. Further, it has been observed that in general as the value of offset factor increases the static and dynamic performance of the 4-lobe four pocket worn misaligned hybrid journal bearing compensated with orifice restrictor is clearly affected as compared to similar four pocket unworn aligned hybrid circular journal bearing. Further the bearing having offset factor ?=1.2 improves the stability due to increase in the bearing stiffness and reduced magnitude of the cross-stiffness components.

9:30 – 10am
Compressible Effects and Bi-fluid Model for Cavitation
Technical Presentation Only. IJ TC 2012-61034
-guy bayada, INSA, Villeurbanne cedex, France

-It has been shown recently that JFO/Elrod Adams models can be recovered by introducing specific barotropic laws in a compressible Reynolds equation. Using this fully compressible model, it is possible to evidence some negative (below saturation pressure) pressure loop in the divergent part of the devices and to consider non constant viscosity in the mixture (or cavitation region). New numerical algorithms are addressed to solve this mode. They will be also applicable to classical J FO/Elrod Adams model. Comparisons with some 2-dimensional experimental journal bearing are presented.

This kind of model, based upon gap-averaged variables does not allowed to recover the position of a possible interface between a full film region and a bubble of gas and consequently the width of the lubricant film. A bi-fluid thin film model is then addressed in which the position of the gas-fluid is explicitly introduced. Contrary to a lot of papers (cf for example), the location of the interface is not given. It is an unknown of the problem. This position is first recovered by solving a specific equation. Then the pressure is obtained by solving a generalized Reynolds equation which takes into account the characteristics of both fluids. Various asymptotic limits can be analytically deduced, as the appearance of slippage. Numerical computations...
allows to recover the velocity of the fluid inside each fluid. The difficulties of obtaining time stabilized solutions are addressed. They are explained by solving a bi-fluid Navier Stokes system without any thin film assumptions.

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

**10:30 - 11am**

**New Generation of Water Lubricated Foil Bearing - Numerical Models and Experimental Verification**

Extended Abstract. J J TC 2012-61105

-Artur Olszewski, Michal Wodtke, Rafal Gawarkiewicz, Gdansk University of Technology, Gdansk, Poland

Because increasingly strong tendency to eliminate classical oil lubricants as harmful to the natural environment forces researchers to design alternative bearing system solutions, which would offer adequate bearing properties without typical lubricants. Bearings lubricated with water, air or self-lubricated are examples of such ecological solutions. Gas lubricated foil bearings belong to that group; they typically operate at very high rotational speed, necessary to develop the aerodynamic effect in gas lubricant. These bearings have been so far known as air or gas lubricated only, and authors idea was to explore the possibility of expanding the range of applicable lubricants by water. Few years ago the first prototype of hydrodynamic foil bearing adapted for water lubrication was built and tested. This bearing design was similar to aerodynamic bearings containing sliding foil and elastic support composed of strips of bump foil, but the water lubrication film requires different geometry of the foil elements and new sliding materials. Laboratory tests of first prototypes performed by authors show that it is possible to get full hydrodynamic lubrication in case of water lubricated foil bearing, however load capacity was not very high in comparison to typical cylindrical water lubricated bearing.

In the paper the idea of water lubricated foil bearing and the calculation methodology for the bearings hydrodynamic characteristics are presented. To assess the theoretical characteristics of these bearings two different computer models were built. First is the structural model coupled with fluid model. It takes into account: fluid flow in the deformed fluid gap, the specific design of bearing support and friction in the bearing support. The second model is based on fluid structure interaction simulation. Because computer models require accurately defined physical properties of materials, a set of tribological and stiffness tests was performed on real materials, which will be used in the prototype bearing. General results of the analysis will be discussed in the paper.

In order to verify the method of bearing calculations a test rig was modernized by installing pressure sensors on bush perimeter in two parallel planes. In addition a high sensitivity friction force measurement system was designed and built for this purpose.

**- Wojciech Litwin, Artur Olszewski, Gdansk University of Technology, Gdansk, Poland**

-Water lubricated rubber bearings are often used in ship building and other industry because of their advantages such as: long serviceable life, low coefficient of friction, long life of shaft sleeve, good vibration damping, good abrasion resistance, low maintenance required, grit particles and other abrasives are expelled through the grooves.

The idea of the conducted research work was to compare properties of two almost identical bearings but made by different manufacturers. Both bearings were accepted by ship classification societies and could be installed on a real vessel or yacht. Size of both the bearings was the same: diameter equal to 100 mm and length to 400 mm. The geometry was very similar in both cases (full molded type with lubricating grooves on bush perimeter) but different manufacturing technology was used in production, resulting in surface quality differences.

Experimental tests were conducted on a test rig purpose built for research work on water lubricated bearings. The working conditions in the tests were similar to real life conditions in small ships. Shaft rotation speed ranged from 1 - 11 revis, radial load ranging from 0.1 - 0.6 MPa, water flow was higher than 10 liters/min. During the tests the following results were recorded: pressure in water film, shaft center trajectories, water flow, supply and outflow pressure and temperature, friction force. Conducted research work reveals some weaknesses of a rubber bearings. Measured movement resistance was higher than in polymer bearings tested in the past. It was an effect of the mixed lubrication regime. Shaft orbits are very small but, unfortunately, they are located outside of experimentally measured clearance circles. It is an effect of significant deformation of very elastic bush. In fact there is no hydrodynamic pressure effect in the bearing. It is a result of very narrow bush pads and grooves located on the bush perimeter. For greater loads pressure sensors are in fact blocked by shaft.

Rubber bearings with molded bush grooved on full perimeter have some advantages and disadvantages. Work in mixed lubrication regime is one of the main disadvantages, resulting in significant wear of both the bush and the shaft. But they also have very important advantages making them irreplaceable in some applications. The most important are: good vibration damping and the ability to expel abrasives such as sand through the grooves.

**1E - TRACK 6 Machine Components Tribology**

Track Chair: Daniel Nelia, INSA-Lyon, CNRS, Villeurbanne, France

**6-1-MACHINE COMPONENTS**

TRIBOLOGY I

8am - Noon - Continental B

Session Chair: Christopher Dellacorte, Nasa, Cleveland, OH, United States

Session Co-Chair: Daniel Nelia, INSA-Lyon, CNRS, Villeurbanne, France
8 – 8:30am
Effect of Oil Separation Property of Diurea Grease on Rolling Friction Under Relative Low Speed Condition
Poster Presentation Only, IJ TC2012-61185
-Fumihiro Itoigawa, Tomohiko Obata, Takashi Nakamura, Nagoya Institute of Technology, Nagoya, Japan
-A low friction linear guide-way becomes to be a key device for high precision machines. Therefore, reducing friction of the linear guide lubricated with grease is strongly required, especially under low speed condition, because churning loss of grease relatively increases due to low temperature rise. It was found that rolling friction of a ball bearing under low speed condition can be considerably reduced if the ball bearing is lubricated with a minute amount of diurea grease, whereas the rolling friction does not decrease if using Li-soap grease. Furthermore, it was also found that its reducing effect depends on the degree of mixing and kneading in a grease production process. In this study, the mechanism of this decrease of friction is experimentally investigated. Some types of diurea grease, which consist of same base oil and thickener but only the different structure and micelle size of thickener, are prepared. The rolling friction under low speed condition is measured when the thrust ball bearing (51206) is lubricated with a minute amount of test greases. Variations of the shapes of channeling grooves can be measured by infrared interferometry and the degree of oil separation can be also evaluated by an intensity ratio of CH bond absorption spectrum(2920cm⁻¹) to that of NH bond(3280cm⁻¹) measured by FT-IR.

From the measurements, it is clarified that well-kneading grease which has the small sized and isotropic structure of the thickener exhibits very low friction. In this case, it is found that the stiff channeling groove is generated and low film thickness in the Hertzian contact region. Furthermore, it can be concluded that moderate oil separation appears in the Hertzian contact region because the intensity ratio of CH bond absorption in that region indicates larger magnitude than that of side band region. In consequence of both phenomena, just the proper quantity of the separated base oil to preserve adequate starved lubrication which leads to low friction might be kept in the rolling track.

8:30 - 9am
Experimental Study of Lubrication Film Formation in Multiple Contacts Device under Starved Conditions
Extended Abstract, IJ TC2012-61123
-Petr Svoboda, David Kostal, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic
-Some machine elements such as gears, rolling bearings, cams and traction drives operate under starved lubrication conditions where the average lubricant film thickness is considerably less than under fully flooded conditions. These parts must operate correctly, often over prolonged periods with sufficient performance. One of the most important parameters determining the performance and life of machine parts is a lubrication film thickness, which is generated within elastohydrodynamic lubricated (EHL) non-conformal contacts. The film thickness in this regime is often time dependent and its value is governed by lubricant supply. If loss outstrips supply this leads to very thin films, which can no longer fulfill their role of separating the surfaces, and thus component failure can result. To achieve optimum bearing performance and component life, it is obviously desirable to be able to predict when starvation will occur. Today the film thickness and pressure in EHL can be predicted using numerical models also in the case of starvation. Although it is very essential to solve the starved EHL problems very little work aimed at comparing experiment and theory has been done. Especially in the case where the starved lubrication model requires as input the inlet layer thickness. This is crucial if the validity of numerical models is to be properly established. This paper is focused on the study of effect of starved lubrication conditions on lubrication film formation of non-conformal contacts. A new optical test rig with multiple EHL contacts was developed for experimental study of lubrication film formation in the thrust ball bearing.

9 - 9:30am
SURFACE TEXTURING FOR ENERGY EFFICIENCY AND SUSTAINABILITY
Extended Abstract, IJ TC2012-61218
-Pradeep Menezes, University of Wisconsin Milwaukee, Milwaukee, WI, United States, Kishore , Indian Institute of Science, Bangalore, Karnataka, India, Satish Vasu Kailas, Indian Institute of Science, Bangalore 560012, Karnataka, India, Michael Lovell, University of Wisconsin-Milwaukee, Milwaukee, WI, United States
-Precise control of friction is very important for energy efficiency and sustainability in manufacturing processes. In the present investigation, various surface textures have been employed to vary the frictional conditions. More specifically, textures were varied from unidirectional to criss-cross to unidirectional by grinding the steel surfaces against emery papers for various numbers of cycles. Sliding experiments were conducted using an inclined pin-on-plate apparatus against the prepared steel surfaces under dry and lubricated conditions. In the experiments, it was observed that the coefficient of friction and transfer layer formation on the harder surfaces were controlled by the textures of the harder surfaces under both dry and lubricated conditions. The asperity angle of the harder surface plays a dominant role in controlling the friction and transfer layer at the sliding interface. Thus, by understanding appropriate roughness parameters, the friction and wear performance can be accurately controlled to enhance energy efficiency and the quality of the finished products in manufacturing process.

9:30 - 10am
Stiffness and Damping Analysis of a Single EHL Contact Between the Rolling Element and Raceways under Wider Load and Speed Ranges
Extended Abstract, IJ TC2012-61086
-Yuyan Zhang, Xiaoli Wang, Beijing Institute of Technology, Beijing, Beijing, China
The numerical analysis for the equivalent stiffness and damping of a single EHL contact between the rolling element and raceways under wider load and speed ranges is presented. The unsteady EHL model and free vibration model are applied to describe the motion characteristics of the rolling element. The inlet length and dimensionless natural frequency are determined according to the corresponding working load and speed. The DC-FFT method is implemented in order to increase the computational efficiency associated with elastic deformation and the semi-system approach is applied to ensure solution convergence under severe conditions which makes the analysis of stiffness and damping in the larger ranges of load and speed possible. The numerical results demonstrate that the stiffness increases with the increasing load and decreases with speed. However, the changes of the damping are complex, which are different in various load and speed ranges, especially under heavier load and higher speed. It is also indicated that the stiffness and damping increases with the increase in ambient viscosity and the decrease in pressure-viscosity coefficient.

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

**10:30 - 11am**

**Influence of Micro Textures on the Tribological Contact and Tribological Behavior on the Example of A CVT**

Extended Abstract. IJ TC 2012-61158

-Albert Albers, Karlsruhe institute of technology (KIT), Karlsruhe, Germany, Sandra Drechsler, karlsruhe institute of technology, Karlsruhe, Germany, Philipp Merkel, Karlsruhe institute of technology (KIT), Karlsruhe, Germany

-The request for vehicles are underlying a significant change: the reasons are not only due to the customers needs for higher performance and improved ride comfort but also the fact that the producers face with more demanding limitations set up by the legislator concerning CO2-emission. Thus there is a need to improve both, the efficiency and the convenience of the power train. A possible solution of such a system optimization is the Continuously Variable Transmission (CVT). This type of transmission transfers the power by friction, with a chain element and two axial displaceable conical disks. Compared to toothed gearings the lower efficiency is a disadvantage of present CVTs. A solution could be the reduction of losses caused by the tribological contact and the peripheral components of the gearbox. A possibility to influence the tribological behavior in the contact is the micro structuring of the friction pairing. Examples for such micro structures are micro pockets or micro channels. In the past a multitude of different applicable proceedings were developed, which show high potential in applications like piston and cylinders. The CVT is a specific issue, because the environmental conditions of the tribological contact are completely different from other tribological applications. The goal of the IPEK researches is to understand the interaction between influencing parameters in the tribological system to define the requirements for such structures. A test bench has been developed, which enables tribological investigations using multi-dimensional pin-on-disk tryouts under cyclic pressure. It offers an independent adjustment of multiple slip directions, the contact pressure and the operating temperature in order to detect the related influences. A main feature is the intermittent tribological contact that enables the investigations on squeeze-effects due to surface and oil properties. At the same time the investigations are performed for six contact element pins interacting with one planar disk in order to enable a statistical consideration of wear and failure. Stochastic structures, like shot peened or barrel finished surfaces, are tested as well as laser beamed deterministic structures. The friction coefficient and wear is identified under the special conditions and conclusions drawn on the effect of the micro texturing of the tribological contact. Furthermore the resulting friction coefficient is a function of an amount of influencing parameters and their interaction, as for example the sliding velocity, surface pressure etc. In addition the interaction between the influence of these parameters and the surface topography can be described.

**11 - 11:30am**

**Experimental Investigation of Transition in Lubrication Regime for Thin-Film Coated Surfaces.**

Extended Abstract. IJ TC 2012-61171

-M. Cinta Lorenzo Martin, Argonne National Laboratory, Lemont, United States, Oyelayo Ajayi, Argonne National Lab, Argonne, IL, United States, Sol Torrel, Argonne National Laboratory, Lemont, IL, United States, George R. Fenske, Argonne National Laboratory, Argonne, IL, United States, Robert Erck, Argonne National Lab, Argonne, IL, United States

-Friction and wear behavior of lubricated sliding contact is determined by the operating lubrication regime. A useful approach to determine the operating lubrication regime is the calculation of the ? ratio, which is defined as the ratio of lubricant fluid film thickness (h), and the composite surface roughness (? ) of contacting surfaces (? +h?). Thin-film tribological coatings are increasingly being used for application in lubricated machine elements such as gears and bearings. It is usually assumed by design engineers that application of thin-film coatings has no effect on fluid-film lubrication. This paper presents our experimental investigation of the impact of several (5) commercially available coatings on lubrication regime during a unidirectional sliding contact. Using a ball-on-flat contact configuration and lubricated with PAO basestock oil, tests were conducted in which the ? ratio was varied as a function of time, for both uncoated and coated flat specimen. In test with uncoated flat, the various distinctive lubrication regime of hydrodynamic, mixed and boundary were observed as indicated by the measured friction coefficient (Striebeck Curve). In tests with some of the coatings, especially the carbon based DLCs, there was no obvious distinctive transition in lubrication regime. In other coatings (ex. TICN), various lubrication regime were also observed; although the rate of transition from one regime to the other was different. The effects of coatings are attributed to their inherent mechanical and...
tribological properties as well as their impact on the run-in process.

11:30am - Noon
Elastohydrodynamic Piston Skirt Lubrication- Effect on Tribological Performances

Extended Abstract. IJ TC2012-61129
-Miloud Tahar Abbes, Laboratory of mechanical and energy, University of Chlef, Chlef, Algeria, Patrick MASPEYROT, University of Poitiers, Poitiers, Poitiers, France, Ahmed Dekkiche, Benbrik Mohamed, Fouad Boukli Hacene, University of Chlef, Chlef, Algeria

-A model of elastohydrodynamic lubrication of piston skirt is developed in this paper. The secondary motion of the piston, the lubrication and the elastic deformations of skirt and cylinder are described by a transient strongly nonlinear system coming from the coupling of the dynamics equations of piston secondary motion and the Reynolds equation. The iterative Newton-Raphson method in conjunction with Murthy algorithm for cavitation was used to solve the problem.

An optimum skirt curved profile, which maintain piston in optimum performance characteristics, is adopted. Using the tribological performance of the lubricated skirt-cylinder, the results - minimum oil-film thickness, maximum pressure in the lubricant film and friction- are compared to the elastohydrodynamic solution and the rigid skirt-cylinder solution. The effect of elastic deformation of both skirt and cylinder show that elastohydrodynamic analysis is necessary for an accurate prediction of a piston- cylinder performance. The computational work, applied to a solid skirt piston of a V-8 direct injection diesel engine truck, should be a powerful design analysis tool, which can be used to increase the available engine power through optimum piston performance characteristics.

IF - TRACK 7 Contact Mechanics
Track Chair: Jeffrey Streator, Georgia Tech, Atlanta, United States

7-1 -CONTACT MECHANICS I
8am - Noon - Continental A
Session Chair: Andreas A. Polycarpou, University of Illinois Urbana-Champaign, Urbana, IL, United States

8 - 8:30am
A Potential Weakening Effect of Very Thin Hard Coatings
Technical Presentation Only. IJ TC2012-61024
-R Goltsberg, Izhak Etsion, Technion, Haifa, Israel

-In a previous study (Goltsberg et al., Wear 271 (2011) 2968-2977) of the onset of plastic yield in a coated sphere compressed by a rigid flat, it was found that very thin hard coating may have a detrimental weakening effect of reducing the resistance to yield inception compared to an uncoated case. Such a weakening effect can result in early coating delamination and hence, it is of both academic and practical interest to study this phenomenon in details.

In this study a numerical approach is utilized to find the effect of various mechanical properties of both the spherical substrate and coating on the range of thicknesses where the weakening phenomenon is encountered. It is shown that proper normalization of the contact parameters provides a universal dimensionless solution for the range of detrimental coating thicknesses as well as for worst thickness associated with the lowest resistance to onset of plasticity. This might be a helpful tool for optimizing the design of coating thickness for different tribological applications.

8:30 - 9am
A Micro-Machine to Study the Fatigue of Rough Contacts
Technical Presentation Only. IJ TC2012-61028

-Laure BERTHE, Philippe Sainsot, Université de Lyon, INSA de Lyon, LaMCoS, CNRS UMR 5259, Villeurbanne, France, Antonius Lubrecht, Insa De Lyon, Villeurban 69621, France, Marie-Christine Baietto, Université de Lyon, INSA de Lyon, LaMCoS, CNRS UMR 5259, Villeurbanne, Select State/Province, France

-The surface roughness evolution in lubricated contacts is a crucial step in the fatigue prediction process. The latter is initially conditioned by the running in process and finally by surface fatigue. This work aims at understanding and predicting rolling contact fatigue with a particular emphasis on the very first cycles. It is based on a combined experimental and numerical approach. The current paper is centred on the experimental description.

A major difficulty in understanding surface degradation is the measurement of the surface roughness evolution at the relevant scales. In fact, current twin disc machines allow a global study of the contact behaviour (normal and tangential load) but it is necessary to dismount the system for each roughness measurement. Furthermore, the duration and costs are important as each pair of discs provides only a single surface observation (at the end of the test).

A twin disc micro-machine, called µMag, developed at the LaMCoS laboratory, was specially designed for this kind of surface roughness analysis. The µMag allows the observation in situ of the disc surface during the test interruption. This avoids dismounting discs, a major cause of perturbations and inaccuracies. This test system offers an accurate and continuous control of the kinematics and load parameters.

At each test interruption, the surface topography is measured using an optical profiler. Marks on the surface allow very accurate relocation of the same profile. This is essential to follow the running in mechanism and for efficient numerical simulations. Contact stress calculations are performed using analytical [1] and numerical [2] tools.

The crowned disc is turned, with a roughness of 0.6 µm. The cylindrical disc is honed, its roughness is...
less than 0.01 μm, therefore the cylindrical disc is called the smooth disc. The first results obtained with the µMaG apparatus are presented in this paper. The surface geometry is observed at the end of the first, fifth and tenth cycle. The steady state of the surface deformation is obtained after few cycles and marks to the end of the running in period.

An FFT based simulation of the experiments is carried out using the actual initial surface topography of both discs. The elastoplastic model developed by Mayeur et al. [3] was used with a bi linear constitutive law. The experimental surface topography at the end of the running in period is compared with the numerical results. This procedure is repeated up to 1 Million cycles leading to surface crack initiation.

9:30 - 10:30am
Contact Analyses for Anisotropic Half Space with an Anisotropic Coating
Extended Abstract. IJ TC2012-61038
-Caroline Bagault, Lamosc INSa Lyon, Villeurbanne Cedex,France, Daniel Nelias, INSa-lyon, CNRS, Villeurbanne,France, Timothy Ovaert, Univ Of Notre Dame, Notre Dame, IN, United States, Marie-Christine Baïetto, Université de Lyon, INSa de Lyon, LaMCoS, CNRS UMR 5259, Villeurbanne, Select State/Province,France

-For most composite and mono-crystal materials their compositions or the elaboration and manufacturing processes imply that it exists one or two main directions or even a general anisotropy. Moreover, coatings are often used to prevent or control wear. Coatings do not have, generally, the same properties as the substrate and may have various thicknesses. The influence of the anisotropy orientations (in the coating and in the substrate) have to be taken into account to better predict the distribution of the contact pressure and the subsurface stress-field in order to optimize the service life of industrial components. A contact model using semi analytical methods, relying on elementary analytical solutions, has been developed. It is based on numerical techniques adapted to contact mechanics. Recent developments aim to quantify displacements and stresses of a layered anisotropic elastic half space which is in contact with a rigid sphere. The influence of material properties and layer thickness on the contact problem solution will be more specifically analysed.

9:30 - 10:00am
PERFECT MECHANICAL SEALING IN ROUGH ELASTIC CONTACTS: IS IT POSSIBLE?
Extended Abstract. IJ TC2012-61070
-Ilya Kudish, Kettering University, Flint, United States, Donald Cohen, Michigan Metrology, LLC, Livonia, MI, United States, Brenda Vyletel, University of Michigan, Ann Arbor, MI, United States

-Generally, it is assumed that under any applied force there will always be some gap between the surfaces in a contact of rough elastic surfaces resulting in a discontinuous (i.e. multiply connected) contact [1-4]. In [5] it is shown that rough elastic surfaces with roughness distributed according to the Weierstrass function (i.e. everywhere continuous but nowhere differentiable function) form a multiply connected contact. The presence of gaps along the line contact relates to the ability to form an adequate mechanical seal across an interface. This paper will demonstrate that for a twice continuously differentiable rough surface with sufficiently small asperity amplitude and/or sufficiently large applied load and/or sufficiently low material elastic modulus singly connected contacts exist. Solution of a contact problem for a rough elastic half-plane and a perfectly smooth rigid indenter with sharp edges is considered. An exact solution of the problem for an indenter with sharp edges resulting in a singly connected contact region is considered and it is conveniently expressed in the form of a series in Chebyshev polynomials. A sufficient (not necessary) condition for a contact of an indenter with sharp edges and a rough elastic surface to be singly connected is derived. The singly connected contact condition depends on the surface micro-topography, material effective elastic modulus, and applied load. It is determined that in most cases a normal contact of a twice continuously differentiable rough surface with sufficiently small asperity amplitude and/or sufficiently large applied load is singly connected. Some microphotographs of rough surfaces with increasing resolution of up to 4 nm support the main conclusion that rough surfaces can be represented by twice differentiable distributions.

10:30 - 11:00am
Three-dimensional Modeling of Elasto-Plastic Sinusoidal Contact Including Creep
Technical Presentation Only. IJ TC2012-61109
-Amir Rostami, Auburn University, Auburn, United States, Andreas Goedecke, Randolf Mock, Siemens Corporate Technology, Munich, Munich, Germany, Robert L. Jackson, Auburn University, Auburn, AL, United States

-The goal of this work is to model the elastoplastic contact between sinusoidal surfaces in 3D and under creep relaxation. This 3D modeling between surfaces is accomplished using FEM simulations. Most of the previous works on the modeling of the contact between rough surfaces employ a spherical shape for the asperity geometry, and therefore many models to consider the elastoplastic contact of spheres exist. There are some works on modeling of the contact between sinusoidal surfaces, but their concentration has been mostly on the elastic part, or they haven’t considered the creep phenomenon in their modeling. Creep can cause the contact area and the contact pressure or stress to change over time. The current work uses the hyperbolic sine or Garofalo formula for creep which is similar to that used by many previous works, and is sometimes considered to be the most general model. Empirical formulas for the change in contact area and contact pressure with time are provided by fitting to the presented FEM results.
11 - 11:30am
Efficient Numerical Modeling of Hertzian Line Contact for Material with Inhomogeneities

Extended Abstract. IJ TC2012-61168

Xiaoping Jin, Northwestern University, Evanston, IL, United States, Zhanjiang Wang, Qinghua Zhou, Chongqing University, Chongqing, China, Leon Keer, Qian Wang, Northwestern University, Evanston, IL, United States

The present work proposes an efficient and general-purpose numerical approach for handling two-dimensional inhomogeneities in an elastic half plane. The inhomogeneities can be of any shape, at any location, with arbitrary material properties (which can also be non-homogeneous). To perform the numerical analysis, we first derive an explicit closed-form solution for a rectangular inclusion with uniform eigenstrain components, where the inclusion is aligned with the surface of the half plane. In view of the equivalent inclusion method, an inhomogeneity problem can be converted to a corresponding inclusion problem. In order to determine the distribution of the equivalent eigenstrain, the computational domain is meshed into rectangular elements whose resultant contributions can be efficiently computed using an efficient algorithm based on fast Fourier transform (FFT). In principle, there is no specific limitation on the type of the external load, although our major concern is the contact analysis. Parametric studies are performed and typical results highlighting the deviation of the current solution from the classical Hertzian line contact theory are presented.

11:30am - Noon
A Comparison of Statistical, Multiscale and Numerical Models of Elastic Rough Surfaces
Technical Presentation Only. IJ TC2012-61145

Yang Xu, Robert L. Jackson, Dan Marghitu, Auburn University, Auburn, United States

During the last 50 years, many different methods have been applied to represent rough surfaces. These methods can be divided into following categories: statistical methods, multiscale methods, and deterministic numerical methods. Perhaps the most popular model is the statistical model, e.g., Greenwood-Williamson (GW) model. However, only a few statistical parameters have been used to represent real rough surfaces, thus the accuracy of the statistical contact model is limited and generally considered only valid for the low load condition. Rough surfaces show a multiscale nature and the statistical parameters of rough surfaces are not always adequate at describing this. Many multiscale models have been developed based on the pioneering work of Archard. Numerical methods make the full usage of rough surface data which can result in better accuracy than the statistical and multiscale models. The finite element method (FEM) and boundary element method (BEM) are the most popular methods among those and will be considered in the current work. Contact between a three-dimensional linearly elastically deforming rough surface and a rigid flat is studied. Computer-generated fractal rough surfaces and real rough surfaces collected by profilometer are both used as input. The GW model and Jackson-Streator models are chosen to represent the statistical and multiscale models, respectively. In our finite element model, only the base of the bottom surface is completely constrained. The assumption of an infinite depth of the substrate is adopted in the BEM. The predicted contact area versus force, derived from the statistical model, multiscale model, FEM and BEM, will be compared first. Then rough surface deformation and pressure distribution will be compared only between the numerical method, i.e., FEM and BEM. The effect of different boundary conditions on contact load, area, pressure and surface distribution will also be explored in the FEM and BEM.

1G - TRACK 13 STLE-CTI Symposium

13-1 - STLE-CTI SESSION I
8am - Noon - Lawrence B
Session Chair: Qian Wang, Northwestern University, Evanston, IL, United States
Session Co-Chair: Xinchun Lu, Tsinghua University, Beijing, China

8 - 8:30am
Research on Green Automotive Brake Materials
Technical Presentation Only. IJ TC2012-61279

Chenghui Gao, Fuzhou University, Fuzhou, China

Presently people pay more attention to the negative impact of the automotive brake linings on the environment and the potential risk to human health because of the deteriorating ecological conditions. As a result, the study focuses on an eco-friendly braking composite that takes the biodegradable bamboo fibers as the main reinforcement, phenolic resin modified by inorganic salt whiskers as the matrix and flyash as the main filler. It makes full use of such characteristics of bamboo fibers as abundant resource, environmental friendly, high specific strength, good antifriction to dual pieces, and well wear resistance at low temperature. The resin matrix modified by inorganic salt whiskers with high specific tenacity/heat resistance and less harm to health also contributes to the excellent tribological performance at elevated temperature. The flyash, considered as industrial waste traditionally, are reused due to the advantage of high heat resistance, lightweight, availability and low cost. In this study, efforts are devoted to the effects of content, slenderness ratio or particle size, surface modification of bamboo fibers/anhydrous calcium sulfate whisker, basic magnesium sulfate whiskers as well as the flyash on the tribological performance of the braking composites. The hybrid effect and multicomponent interaction are analyzed to achieve the proportion optimization of the friction materials with excellent braking capacity and comfort?long-term stability and ease to biodegrade. Base on the thermogravimetric analysis and wear surface morphology, combined with the analysis of compositions and films, the effectiveness of the
additives on reinforcing and filling the composites is illuminated, and the mechanisms of friction and wear of these composites in different conditions are elaborated.

8:30 - 9am
Modeling of Sub-Surface Initiated Spalling in Rolling Contacts
Technical Presentation Only. IJ TC2012-61282

Farshid Sadeghi, Purdue University, West Lafayette, IN, United States

In this presentation an approach is described to include the effects of material microstructure on the modeling of sub-surface initiated spalling in bearing contacts. The material domain is formed by an assemblage of micro-elements that are constrained to each other. Two levels of randomness are considered: (i) the topological randomness due to geometric variability in the material microstructure and (ii) the material property randomness due to non-uniform distribution of properties throughout the material. A damage mechanics model is introduced in which there is progressive degradation of material properties with contact cycling. The model is applied to the inter-element fibers to study damage evolution in each joint under contact loading. A joint is assumed to fail upon accumulation of a critical damage state after a certain number of load cycles, initiating a micro-crack. The crack initiation location is found to vary for each material domain. However, the depths of crack initiation are found to be consistent with experimentally observed sub-surface cracks. The micro-cracks coalesce into dominant cracks with continued cycling and propagate to the bearing surface to form a spall. The propagation phase of the crack is modeled using a chain of joints (damage zone) that have failed. The computed crack trajectories and spall profiles are found to be consistent with experimental observations.

9 - 9:30am
Advancements of Liquid Superlubricity
Technical Presentation Only. IJ TC2012-61274

Jianbin Luo, Jinjin Li, Zhizuo Ma, Tsinghua University, Beijing, China

Superlubricity has been developed fast in the recent years, which has adsorbed more and more attentions in physical and tribological areas. It will play an important role in the near future industry and will be useful to reduce the loss of energy or materials during trib-process. Superlubricity includes different kinds of lubricants having an ultra-low friction coefficient down to the level of 0.001. In present work, some new kinds of superlubricity liquids found by our group have been introduced, such as phosphoric acid system, Brasenia schreberi which is an aquatic plant of the family Nymphaeaceae and, and mixed liquids. An ultra-low friction coefficient ranging from 0.002 to 0.005 has been obtained. It was found that the ultra-low friction is closely related to structure of superlubricity layer and the content of water. The lubrication mechanism has been discussed.

9:30 - 10am
Progress in Low-dimensional Solid Lubrication Additives for Demanding Tribological Applications
Technical Presentation Only. IJ TC2012-61277

Ali Erdemir, Argonne National Laboratory, Argonne, IL, United States

Low-dimensional materials with self-lubricating capabilities may offer unique opportunities for addressing growing environmental concerns and fuel efficiency requirements of future transportation systems. In particular, due to increasingly tougher environmental regulations, 0 to 3D nano-colloidal lubricants can be considered as potential anti-friction and -wear alternatives for future applications. Accordingly, concerted research efforts on novel nano-additives and lubricants have increased tremendously in recent years and significant strides have been made toward the formulation of nanomaterials-containing lubricants for possible uses in not only transportation but also manufacturing and energy fields. In particular, these research efforts have concentrated on a variety of low-dimensional solid lubricants with 0 to 3D architectures; 0D representing nano-onions, nano-diamonds, and amorphous carbon nano-spheres, while nano-tubes, -rods, and -whiskers are good examples of 1D materials. Some of the prime examples for 2D materials are graphene and h-BN, while larger nano/micro particles with various shapes represent 3D materials that are being explored by many investigators for their possible uses in lubricating oils and greases. In this presentation, we will present some of the latest developments in 0 to 3D nanomaterials that may be considered as high-performance lubrication additives. We will also point out many challenges that remain to be addressed prior to full-scale commercial deployment of these products including cost, toxicity, scale-up, colloidal dispersability, adverse additive interactions, underlying lubrication mechanisms, etc.

10 - 10:30am - BREAK

10:30 - 11am
Interfacial Fluid Lubrication and Wafer Status During CMP of 12-Inch Wafer
Technical Presentation Only. IJ TC2012-61270

Xinchun Lu, Dewen Zhao, Tsinghua University, Beijing, China

Mixed-lubrication is generated at the wafer-pad interface, and the interaction between the wafer and the pad is very complex during a CMP process. Although there are some theoretical simulations and simplified experimental studies on the lubrication of CMP process, it is still very important to study and explore the fluid lubrication behavior during the CMP process of industrialized CMP equipment. A novel integrated in-situ measurement system is developed and integrated into a 12-inch CMP equipment, which can measure the fluid pressure distribution and can monitor the wafer bending and the wafer orientation during a dynamic polishing process. Using this in-situ measurement system, the fluid lubrication behavior is studied for the industrialized CMP process of a 12-inch wafer. New
features of the fluid pressure distribution are observed: positive-dominated fluid pressure exists at the leading edge, only a small region near the leading edge shows negative pressure. The fluid pressure can reach 1.0~2.5kPa under normal downforce and can support 10%~30% of the downforce, which indicates that mixed-lubrication is formed at the wafer-pad interface.

Furthermore, wafer bending and wafer orientation are studied using the in-situ measurement system. The results reveal that there exists a slightly convex wafer bending in the order of 107m under a uniform downforce, and the wafer bending increases almost linearly with the downforce; and the wafer has a pitch angle and a rolling angle both on the order of 10-5~10-4 degree. The effects of the downforce on the wafer bending and the pitch angle are accordant with that on the fluid pressure, which indicates that the wafer bending and the wafer orientation plays an important role in the hydrodynamic lubrication of CMP.

11 - 11:30am
Tribo-Electrochemical Evaluation of Patterned Copper Surfaces
Technical Presentation Only. IJTC2012-61298
Sukbae Joo, TAMU, College Station, TX, United States, Hong Liang, Texas A&M University, College Station, TX, United States
- The topographic response of patterned copper surfaces to chemical-mechanical polishing was investigated using a tribo-electrochemical approach. Experimental methods include using a combined system containing a tribometer and a potentiostat. Results showed that formation of oxide and its complex dominated the removal mechanisms in acidic environments. Such an interfacial layer resulted in the decrease in corrosion current. The increased contact area was associated with the increase in friction. In alkaline environment, the exposure time of pure copper surface to the electrochemical environment led to the increase in corrosion current and variation in topography. The in situ approach pinpointed interactions between mechanical stimulation, chemical reaction, and electrochemical passivation. This research is beneficial to understand tribo-electrochemistry in Cu chemical-mechanical polishing (CMP) of patterned wafer, an important application in semiconductor manufacturing.

11:30am - Noon
Study on Micro Friction of Randomly Rough Surface
Technical Presentation Only. IJTC2012-61275
Ping Huang, South China Univ Of Tech, Guangzhou 510640, China, Yazhen Wang, South China Univ. of Tech., Guangzhou, Guangdong, China
- It is well known that the surface topography strongly determines the tribological performances and all practical surfaces are rough. However, most of the current studies on friction of the micro tribology consider the surfaces to be atomic-level smooth. Since the actual friction process is apparently of random characteristics, in order to obtain the friction suitable to the rough surfaces, it is necessary to set up a random friction model. Lennard-Jones potential is a semiempirical expression including the repulsive and attractive terms to build the relationship of the potential energy and the force varying with the distance r. In the present paper, the friction between a randomly roughness surface and an atomic-level smooth rigid plane has been studied based on the L-J potential model. A micro friction model has been proposed. In the model, the potential energy between interfaces is determined by the normal load and the balanced spacing. Therefore, under a certain normal load, the potential energy between two interfaces can be determined. In order to move the upper surface, it is needed to overcome the potential energy. This should be the origin of the sliding friction between surfaces.

With the numerical technique, the frictional force is calculated and the relationship between the frictional force and the normal load is analyzed as well. Then, the comparison between the theoretical and the experimental results is carried out and it shows that the proposed method feasible.

Key words: randomly rough surface, Lennard-Jones potential, sliding friction, micro tribology

2A - TRACK 2 Biotribology
Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

2-2 - BIOTRIBOLOGY 2
1:30 - 5:30pm - Lawrence A.
Session Chair: Christian Schwartz, Iowa State University, Ames, United States
Session Co-Chair: Connor Myant, Imperial College, London, United Kingdom

1:30 - 2pm
Tribology of Insulation Materials Within Implantable Cardioverter-Defibrillation Leads
Extended Abstract. IJTC2012-61053
Charles L Wilson, Medtronic, Inc., Mounds View, MN, United States, Adam Himes, Medtronic, Mounds View, MN, United States
- Transvenous cardiac leads are a critical component of an implanted cardioverter-defibrillator (ICD) system. The lead conducts electrical signals for sensing heart rhythms, pacing, and applying high-voltage shocks. Multiple conductors responsible for the various electrical functions are separated by insulation materials, typically silicone, polyurethane, ETFE or PTFE.

The failure modes associated with insulation wear are severe. Short circuits in the pace-sense or defibrillation circuits may lead to loss of therapy, inappropriate shocks, or tissue damage during lead revision.

Although the clinical importance of lead insulation wear has been widely recognized, there have been very few tribological studies of any material used in the construction of cardiac leads.

The purpose of this work is to characterize the tribological behaviour of ETFE cable insulation against several outer insulation materials using a
A mechanistic approach to predicting the friction behavior of human skin

Extended Abstract.

-Julien van Kuilenburg, Marc A. Masen, Emile van der Heide, University of Twente, Enschede,Netherlands

-Understanding ‘product feel’ and the interaction of skin with product surfaces, packaging materials or medical equipment begins with an understanding of the friction behavior. As a material, skin behaves in a contact mechanism, its behavior is viscoelastic, anistropic and there may or may not be an influence of underlying tissue and bones. Furthermore, the surface properties of the skin may vary with anatomical site, environmental conditions or even dietary habits. If possible at all, an exact description of the friction behavior of the skin would thus require an anistropic, nonlinear, viscoelastic model. In this work, analytical models available from contact mechanics theory having a proven record in mechanical engineering were used to develop a model predicting the friction behavior of human skin. To account for the multilayered and nonhomogeneous structure of the skin, the concept of an effective elastic modulus was adopted, which led to a closed form expression describing the elasticity of the skin as a function of contact length scale. A multi-scale contact model was developed in which the contact area is calculated at three levels, each level characterized by its elastic behavior and geometry. The model shows that the skin micro-relief, at the meso-level, plays an important role in the friction behavior of the skin. For a product part in contact with the so-called hairy skin the skin topography can be described as being composed of spherical contacts, whereas for the finger in contact with a product surface the fingerprint ridges are modeled as annulus shaped line contacts.

To investigate friction at the asperity-level, surface textures consisting of evenly distributed spherically-tipped asperities were produced using ultra-short pulsed laser technology. Sliding friction was measured in vivo between the skin and surface textures with tip radii varying between 2 and 20 µm and varying asperty density. The surface properties of the skin, topography, hydration level and thickness of the lipid layer, were characterized experimentally.

The results observed during in vivo experiments are very well explained by the developed model, which predicts the friction as a function of product geometry, asperity geometry and normal load. Further work will involve the definition of design rules for the engineering of surfaces in contact with the skin, which are based on the friction model.

Understanding Wear Mechanisms by Analyzing Wear Debris from Various Grades of Polyethylene

Technical Presentation Only. IJTC2012-61250

-Kevin Plumlee, Oklahoma Christian University, Edmond, OK,United States, Christian Schwartz, Iowa State University, Ames,United States

-Ultra-high molecular weight polyethylene (UHMWPE) has dominated the market as a polymer bearing material in total joint replacement devices, mostly due to its extremely low wear rate. Other grades of polyethylene have similar molecular backbone structures, but have very different wear rates. By comparing the wear behavior and material properties of various grades of polyethylene, a more thorough understanding of wear mechanisms can be gained, leading to the development of more effective wear reduction techniques. In this study, the wear behavior of high density polyethylene (HDPE), which has greater stiffness and strength than UHMWPE, and linear low density polyethylene (LLDPE), which has much greater elongation-to-failure, was compared to UHMWPE behavior. Wear debris was collected from each function and analyzed for size, shape, and fractal dimension. This information, along with markers on the wear surface, reveals insights into the wear process which suggest that the accumulation of plastic deformation at the wear surface is a dominant wear mechanism and plays a role in determining overall wear rate.

A Novel Tribometer for the Investigation of UHMWPE Wear

Technical Presentation Only. IJTC2012-61227

-Marc A. Masen, University of Twente, Enschede,Netherlands, Connor Myant, Imperial College, London,United Kingdom, Philippa Cann, Imperial College Tribology Sec, London Sn72bx,United Kingdom

-Artificial articular joints, such as hips or knees, are implanted to restore joint function which has been impaired due to disease, trauma or genetic condition. Over the last 50 years, the number of arthritic joint replacement procedures has rapidly increased. Ultra-high molecular weight polyethylene (UHMWPE) is often employed as one of the contacting surfaces in these implants due to its good tribological properties, ease of manufacture and cost benefits. There are, however, growing concerns over premature failure of the implants and adverse tissue reaction to wear particles created in contact. Conventional Metal-on-Polymer (MoP) or Ceramic-on-Polymer (CoP) hips and knees have a limited life of approximately 15 years due to the progressive wear of the polyethylene surface, which can result in osteolysis, bone loss and implant loosening.

Under normal in-situ operating conditions the implants will undergo complex kinematic and loading cycles. Early investigations into the tribological behaviour of UHMWPE employed simple pin-on-disc tribometers to measure real time friction and wear. However, these devices over simplify the contact conditions because non-transient speeds and loads, a single axis of rotation and unidirectional sliding are often employed and the obtained results are not comparable to the performance of real artificial joints. The alternative is to employ joint simulator testing stations which reproduce the complex movement and loading conditions of a real human joint. However, these

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4 - 4:30pm
A Novel Approach to Artificial Hip Joint Design
Technical Presentation Only. IJTC2012-61236

Stephen Boedo, Rochester Inst Of Tech, Rochester, NY, United States, John F Booker, Cornell Univ, Ithaca, NY, United States

A continuing problem with current artificial hip joint replacements is friction and wear of the articulating cup and ball surfaces. In metal-on-plastic designs, osteolysis and associated loosening of the socket from the acetabulum is attributed to wear particles generated from the relatively softer UHMWPE cup material. In metal-on-metal designs, high concentrations of metallic ions associated with nanoscale wear particles have been found deposited in the surrounding tissue, and these high ion concentrations pose long-term health concerns. Ceramic-on-ceramic designs are prone to squeaking during walking, presumably due to stick-slip friction developed between the articulating surfaces.

Although considerable research has been conducted on bearing materials and surface treatments to reduce friction and wear, the bearing geometry associated with artificial hip joints and the bearing duty (load and kinematics) associated with the human gait cycle do not encourage hydrodynamic lubricated contact. Conventional artificial joint designs typically employ spherical ball and cup surfaces, and the periodic time history of bearing load transmitted from ball to cup varies significantly in magnitude but not direction. The result is a relatively small load-carrying point contact region compared with the overall dimensions of the cup, lubricated by limited wedge-film action associated with the corresponding limited oscillatory nature of the gait-cycle kinematics.

This paper describes a novel approach to artificial hip joint design. Special structural features and geometry are incorporated into a design that takes advantage of the characteristics of the bearing duty cycle. Substantial improvements in bearing performance, as measured by cyclic-minimum film thickness and cyclic-maximum film pressure, are predicted over conventional designs.

4:30 - 5pm
The Effect of Transient Motion on Artificial Articular Joints
Technical Presentation Only. IJTC2012-61223

Connor Myant, Imperial College London, London, United Kingdom, Philippa Cann, Imperial College Tribology Sec, London, Sn72bx, United Kingdom, Mark Fowell, Imperial College London, London, United Kingdom

Despite increased research over the last decade wear of artificial articular surfaces remains a major problem. This has been recently highlighted for Metal-on-Metal (MoM) hip joints amid fears of adverse biological reaction caused by metallic wear debris. Coupled to this, increasing implant rates and the burgeoning healthcare costs emphasize the need for research to improve implant function and longevity to avoid the need for expensive revision surgeries. The majority of current research is focused on material development through large scale simulator testing driven by the orthopaedic implant industry. This has meant our understanding of the fundamental lubrication mechanisms, which operate during articulation, is lacking. Little is known about these mechanisms which may cause the accelerated wear of some artificial implants.

Recently the authors published findings which concluded that protein-containing solutions demonstrate complex time-dependent film thickness behaviour that is not characteristic of a simple Newtonian fluid. An inlet aggregation mechanism caused bulk-phase separation rheology, creating a new gel like protein phase. This protein gel formed a new inlet reservoir feeding the contact with a high viscosity lubricant causing larger than predicted film thickness. Contact entry of this protein phase was complex and showed time and shear rate dependency. Proteins which passed through the contact were denatured and formed thick protective films on the metallic surface. The lubrication behaviour did not obey classical fluid film lubrication theory; inverse speed dependence and high sensitivity to contact pressure was observed. This initial work was applied to simple pure sliding uni-directional (fixed flow axis and direction) contacts, which enabled us to determine the fundamental lubrication mechanisms occurring for protein containing fluids. However, a real articular joint undergoes complex transient kinematics and loading cycles.

This paper examines the effect of sinusoidal transient load and motion on the film thickness behaviour and the inlet aggregation mechanism. Film thickness measurements were carried out using optical interferometry with a CoCrMo femoral component loaded against a moving glass disc. This arrangement allowed visualisation of the inlet and contact region, so development of the interfacial film could be observed. Film thickness results are presented for sinusoidal loading cycles with and without sliding, and oscillating sliding speed for both bi-direction and uni-directional conditions under constant load. The time dependent film thickness behaviour over multiple cycles is also investigated.
5 - 5:30pm
Using a Synthetic Skin Platform to Further Investigate the Results of a Classic Dermal Blistering Study
Technical Presentation Only. IJ TC2012-61256

Geetha Chimata, Christian Schwartz,
Iowa State University, Ames, IA, United States

Frictional loading of the skin from contact with foreign surfaces can lead to blistering that ranges from slightly irritating to life-threatening. Naylors work in the mid 1950s established some of the fundamental scientific understanding of the mechanisms of friction blistering. In his pioneering work, large numbers of human subjects were used to identify relationships between applied normal load and the number of loading cycles required to initiate a blister. These studies would be impractical today due to the expense of using human subjects and the ethical challenges of inflicting pain. A new version of the synthetic skin simulant platform (3SP) has been developed by the authors to duplicate some of the work done by Naylor in order to better understand the mechanics of blistering with respect to normal load and surface friction. The 3SP is a construct of layered elastomers that approximates the mechanical properties and surface friction of skin, and allows for blister size to be precisely quantified.

The results of the work confirm the inverse relationship between normal load and number of cycles required for blistering that was reported by Naylors. Classic fracture mechanics theory was employed to explain the mechanics of blister onset to determine how well the behavior can be explained by existing theories.

2B - TRACK 3 Engineered Surfaces
Track Chair: Daniel Nelias, INSA-Lyon, CNRS, Villeurbanne, France

3-2 - ENGINEERED SURFACES II
1:30 - 5:30pm - Molly Brown
Session Chair: M. Cinta Lorenzo Martin, Argonne National Laboratory, Lemont, United States

1:30 - 2pm
Ultra-fast and Large-scale Boriding of Metals and Alloys for Demanding Tribological Applications
Technical Presentation Only. IJ TC2012-61107

Ali Erdemir, Argonne National Laboratory, Argonne, IL, United States, Osman Eryilmaz, Argonne Nat Lab, Argonne, IL, United States, Vivekanand Sista, Argonne National Laboratory, Argonne, IL, United States, Guldem Kartal, Ozgenur Kahvecioglu, Servet Timur, Istanbul Technical University, Istanbul, Turkey

Increasingly more stringent operating conditions of next-generation tribological systems call for the development and uses of much tougher, harder, and thicker layers for longer durability and better functionality than before. Therefore, there is an urgent need for the development of more robust surface engineering technologies that can meet such requirements for future applications. In this study, we report an ultra-fast and large-scale boriding process that can results in very hard and thick boride layers in minutes. Specifically, the new technique produces 80-100 µm-thick boride layers on steel substrates in about 30 min., depending on the type of steel. Compared to conventional surface treatment methods, such as nitriding, carburizing, and pack-boriding which are used extensively by industry to achieve superior hardness and tribological properties in all types of steel components, novel ultra-fast boriding provides great advantages in terms of productivity, versatility, and environmental cleanliness. It is done in a molten salt electrolyte consisting of natural borax at elevated temperatures. Work pieces to be borided are attached to a cathode, while a graphite plate acts as the anode. The hardness of borided steel surfaces may range from 17 GPa to more than 20 GPa (depending on the steel type); but in the case of transition metals, like Ti, Zr, or Hf, the boride layers can achieve hardness values of more than 40 GPa. The very thick boride layers produced on the surface has excellent resistance to wear, erosion, and corrosion. Under boundary lubricated sliding conditions, the boride layers provide ultra-low friction and extreme resistance to wear and scuffing.

In addition to being ultra-fast, the new boriding technique is very cheap and produces no greenhouse gases or solid wastes. Overall, the new process may have significant positive impact on tribological applications that rely on hard coatings or surface treatments for improved properties.

2 - 2:30pm
Influence of Coating Thickness and Substrate Elasticity on the Tribological Performance of PEEK Coatings
Extended Abstract. IJ TC2012-61190

Yuanyuan Wang, Columbia University, New York, New York, United States, Elon J. Terrell, of Department of Mechanical Engineering Columbia University in the City of New York, New York, NY, United States

-Influence of Coating Thickness and Substrate Elasticity on the Tribological Performance of PEEK Coatings

When a material is subjected to repeated sliding contact, a surface fatigue and crack nucleation may occur on its surface. This damage weakens the material and can lead to debris formation. In many practical engineering assemblies, a thin PEEK (polyether-ether-ketone) coating is applied to reduce the damage, since PEEK exhibits wear resistance, corrosion resistance self-lubricating capacity and is lightweight. However, little is known about the effect of coating thickness on the plastic deformation, residual stresses and energy dissipation of PEEK when placed under sliding load. Moreover, the effect of substrate rigidity on coating stresses and deformation under sliding load are also under-researched. Having such knowledge is of significant importance in order to reduce damage of engineering parts and extend their lifetime.

In this study, the effects of PEEK coating thickness and substrate elasticity were analyzed using a 3D ball-on-flat finite element model as well as experimental analysis using a linear reciprocating
Prohesion Testing

Corrosion Resistance Evaluation Of Coatings Within Large Vehicles Through Prohesion Testing

Technical Presentation Only. IJ TC2012-61054

Adil Saeed, Zulfiqar Khan, Mark Hadfield, Bournemouth University, Poole, Dorset, United Kingdom

The current research programme is concerned with an array of structural deterioration through aging mechanisms within the museum environment. The Tank Museum at Bovington, South West of United Kingdom, is home to over 300 military tanks which has significant cultural and historic heritage. This collection includes the only running Tiger I tank in the world. These historic artefacts are exposed to aging mechanisms such as corrosion, stress corrosion cracking, fatigue and wear in the interacting surfaces. This paper focuses on surface engineering through application of corrosion resistant coatings. Majority of the Tanks are going through various levels of corrosion failures. Three key military tanks Centaur, M10 and Sherman were selected to perform prohesion experiments separately. Corrosion resistance was severe which resulted only after 48 hours of exposure. Primer and coatings demonstrated some degree of corrosion resistance, however, these were subsequently failed as well. Results of corrosion propagation and a comparison between uncoated and coated surfaces are presented.

Keywords: corrosion, tiger I, prohesion, military vehicles

2:30 - 3pm

Corrosion Resistance Evaluation Of Coatings Within Large Vehicles Through Prohesion Testing

Technical Presentation Only. IJ TC2012-61054

Oyelayo Ajayi, Argonne National Laboratory, Lemont, United States

Oyelayo Ajayi, Argonne National Lab, Argonne, IL, United States, Sol Torrel, Argonne National Laboratory, Lemont, IL, United States, Nick Demas, Ali Erdemir, Argonne National Laboratory, Argonne, IL, United States, Ronghua Wei, Southwest Research Institute, San Antonio, TX, United States

- One of the most commonly used tribological thin-film coatings is Chromium Nitride (CrN), typically deposited by PVD process. Examples of current applications of this coating include cutting and forming tools: ICE passenger cars, etc. In selecting coating for tribological applications, one of the critical parameter is the coating thickness. In the present work, we experimentally studied the effect of coating thickness on friction and wear performance of CrN coatings under unidirectional sliding. Test were conducted with ~ 1, 5 and 10 microns thick coatings deposited on a hardened H-13 steel substrate by plasma enhanced magnetron sputtering (PEMS) process. The friction behavior was strongly dependent on coating thickness, especially at relatively low loads. At higher load however, the thinner coating (1 µm) was quickly worn through while the thicker ones (5 and 10 µm) remained intact. It was observed that coating was also observed to depend on coating thickness. The observed effect on coating thickness on tribological behavior is attributed to differences in the microstructure and mechanical properties of coatings as function of thickness.

4 - 4:30 pm

Simulation of Coating Deposition by High-Velocity Metal Particles in the Cold Spray Process

Extended Abstract. IJ TC2012-61202

Baran Yildirim, Andrew Hulton, Seyed Ali Alavian, Teichi Ando, Andrew Gouldstone, Sinan Muftu, Northeastern University, Boston, MA, United States

In cold spray process, micron-sized metal particles are accelerated by a converging/diverging nozzle and impact a substrate with velocities in the range 300-1200 m/s. This additive manufacturing process results in a coating, which can be used for freeform manufacturing of parts. Experimental findings in the literature show that there is a critical velocity of particle deposition for each particle/substrate material system. Over this critical velocity, the process consists of sequential impact, deformation and bonding of many particles. Therefore, formation and properties of a deposited layer are not only affected by the impact behavior of a single particle, but also by the interaction of subsequently impacted particles. In order to investigate the material behavior under such conditions, impact of multiple particles in cold spray is studied by the finite element method. Effects of high strain rates and temperatures on the material yield and failure are considered. Particle conditions prior to impact are derived from fluid dynamics calculations. In order to predict stick behavior of the particle, an interfacial cohesive strength parameter is defined between the particle and the substrate. The effects of this cohesive strength, temperature, and particle positioning are examined for three particle impacts. In addition, simulations involving 100 consecutive particle impacts are carried out. The random lateral positioning of the 100 particles are generated numerically. Results show that subsequent impacts have a large effect on the previously impacted particles for both cohesive ability, degree of deformation, and residual stresses. Deformation increases with both increased temperature as well as a more direct secondary impact.
4:30 - 5pm
Tribological Property Analyses of DLC Films on Ceramic Surfaces with 3-D FEA Method and Experiments
Extended Abstract. IJ TC2012-61068
-Chuanwei Zhang, Le Gu, Dezhi Zheng, Harbin Institute of Technology, Harbin, Heilongjiang,China
-Diamond-like carbon (DLC) films are excellent candidates to improve tribological properties of silicon nitride (Si3N4) ceramic elements. Particular attentions have been paid to the preparation and analysis of DLC films on rings and discs. However, few researches on fabrication of DLC films on ball surfaces were carried out, especially on ceramic ball surfaces, because it is hard to achieve uniform coatings on ball surfaces.

In this paper, DLC films on ceramic ball surfaces were studied with both experiment and FEA method. DLC films were deposited on Si3N4 ceramic ball and disc surfaces with plasma immersion ion implantation and deposition techniques (PIII-D). Surface topography of ceramic balls before and after coated with DLC films showed that DLC films on ceramic ball surfaces were uniform. Tribological tests under dry friction were conducted with a ceramic ball sliding against ceramic disc and, alternatively, one of the two surfaces was coated with DLC films. The tests demonstrated that DLC films on disc surfaces were worn, while ball surface films were partly flaked.

3-D FEA models of ceramic ball sliding against ceramic disc were built and the ceramic ball/disc was coated with DLC films alternatively. DLC films were supposed to be bonded with ceramic substrates. The FEA stress fields in DLC films and on film/substrate interface showed that DLC films had great effects on stress distribution due to the low frictional coefficient and material difference from substrates. The friction force caused an increment of the stress near surfaces during sliding process, and the material difference leaded to discontinuous stress distribution on film/substrate interface. The shear stress on film/substrate interface was very slightly different between DLC films coated on ceramic balls and discs. Under almost the same shear stress, the flakes and wear of DLC films were mainly determined on the adherence of DLC films to ceramic substrates.

2C - TRACK 4 Boundary and Thin Film Lubrication
Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

4-2 -BOUNDARY AND THIN FILMS 2
1:30 - 5:30pm - Horace Tabor
Session Chair: Robert Erck, Argonne National Lab, Argonne, IL, United States

1:30 - 2pm
Performance of Rotating Rough Circular Step Bearing: Characteristic of Lubrication at Nano Scale
Extended Abstract. IJ TC2012-61022
-Himanshu Patel, L. D. College of Engineering, Ahmedabad, Gujarat,India, Gunamani Deheri, Sardar Patel University, Anand, Gujarat,India, Paresh Dave, Commissionerate of Technical Education, Gandhinagar, Gujarat,India
-An endeavor has been made to investigate the effect of transverse surface roughness on the behaviour of thin film lubrication at nano scale of a magnetic fluid based rough porous rotating circular step bearing. Mainly, the combination of the properties of the surfaces, the lubricant and viscosity of the lubricant are responsible for thin film lubrication between two rough surfaces in relative motion. The effects induced by the transverse roughness and the couple stress can not be disregarded in the regime while the ordered molecules dominate the fluid field. The random roughness of the surfaces is characterized by a random variable with non zero mean, variance and skew-ness. The associated Reynolds equation is then stochastically averaged and solved with appropriate boundary conditions to obtain the pressure distribution, leading to the calculation of load carrying capacity. It is easily observed that basically, the magnetic fluid lubricant combined with the couple stress effect is responsible for the improved performance of the bearing system. It is clearly seen that the adverse effect of transverse roughness is relatively less when considered with thin film lubrication at nano scale. The increased load carrying capacity due to variance (-ve) gets further increased due to negatively skewed roughness which becomes more pronounced owing to thin film lubrication at the nano scale. It is seen that the existence of couple stress enhances the load carrying capacity. In addition, the characteristic length contributing to the couple stress increases load carrying capacity considerably. Even, size dependent effects are noticed in the lubrication with couple stress while the thinner the lubrication film the more obvious is the effect.

2 - 2:30pm
Influence of Surface Texture on Micro EHL in Boundary Regime Sliding
Extended Abstract. IJ TC2012-61065
-Robert Erck, Oyelayo Ajayi, Argonne National Lab, Argonne, IL,United States, M. Cinta Lorenzo Martin, Argonne National Laboratory, Lemont,United States, George Fenske, Argonne National Laboratory, Argonne, IL,United States
-A hard steel ball was slid against hard and soft steel disks that had strongly directionally ground surfaces. The friction coefficient during low-speed lubricated sliding was continuously measured. The coefficient of friction rose from about 0.1, which is typical for boundary lubrication regime, to as high as 0.3 whenever the ball was sliding parallel to the grinding ridges on the disc surface. The persistence of this spike was observed to be correlated with the hardness of the disc surface. We propose that the frictional spike is due to loss of micro-elastohydrodynamic lubrication, combined with side leakage, leading to intimate asperity-asperity contact. This conclusion is supported by the persistence of the frictional spikes in tests conducted with discs coated with a very hard nitride
Approaches of Transfer Film Deposition on the Asperities
Technical Presentation Only. IJTC2012-61110

-Randyka Pudjoprawoto, Patrick Dougherty, C.F. Higgs III, Carnegie Mellon University, Pittsburgh, PA, United States

Thin film in which plastic deformation is minimal. For a disk coated with hydrogenated amorphous carbon, no variations in coefficient of friction were measured.

2:30 - 3pm
Approaches of Transfer Film Deposition on the Asperities
Technical Presentation Only. IJTC2012-61110

-Randyka Pudjoprawoto, Patrick Dougherty, C.F. Higgs III, Carnegie Mellon University, Pittsburgh, PA, United States

-In the setup, a pellet is formed by compacting MoS2 powder, which is then sheared against a disk surface while a slider pad rides on the transferred film deposited by the pellet. The purposes of the slider pad are to deplete and distribute the lubricant on the disk evenly. The topography of the disk is measured before and after the test by an interferometer to determine both the z locations of the asperities for modeling purposes and to measure the roughness of the disk (root mean square (RMS) values). Using the outputs from the volumetric fractional coverages (VFC) model, the process of transfer film deposition on the asperities can be predicted via three different techniques. To validate the merit of each technique, the root mean square (RMS) values have been compared with the RMS values obtained from a profilometer after a test run on a pellet-on-disk with slider tribometer. This paper contributes to a better understanding to how asperities are being filled up by powder lubricant for a transfer film lubrication process.

3 - 3:30 - BREAK

3:30 - 4pm
The Effects of Floor Roughness On Shoe-Floor Adhesion and Hysteresis
Extended Abstract. IJTC2012-61152

-Matthew Cowap, Kurt Beschorner, University of Wisconsin - Milwaukee, Milwaukee, United States

-Slip and fall accidents are a major source of occupational accidents. Typically, a CoF of approximately 0.2 is required to maintain level walking without a slip. While floor roughness is known to be a major contributing factor to shoe-floor CoF, the tribological mechanism behind this effect is currently unknown. This research aims to investigate the effect of changing floor roughness on the two primary components of shoe-floor friction: adhesion and hysteresis. The experiments were carried out using a pin-on-disk type tribometer. Two common shoe materials, soft rubber (Shore A 50) and Neolite (Shore A 95), were tested against ceramic tiles. The tiles were abraded using aluminum oxide media (commonly called sand blasting+) to achieve three levels of roughness (Rpm): 16.6 ?m, 24.3 ?m, and 34.6 ?m. The experiments were conducted at a low sliding speed of 0.01 m sec^-1 to limit hydrodynamic effects and at a biomechanically-relevant contact pressure of 266.1 kPa. The coefficient of friction was recorded without lubricant (dry) and lubricated with: 2% detergent solution, canola oil, and SAE 75W140 gear oil. Hysteresis was measured with SAE 75W140 because the high lubricity of the gear oil minimizes adhesion. Adhesion in dry and wet conditions was measured by subtracting the hysteresis from the coefficient of friction. Hysteresis was found to increase with increasing floor roughness from 0.101 to 0.358 for the Neolite and from 0.269 to 0.611 for the soft rubber. Higher roughness was also associated with a decrease in dry adhesion from 0.651 to 0.277 for the hard rubber and from 0.435 to 0.041 for the soft rubber. Hysteresis CoF showed strong, positive correlations with floor roughness (r = 0.705) and dry adhesion was negatively correlated with floor roughness (r = -0.681). Wet adhesion did not demonstrate a consistent pattern with floor roughness although the diluted detergent had higher adhesion than the canola oil. The increase in hysteresis and decrease in adhesion with increased roughness may be explained by larger asperities, associated with higher roughness, causing greater viscoelastic deformation in the flooring but a smaller real area of contact. Because hysteresis is a more robust source of friction than adhesion, particularly under boundary lubrication, high roughness flooring may provide more consistent friction when both dry and lubricated conditions exist. Abrasively blasting floor tiles to increase the roughness of the floor surface may be an effective intervention for enhancing shoe-floor friction, particularly when accompanied by soft shoe materials.

4 - 4:30pm
Experimental Study on Analytical Methods for Roughness Deformation Description in EHL contacts
Extended Abstract. IJTC2012-61175

-Petr Sperka, Ivan Krupka, Martin Hartl, Brno University of Technology, Brno, Czech Republic

-The trend of decreasing of lubricant film thickness in tribological systems is one of the important features of current tribology stirred up by the quest for higher efficiency and energy saving. As a result, the influence of the surface micro geometry on the contact performance and machine component life increases steadily. This has led to a systematic effort to develop a theory that describes unifying mechanism governing the amplitude reduction of harmonic patterns in EHD contact. This theory provides formulas that can serve as a simple tool to predict the deformed geometry inside the contact for arbitrary micro geometry when used in combination with a Fourier analysis. Therefore, it is possible to give a reasonable explanation of the basic phenomena involved in real rough surface EHL and mixed lubricated contacts.

In the study a high pressure ball on disk tribometer and thin film colorimetric interferometry were employed for mapping real and artificial roughness features inside contact area. This study represents further step in validation and development of amplitude attenuation theory under conditions of pure rolling in elliptical contacts.

4:30 - 5pm
Pressure Increase in Elliptical Impact EHL Contacts with Surface Asperities
Extended Abstract. IJTC2012-61072

24
The surface roughness often shows a strong texture orientation depending on the machining process. The effect of the surface roughness on rolling and/or sliding elastohydrodynamic lubrication (EHL) has been investigated extensively through experiments and numerical analyses. The results contribute very much to improve the performance and durability of machinery. Nevertheless there are some phenomena that are still waiting for the explanation. These involve the behavior of EHL contacts under unsteady conditions such as impact and vibration when two contact surfaces approach to each other, resulting in high contact pressures. Therefore, the understanding of squeeze EHL phenomena is an important subject to improve machine performance. However, there are very few studies about the effect of surface roughness on squeeze EHL.

With the sinusoidal asperities used as the surface roughness model, the authors have found through isothermal Newtonian numerical analysis that the surface asperities produce a large local pressure, particular in elliptical contacts, when constant loads are imposed on the contact by impact. The pressure level is usually larger when the bumps are located along the major contact direction than along the minor contact direction, and increases as the loading speed increases. The high pressure induces a micro-groove in the bump and the horse-shoe shaped constriction is formed at the bumps locating around the contact edge. This phenomenon seems to be related closely to surface failure problems.

2D - TRACK 5 Fluid Film Lubrication

Track Chair: Daejong Kim, University of Texas at Arlington, Arlington, United States

5-2 - FLUID FILM LUBRICATION II

1:30 - 5:30pm - Tabor Auditorium
Session Organizer: Benyebka Bou-Said, INSA, Villeurbanne, France

1:30 - 2pm
Experimental Analysis of the Start-up Torque of a Thrust Foil Bearing
Technical Presentation Only. IJ TC 2012-61148
-Franck Balducchi, Mihai Arghir, Institut Pprime, Université de Poitiers, Futuroscope, France
-The paper deals with the experimental analysis of the start-up torque of a thrust foil bearing. The geometric characteristics of the thrust foil bearing follow the design recently proposed by NASA Glenn research center. A dedicated test rig was developed and enables the measurement of speed, start-up torque, displacement of the thrust bearing and temperatures under the foils. The start-up torque was measured by using either a static force transducer or by interpreting the recordings of a rapid camera. The displacement transducers located on the circumference underlined that after take off the thrust foil bearing was in a slightly static misaligned position. The measurements of the start-up torque and the analyses of the resulting Stribeck curves showed that take-off speed is close to 15 krpm even for a moderate loading of 2500 Pa. In fact, as often cited in the literature, heating proved to be a critical aspect of the thrust foil bearing operating conditions. Results showed that the take-off or the landing of the thrust foil bearing can be identified also from temperature measurements. Moreover, the temperature field is correlated with the misalignment of the thrust bearing.

2 - 2:30pm
The Validity of the Compressible Reynolds Equation for Gas Lubricated Textured Parallel Slider Bearings
Extended Abstract. IJ TC 2012-61051
-Mingfeng Qiu, Brian Bailey, Rob Stoll, Bart Raeymaekers, University of Utah, Salt Lake City, UT, United States
-Surface texturing is used to increase hydrodynamic pressure and reduce friction between gas lubricated parallel sliding surfaces. Many authors have used the Reynolds equation to model the pressure distribution between textured parallel slider bearings. Pressure is expressed for incompressible and compressible lubricants. However, the operating domain in which the solution of the Reynolds equation is valid in the case of compressible hydrodynamic gas lubrication is not well studied. In this paper, computational fluid dynamics techniques are used to evaluate the accuracy of the Reynolds equation in compressible hydrodynamic gas lubrication problems between parallel textured surfaces, by validating the assumptions inherent in the Reynolds equation.

The pressure distribution, load carrying capacity, and velocity distributions for a single three-dimensional spherical dimple were calculated by solving the full three-dimensional Navier-Stokes equations and the simplified Reynolds equations, respectively, for different texture geometries and operating conditions. The accuracy of the simplifying assumptions used to derive the Reynolds equation, including neglecting the pressure gradient across the film thickness and inertia effects, was evaluated quantitatively by comparing the results of the Reynolds and Navier-Stokes equations. Comparison between both solutions illustrates that the differences in the load carrying capacity are small for realistic texture parameters and operating conditions, despite more significant differences in pressure distribution and velocity profiles. Deviations are largest in regions where the velocity component orthogonal to the sliding interface is large and/or when gradients of the streamwise and spanwise velocity components are significant.

2:30 - 3pm
Thermal Behavior of Three-Pad Radial Foil Bearing Under Different Cooling Methods
Technical Presentation Only. IJ TC 2012-61101
- Daejong Kim, University of Texas at Arlington, Arlington, United States, Suman Shrestha, University of Texas at Arlington, Irving, TX, United States, Youngchoel Kim, Korea Institute of Machinery and Material, Daejon, Korea (Republic)

Air foil bearing is one of the oil-free bearings with favorable acceptance in small high speed turbomachinery with shaft diameter below 100mm. This work presents thermal behavior of 50mm diameter three-pad radial foil bearing under two different cooling methods. The first method is traditional axial cooling by passing cooling air through the bump foils, and the second method is a multiple radial injections of cooling air directly on to the journal shaft at the leading edge groove region where bump foils do not exist. Study shows the radial injection speed is very important parameter determining the cooling effectiveness. Trend shows that when injection speed is below the journal diameter three-pad radial foil bearing under two different cooling methods. The first method is traditional axial cooling by passing cooling air through the bump foils, and the second method is a multiple radial injections of cooling air directly on to the journal shaft at the leading edge groove region where bump foils do not exist. Study shows the radial injection speed is very important parameter determining the cooling effectiveness. Trend shows that when injection speed is below the journal surface speed, cooling effectiveness is marginal. However, higher injection speed than the journal surface speed shows better cooling performance than axial cooling when the same volumetric flow rate is used for both radial injection and axial cooling. It is believed that the boundary layer attached to the journal shaft is not easily broken and most of the air that comes out of the upstream trailing edge of the foil reenters the leading edge of the downstream foil. When injection speed is high, boundary layer is broken more easily, and two synergistic effects are expected from the high injection speed; one is a direct cooling effect of the shaft and the second is the reduction of the air temperature that enters the film region at the leading edge of the foil.

3 - 3:30pm - BREAK

3:30 - 4pm

Performance of Different Microtexture Shapes for Gas Lubricated Textured Parallel Slider Bearings

Extended Abstract. IJ TC2012-61064

-Mingfeng Qiu, Bart Raeymaekers, University of Utah, Salt Lake City, UT, United States

-Surface texturing is used to increase hydrodynamic pressure and reduce friction between gas lubricated parallel sliding surfaces. The shape, geometry, and density of the patterned microtexture features (dimples) play a key role in the tribological performance of the surface-textured slider bearings. While it is well-documented that the optimal microtexture geometry and density for a specific dimple shape and set of operating conditions can be determined, an unbiased comparison of the tribological performance of different dimple shapes does not seem to be available in the open literature. Existing studies that compared the hydrodynamic pressure generated by different dimple shapes have applied constraints to for instance the texture density. As a result, the dimple shapes are compared without taking their optimum geometry into account. The objective of this paper is to investigate and compare the performance of commonly used dimple shapes in terms of load carrying capacity, in the case of gas lubricated, textured parallel slider bearings.

Six different texture shapes were considered, including spherical, ellipsoidal, circular, elliptical, triangular, and chevron-shaped dimples. The pressure distribution and load carrying capacity generated by different texture shapes were calculated numerically by solving the compressible Reynolds equation over a domain containing a column of ten dimples. The texture geometry and density were optimized in terms of maximum load carrying capacity for each different dimple shape, as a function of operating parameters such as relative velocity and spacing between the two sliding surfaces. The maximum load carrying capacity of each different texture shape - with optimized geometry and density - was then compared relative to each other. It was concluded that the ellipsoidal shape results in the highest load carrying capacity, and the optimal geometry and density were found to be almost independent of the operating conditions.

4 - 4:30pm

Local Adaptive Multi-Grid Control Volume Method for Solving the Air Bearing Problem in Hard Disk Drives

Extended Abstract. IJ TC2012-61118

-Liping Li, UC-Berkeley, Berkeley, CA, United States, David B. Bogy, University of California, Berkeley, Berkeley, CA, United States

-In modern hard disk drives, the head disk spacing has decreased to sub-5 nm as required to meet the demand of higher storage density. Various technologies such as TFC (Thermal Fly-height Control), BPM (Bit Pattern Media) and HAMR (Heat-Assisted Magnetic Recording) have also been proposed to achieve this objective. In order to obtain stable flying heights under different conditions, the ABS (air bearing surface) designs used in current hard disk drives have rather complicated rail shapes, multiple etch depths and highly recessed regions between the rails. This causes the pressure distribution under the slider to vary dramatically. Therefore, an efficient and stable numerical scheme is required to solve the Generalized Reynolds equation, which is used to model the air bearing under the slider.

A control volume method is implemented in the CML Air Bearing Simulator to solve the Reynolds equation. A FAS (Full Approximation Storage) scheme and an adaptive grid method have also been developed to improve the efficiency and stability of the CML Air Bearing Simulator. However, this adaptive method requires the node number on each line in one direction to be the same, which may lead to a dense mesh on some areas where only sparse meshes are needed and thereby increase the computation time without benefit. It is highly recommended to have an adaptive grid generator to create dense mesh only on some critical areas which have higher pressure gradient or larger recess depth.

In this paper, a local adaptive grid-generating algorithm is proposed and integrated with the multi-grid control volume method to form a scheme to solve the problem. After the pressure distribution has been obtained on an initial uniform mesh, finer meshes (mesh size decreases by half) are created on the nodes of the current finest grid that has its pressure gradient or geometry gradient larger than a pre-defined tolerance. So only those pressure or
geometry sensitive regions will have higher resolution, which is critical for obtaining more accurate results. Two rather complex slider designs are used to demonstrate the applicability of this method. It is found that the new local adaptive grid-generating method dramatically improves the efficiency and stability of the simulation scheme.

4:30 – 5pm
**A Fully Coupled Fluid-Structure-Interaction Model for Foil Gas Bearings**

*Extended Abstract.* IJTC2012-61019

-Wei Zhang, United Technologies Research Center, [China] Ltd., Shanghai, China, Abbas Alahyari, Louis Chiappetta, United Technologies Research Center, East Hartford, CT, United States

-Foil gas bearings are self-acting, compliant-surface hydrodynamic bearings that usually use air or other process gas as their working fluid or lubricant. Foil gas bearings are made of one or more bump foils, which are compliant surfaces of corrugated metal, and one or more layers of top foil. Because foil gas bearings experience large deflections, such as load capacity, are dominated by foil material and foil geometric designs, numerical models have been developed to predict the bearings performance based on these characteristics. However, previous models often simplify bump foil as elastic foundation with constant stiffness and neglect top foil altogether. Further, they typically use the Reynolds equation to simplify the fluid solution. In this study, ANSYS software is used to build a 3D, fully-coupled, fluid-structure-interaction model for a foil gas bearing to predict key performance parameters such as load capacity and journal attitude angle. The models results show good agreement with previously published test data. This not only demonstrates the feasibility of 3D fully coupled fluid-structure-interaction model for a conventional foil bearing using commercial codes, but also shows modeling capability for future generations of foil gas bearing.

2E - TRACK 6 Machine Components Tribology

Track Chair: Daniel Nelias, INSA-Lyon, CNRS, Villeurbanne, France

6-2 -MACHINE COMPONENTS TRIBOLOGY II

1:30 - 5:30pm - Continental B

Session Chair: Nans Biboulet, Université de Lyon, INSA-Lyon, LaMCoS, CNRS UMR 5259, Villeurbanne, France

1:30 - 2pm
**The Effect of Pre-Stressing on the Static Indentation Load Capacity of the Superelastic 60NiTi**

*Technical Presentation Only.* IJTC2012-61035

-Christopher Dellacorte, NASA, Cleveland, OH, United States, Lewis E. Moore, III, Joshua S. Clifton, NASA, Huntsville, AL, United States

-Superelastic nickel-titanium alloys, such as 60NiTi (60Ni-40Ti by wt.%), are under development for use in mechanical components like rolling element bearings and gears. Compared to traditional bearing steels, these intermetallic alloys, when properly heat-treated, are hard but exhibit much lower elastic modulus (~100 GPa) and a much broader elastic deformation range (~5% or more). These material characteristics lead to high indentation static load capacity, which is important for certain applications especially space mechanisms. To ensure the maximum degree of elastic behavior, superelastic materials must be pre-stressed, a process referred to as training. In shape memory effect (SME) terminology, at loads and stresses beyond expected use conditions. This paper, static indentation load capacity tests are employed to assess the effects of pre-stressing on elastic response behavior of 60NiTi. The static load capacity is measured by pressing 12.7 mm diameter ceramic Si3N4 balls into highly polished, hardened 60NiTi flat plates that have previously been exposed to varying levels of pre-stress (up to 2.7 GPa) to determine the load that results in shallow and measurable (0.6 micron, 25 micron deep) permanent dents. Hertz stress calculations are used to estimate contact stress. Without exposure to pre-stress, the 60NiTi surface can withstand an approximately 3400 kN load before significant denting (>0.4 micron deep) occurs. When pre-stressed to 2.7 GPa, a static load of 4900 kN is required to achieve a comparable dent, a 30% increase. These results suggest that stressing contact surfaces prior to use enhances the static indentation load capacity of the superelastic 60NiTi. This approach may be adaptable to the engineering and manufacture of highly resilient mechanical components such as rolling element bearings.

2 - 2:30pm
**The Effects of Roughness, Sliding Speed and Material Property on Visco-Elastic 3-Dimensional Viscoelastic FE Model**

*Extended Abstract.* IJTC2012-61176

-Gurjeet Singh, University of Wisconsin Milwaukee, Milwaukee, Wisconsin, United States, Vikas Hasija, Bowhead Systems Management, Washington DC, DC, United States, Pradeep Menezes, University of Wisconsin Milwaukee, Milwaukee, WI, United States, Kurt Beschorner, University of Wisconsin - Milwaukee, Milwaukee, WI, United States

-Slip and fall accidents are a major occupational health concern. Important factors affecting shoe-floor friction are critical to identifying and resolving unsafe surfaces and designing. Experimental studies have indicated that several factors including floor roughness, sliding speed and shoe materials affect shoe-floor friction although the precise nature of the mechanism behind this phenomenon is not well understood. In addition, recent studies have suggested that boundary lubrication is highly relevant to slipping and that adhesion and hysteresis are the main contributing factors to boundary lubrication. The purpose of this study is to perform the numerical simulations to analyze the
effects of floor roughness (asperity height), sliding speed and material properties on ratio of real area of contact and normal force (relevant to adhesion friction) and hysteresis friction for a viscoelastic shoe material interacting with a hard floor surface. A 3D shoe model and 3D vinyl floor model was simulated with speed 0.01 m/s, 0.5 m/s, 0.75 m/s and 1 m/s in three different floor surfaces. The material property was also varied in the numerical simulations. The study showed that roughness affects both the hysteresis and adhesion friction whereas sliding speed and material property affects the adhesion friction only. The dependence of adhesion and hysteresis friction on roughness, sliding speed and material property is useful in understanding the shoe-floor friction phenomenon and development of slip resistant sports and work shoes.

2:30 - 3pm
Rolling Contact Fatigue under Grease Lubrication in Hydrogen
Technical Presentation Only. IJTC2012-61248
-Hiroyoshi Tanaka, Kyushu Univ, Fukuoka, Fukuoka,Japan, Yuki Ohara, Masaaki Hashimoto, Kyushu University, Fukuoka, Fukuoka,Japan, Joichi Sugimura, Kyushu Univ, Fukuoka, Fukuoka,Japan
-This paper describes experimental study of rolling contact fatigue under grease lubrication in hydrogen. Balls on disk type rolling contact tests were conducted in hydrogen and in air. The tested greases ranged from lithium soap greases and urea greases with synthetic base oils to perfluoro poly ether greases. The balls and the disk were made of 52100 steel. After the rolling contact tests, observation of the specimen surfaces and their cross sections, measurement of hydrogen concentration by thermal desorption spectroscopy, and surface analysis with X-ray photoelectron spectroscopy were conducted. With only a few exceptions, flaking failure occurred earlier in hydrogen than in air with most of the greases tested. Concentration of hydrogen diffused into the steel is greater in the tests conducted in hydrogen, which led to crystallographic change in the steel. White layer formation possibly due to hydrogen was found in some tests, but it did not cause early flaking. Perfluoro poly ether greases provided relatively longer fatigue lives. This was found to be due to deposited film of PTFE thickeners on the tracks. Influence of surface film formation including oxidation on hydrogen permeation is discussed.

3 - 3:30pm - BREAK

3:30 - 4pm
Influence of Surface Topography on the Tribo-Characteristics of an Eccentric-Tappet Pair
Extended Abstract. IJTC2012-61196
-Jing Wang, Qingdao Technological University, Qingdao, Shandong,China, C.H. Venner, Twente University, Enschede,Netherlands, Antonius Lubrecht, Insa De Lyon, Villeurbann 69621,France
-Cam-tappet pair is one of the most important components in engine and determines the overall performance of the motor. Compared with modern car engines using rolling-sliding tappets for transmission of rapid up-down lifting motion of the cam to open and close the engines inlet and exhaust valves, the flat-tappets are easily subjected to failure by fatigue. On stripping down a damaged motor, the tappets are invariably found to be heavily pitted. This study theoretically simulated the influence of surface topography on the tribo-characteristics of an eccentric-tappet pair. The asperities on the tappet surface introduce fluctuation in pressure, film thickness and thermal rise profiles. The fluctuation of the pressure results in alternative stresses in metals during working process. The periodical variations of pressure, minimum film thickness and thermal rise are investigated by changing the eccentricity and wave length of the roughness. The results suggest an explanation for the quick occurrence of cracks or even complete fracture in cam and flat-tappet pair.

4 - 4:30pm
Performance and Failure Modes of Grease Lubricated Hybrid Ceramic Bearing in High Speed and High Temperature Condition
Extended Abstract. IJTC2012-61189
-Dezhi Zheng, Le Gu, Tingjian Wang, Liqin Wang, Harbin Institute of Technology, Harbin, Heilongjiang,China
-Ceramic rolling element bearings have promising application in extreme operating condition such as high speed, high temperature, and heavy load. Compared with all steel bearing, ceramic bearing have many advantages such as longer rolling contact fatigue life, lower density of the material, better tribological properties and less heat generation in severe lubrication conditions.

In high speed and long life requirement bearings, the oil lubrication is most commonly adopted because of lubrication reliability and heat dissipation consideration. However for oil lubrication, lubricants supply system will increase the sophistication of the machine. Using grease lubricated bearing can simplify the lubrication system. For ceramic bearing, through adoption of superior materials and delicate structure design, grease lubrication can have potential application in high speed conditions.

In this study, hybrid silicon nitride ceramic ball bearing lubricated with high temperature grease is presented. The structure and parameters of the bearing are specially designed to satisfy the requirement of grease lubrication, high temperature and high speed conditions. The bearing type is angular contact ball bearing, and the designed contact stress of the ball with inner ring and outer ring is 1.5GP and 2GPa respectively. The bearing structure is designed by considering the grease storage and flow to increase the grease life. A test rig was developed for the experiments of ceramic bearing performance in high speed and high temperature conditions. In this rig, the lifetime of the bearing can be up to 1.05x10^6mm/r.min. The experiments about the performance of bearing were conducted, and effects of grease amount on the bearing lubrication were investigated.
The experimental results show that grease lubricated ceramic bearings with fine design have excellent high speed and high temperature performance. In different operating phases, the bearing performance changes in great scale. After running-in, the bearing can operate stably, while some interesting phenomena can be observed that the bearing operations occasionally fluctuate in small scale, which indicates that the grease redistributes inside the bearing.

By analyzing the operation performance and failure bearing inspection, the failure modes of grease lubricated ceramic bearings is analyzed. Thermal instability caused by the grease insufficient supply is the main factor of failure. Through investigation of the failure bearing surfaces, it is found that starvation of lubricants in contact zones between ceramic balls and steel raceways causes the frictional failure of the contact surface, and failure modes exhibit as combination of fatigue and seizure.

4:30 - 5pm
Structural Changes in Steel under Rolling Contact in Some Gas Environments
Technical Presentation Only. IJTC2012-61251

-Hiroyoshi Tanaka, Kyushu Univ, Fukuoka, Fukuoka,Japan
-Kakeru Enami, Masaaki Hashimoto, Kyushu University, Fukuoka, Fukuoka,Japan
-Joichi Sugimura, Kyushu Univ, Fukuoka, Fukuoka,Japan

This paper describes experimental study of rolling contact fatigue in hydrogen. Balls on disk type rolling contact tests were conducted in hydrogen, in argon and in air. Poly alpha olefin was used as lubricant. The balls and the disk were made of 52100 steel. After the rolling contact tests, observation of the specimen surfaces and their cross sections, hydrogen concentration measurement with thermal desorption spectroscopy, and surface analysis with SEM and Auger electron spectroscopy were conducted.

It was found that, at a temperature as high as 393 K, the rolling contact fatigue life was shorter in air than in argon and hydrogen, which was different from the effect of environmental gas on fatigue life found at lower temperature. The concentration of hydrogen diffused into the steel was greater in the tests conducted in hydrogen, and in argon than in air. Characteristic changes in steel were found in the ball specimens tested in hydrogen and in argon. One was the formation of voids at particular depth beneath the contact track. Fatigue cracks appeared to propagate through the voids. The other was the formation of white ferrite phase transformed from martensitic phase, which should enhance fatigue crack growth.

5 - 5:30pm
Localized hardening and structuring of steels by a simple process
Technical Presentation Only. IJTC2012-61166

-Mathias Woydt, Bam, Berlin,Germany
-Stanislav Kislov, Valentin Kislov, Paul Ostroovsky, NPO Geoenergetika, Kaluga

-Authors: S. Kislov, V. Kislov, M.Woydt and P.Ostroovsky

Hardness is known as a property to fight against adhesive wear and abrasion. Structuring is a modern path to enhanced hydrodynamic lubrication and support deficient lubrication. The present paper illuminates a simple and robust process to harden ferritic, perlitic or austenitic steels and/or to implement a texturing to the contact zone both as localized and cold treatments. An integral processing step is the incorporation of substances and minerals into the surfaces, which substantially reduces friction and further increases wear resistance.

This process transforms the structure of the subsurface region from a pre-existing metallurgical structure into a new structure, preferably a martensitic one. These transformations of the pre-existing steels were confirmed by means of TEM and nano-indentation. For example, the plastic hardness of an X20Cr13 is increased from 2,530 MPa to 6,300 MPa. The resulting tribological effects will be shown for sliding and slip-rolling tribosystems.

2F - TRACK 7 Contact Mechanics
Track Chair: Jeffrey Streator, Georgia Tech, Atlanta, United States

7-2 -CONTACT MECHANICS II
1:30 - 5:30pm - Continental A
Session Chair: Ilya Kudish, Kettering University, Flint, United States

1:30 - 2pm
The Experimental Evaluation of Models for Contact between a Sphere and a Layered Foundation
Technical Presentation Only. IJTC2012-61246

-Hyeon Lee, Robert L. Jackson, Austin Adamson, Morgan Hamon, Jong Wook Hong, Auburn University, Auburn, AL,United States

-Experiments for circular point contact between a sphere and a soft coating on a foundation were developed and compared to an existing theoretical model and finite element simulations. Several indentation tests of bodies consisting of glass coated with PDMS of different thickness were conducted. The relationship between force and indentation depth as well as the relation between force and thickness of the layer from the model and the test were compared. The experiments showed dissimilar results in some ranges from the predictions of the models, but agree in other ranges.

2 - 2:30pm
A Fast-Solving Semi-Analytical Solution Method for Contact Problems Involving
Multi-Layered Inhomogeneously Elastic Solids  
Extended Abstract. IJ TC2012-61153  
-Stewart Chidlow, Cranfield University, Cranfield, United Kingdom, Mircea Teodorescu, UC Santa Cruz, Santa Cruz, CA, United States  
The subsurface mechanical properties of two contacting objects in a micro-scale conjunction are rarely homogeneous. It is very common for a protective layer to be applied to the surface of one or both materials to reduce friction and decrease surface adhesion. A possible side-effect that can occur during the deposition process is the formation of a transition layer between the coating and the original material (substrate) which typically results from either localized diffusions or chemical reactions. As a result, computational models which seek to approximate the solution of such contact problems need to take into account the innate inhomogeneity of the materials to ensure a reasonable degree of accuracy. 

The current paper proposes a semi-analytical solution which predicts both the sub-surface stress fields and pressures that result from the contact between an inhomogeneously elastic solid and a rigid indenter. The solid is assumed to consist of a homogeneously elastic coating and substrate joined together by an arbitrary number of functionally graded layers whose shear modulus depends on the depth coordinate whilst it is also assumed to be in a state of plane strain so that we may perform a two-dimensional analysis. 

We initially present analytical solutions for the horizontal and vertical displacements within the solid which hold when the pressure induced through contact is known. We then use these solutions to formulate an algorithm from which both the contact pressure and contact half-width may be computed before finally presenting some numerical results.

2:30 - 3pm  
On the Role of Local Slip in Contact and Sliding  
Technical Presentation Only. IJ TC2012-61220  
-Jeffrey Streator, Georgia Tech, Atlanta, United States  
- Vahid Mortazavi, Pradeep Menezes, Michael Nosonovsky, University of Wisconsin Milwaukee, Milwaukee, WI, United States  
The directionality of machining marks influences friction and transfer layer formation during sliding contact. Recent experimental investigations showed that this directionality influences the occurrence of stick-slip phenomena and friction coefficient. More specifically, sliding experiments were previously conducted using a pin-on-plate sliding apparatus under dry and boundary lubricated conditions. In the experiments, it was observed that the coefficient of friction and stick-slip phenomena depend on parameters like machining angle, normal load, roughness of the texture, material pair and lubricant. In the current study, we focus on a mathematical model to predict such experimental observations and their correlations. Based on the results, we discuss the dependency of stick-slip motion on the normal load, grinding angle, roughness, lubrication, and the material pair.

3 - 3:30pm - BREAK

3:30 - 4pm  
A Mathematical Model to Study the Stick-Slip Phenomenon during Sliding at Various Machining Angles  
Technical Presentation Only. IJ TC2012-61221  
-Michael Nosonovsky, University of Wisconsin Milwaukee, Milwaukee, WI, United States  
-Andreas A. Polycarpou, University of Illinois Urbana-Champaign, Urbana, United States  
-Pre-sliding friction dominates the contact behavior when the relative motion of contacting surfaces is minute as seen in a wide range of practical applications such as connections in assembled structures, high accuracy positioning systems, soft materials loaded by sticking contacts, and MEMS actuators. Pre-sliding friction introduces nonlinear softening, hysteresis, and nonlinear damping, and its dependence on loading history complicates many dynamical processes. A thorough physical formulation of pre-sliding friction has not been achieved yet due to stochastic and multiscale nature of contacting surfaces and materials. Attributing the onset of sliding to accumulation of partial slip or plastic flow over contact predicts the nonlinear features of pre-sliding friction. However, a comprehensive model bridging these conflicting theories over multiple length scales is still missing. This work presents pre-sliding friction experiments
and simulations with nanometer to millimeter-scale contact sizes, and describes a modeling approach to capture the multiscale nature of the observed partial slip. The models are compared with the molecular dynamics and discrete-distraction dynamics simulations found in the literature, and the breakdown of continuum-scale formulation for pre-sliding friction is investigated.

**4:30 - 5pm**

**Numerical Analysis of Partial Slip Contact Involving Inhomogeneous Materials**

Extended Abstract. IJ TC2012-61108

-Zhanjiang Wang, Chongqing University, Chongqing, China, Xiaoqing Jin, Northwestern University, Evanston, IL, United States, Leon Keer, Qian Wang, Northwestern University, Evanston, IL, United States

-When two elastic bodies are brought into contact without sliding, surface deformations of the two bodies do not always match each other at every contact location due to limited friction. Assuming the shear traction does not exceed the limiting value determined by the localized Amontons law of friction, some portions of the contact area may stick while others may slip. Those contacts involving partial slip are commonly found in the contact interfaces of many mechanical parts. However, most theoretical investigations of partial slip are limited to homogeneous materials.

-When solving the problems involving inhomogeneous materials, the influence of the inhomogeneity upon contact behavior should be properly considered. This research proposes a fast and novel method, based on the equivalent inclusion method where the inhomogeneity is replaced by an inclusion with properly chosen eigenstrains, to simulate partial slip for the interface involving inhomogeneous materials. The total stress and displacement fields represent the superposition of homogeneous solutions and perturbed solutions due to the chosen eigenstrains. In the present numerical simulation, the half space is meshed into several cuboids of the same size, where each cuboid is assumed to have uniform eigenstrains. The stress and displacement fields due to eigenstrains are formulated by employing the recent half-space inclusion solutions derived by the authors and solved using a three-dimensional fast Fourier transform algorithm.

-The effectiveness and accuracy of the proposed method is demonstrated by comparing its solutions with those from the finite element method. The partial slip contact between an elastic ball and an elastic half space containing a cuboidal inhomogeneity was further investigated. A number of in-depth parametric studies are performed for different sizes of the cuboidal inhomogeneity at different locations. The results reveal that the contact behavior of the inhomogeneous material is more strongly influenced by the inhomogeneity when it is closer to the contact center and when it is made with a larger size. The discontinuous von Mises stress at the interfaces can be observed. When the inhomogeneity touches the surface, a sudden change of shear traction is shown to arise at the interfaces. Under a relatively small tangential load, slip will exist in several unconnected regions. Layered materials can be investigated by considering infinite extension some of the height, width or length of the cuboidal inhomogeneity. The results indicate that the partial slip case of a composite layer can be solved with the present method.

**2G - TRACK 13 STLE-CTI Symposium**

**13-2 -STLE-CTI SESSION II**

1:30pm - 5:30pm - Lawrence B

Session Chair: Zhongmin J in, Xian Jiao-Tong University, Xian, China

Session Co-Chair: Ali Erdemir, Argonne National Laboratory, Argonne, IL, United States

1:30 - 2pm

**Improvement of Friction and Wear Resistance of DLC Films via Element Doping**

Technical Presentation Only. IJ TC2012-61271

-Jyunyan Zhang, Bin Zhang, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou, China

-Tribological properties of diamond like carbon (DLC) films vary to some extent in different environments or under service conditions, which restrict the reliability and durability of DLC films in applications. The reasons that DLC films behaved differently in various environments or conditions could be attributed to the intrinsic factors of DLC films, mainly high internal stress, poor high temperature resistance, and high sensitivity to environment. Aiming at above intrinsic factors of DLC films, this work applies trace element doping of Ti to reduce the internal stress of DLC films without sacrifice of mechanical properties. Si doping was introduced to enhance the high temperature resistance of DLC films; F element, insensitive to humidity, was inserted to the DLC films to reduce the humidity sensitivity of DLC films. It is proved that element doping is an efficient way to enhance or improve the above properties of DLC films.

2 - 2:30pm

**Challenges in Biotribological Research of Natural Synovial Joints and Artificial Replacements**

Technical Presentation Only. IJ TC2012-61278

-Zhongmin J in, Xian Jiao-Tong University, Xian, China

-Natural synovial joints are remarkable bearings. These bearings are expected to function in the human body for a lifetime whilst transmitting large dynamic loads and yet accommodating a wide range of movements. However, diseases such as osteoarthritis, rheumatoid arthritis and trauma sometimes require these natural bearings to be replaced by artificial ones. Currently, over 1 million joint replacements are carried out every year worldwide. Tribological principles play an important role in the understanding of how natural synovial joints operate and fail, as well as how artificial joints should be designed. The purpose of this study is to highlight some of the challenges in the tribological
Wear mechanisms and modelling of artificial knee joints: what is the wear mechanism for polyethylene in artificial joints? How to model wear computationally?

Lubrication mechanisms of natural synovial joints: how to model the full spectrum of lubrication mechanisms from boundary to full fluid film? How to incorporate the biphasic deformation of articular cartilage into the lubrication modelling?

2:30 - 3pm
Impact of Advanced Lubricants for Legacy Vehicles
Technical Presentation Only. IJTC2012-61269

-George Fenske, Argonne National Laboratory, Argonne, IL, United States, Steven Przesmitzki, Argonne National Laboratory, Argonne, IL, United States

-There are 248+ million vehicles on the road in the US; another 11 million of new vehicles are added each year, with a comparable number of older vehicles being removed/ from use. These vehicles travel 3 million-million miles per year and consume 12-14 MBBL of petroleum per day. Approximately 15% of the fuel consumed in transportation is lost to overcoming parasitic friction in the engine, transmission, and axle. The potential for advanced tribological concepts to improve fuel economy will vary significantly: new vehicles can utilize not only advanced lubricants, but can also take advantage of advanced low-friction materials and coatings, as well as new component designs. Legacy vehicles, e.g. those already on the road, however are limited to advanced fuel conserving lubricants. While improvements in fuel economy for new vehicles in the range of 5-7% are thought possible (strongly dependent on driving behavior), the improvement in fuel economy for legacy vehicles is in the 1-3% range. However, the magnitude of the legacy fleet (250 million vehicles) is so large that even a small improvement can have a large impact of petroleum use. This presentation will provide an overview of a number of projects being pursued to develop advanced lubrication concepts to reduce parasitic friction losses and improve fuel economy.

3 - 3:30pm - BREAK

3:30 - 4pm
Study on Bending Fretting Fatigue Behaviors
Technical Presentation Only. IJTC2012-61287

-Min-Hao Zhu, Jin-Fang Peng, Zhen-Bing Cai, Chuan Song, Jan-Hua Liu, Da-Wei Liu, Southwest Jiaotong University, Chengdu, Sichuan, China

-Many researchers have studied the behaviors of the tension-compression or tension-tension fretting fatigue in detail; however, few are on bending fretting fatigue (BFF). In order to know the life reduction due to fretting damages induced by cyclic bending loads and to understand the relationship between BFF and the dislocation structure, micro-crack initiation and propagation as function of the number of cycles, the BFF behaviors of several metallic materials (316L steel, L250 steel, 17CrNiMo6 steel and 7075 aluminum alloy) have been investigated. The BFF S-N curves of various materials were developed, which indicated that the fretting contact stress strongly influenced the fatigue life. The contact surfaces were sequentially running in the partial slip regime (PSR), mixed fretting regime (MFR), and slip regime (SR), respectively. The shortest fretting fatigue life has been identified, which corresponds to the fretting regime of MFR. Wear occurred firstly and then micro-cracks generated even at a lower bending fatigue load. However, under higher bending fatigue loads, some obvious surface delamination can be observed. Corresponded to the MFR, the contact surfaces of samples were found to have fatigue cracks. The BFF crack sources were usually located in the subsurface area of the contact zone, but plain fatigue regularly located on the surface. The TEM analysis showed that the fretting fatigue cracks imitated by two different mechanisms for different materials due to the different material characteristics. A damage physical model of BFF has been developed according to the damage processes under different test parameters.

4 - 4:30pm
Wind Turbine Tribological Challenges
Technical Presentation Only. IJTC2012-61267

-Shuangwen Sheng, Jonathan Keller, James Johnson, Yi Guo, National Renewable Energy Laboratory, Golden, CO, United States, Aaron Greco, Ali Erdemir, Argonne National Laboratory, Argonne, IL, United States, Robert Errichello, GEARTECH, Townsend, MT, United States

-Wind power is currently the fastest growing renewable energy source. However, the industry is still challenged by premature component failures, leading to increased turbine downtime and cost of energy. Some of these failures are highly dependent on tribological issues associated with blade pitch systems, main shaft bearings, yaw systems, gearboxes, and generators. This presentation gives a brief overview of the tribological challenges faced by utility-scale wind turbines. Several tribology-related failure modes seen in wind turbine subsystems will be discussed with a focus on the mode of white etching cracks (WEC), which has been reported as one dominant failure mode currently seen in wind turbine gearbox bearings and main shaft bearings. Several different hypotheses on the root causes of WEC are discussed along with an introduction of a research effort initiated at National Renewable Energy Laboratory and Argonne National Laboratory through the funding provided by the U.S. Department of Energy. Other factors affecting wind turbine tribology, such as offshore salt water environment, are also touched on. The main objective is to provide motivation engineers and tribologists with up-to-date information on wind turbine tribological challenges.
As a result, needed research can be conducted to improve wind turbine reliability and help the wind industry lower the cost of energy.

4:30 - 5pm
**Tribological Behaviors of Metal Materials in Magnetic Field**
*Technical Presentation Only.* IJ TC2012-61285
-Yongzhen Zhang, Hongbin Xiao, Henan University of Science and Technology, Luoyang, Henan, China

*Introduction*
The paper presents the results of a study concerning the influence of magnetic field on the performance of sliding metal contacts. It is important to understand the influence of magnetic field on their performance in order to prevent premature failure and to achieve higher service life. In this study, we examine simultaneously the influence of magnetic field on the tribological behaviors of 45 steel/ high-speed steel couple and Ti6Al4V/ high-speed steel couple under different experiments conditions.

*Experimental*
The wear tests were carried out on a pin-on-roll tribometer subjected to a magnetic field applied perpendicularly to the rubbing surface in an ambient environment. The sample pin was made of Ti6Al4V alloy and 45 steel, respectively. The sample ring was made of high-speed steel. During the test, the friction pair will be operated with a load of 250N at a sliding speed of 0.6m/s for 20 min. The magnetic field can be obtained by using an energized coil and the magnetic field intensity can be controlled by adjusting the exerted voltage or current.

*Results*
Under the same test conditions, the friction coefficients of the 45 steel are significantly less than that of the Ti6Al4V alloy in the magnetic field, and the wear rates of the 45 steel are much higher than that of the Ti6Al4V alloy. The effects of magnetic field on the 45 steel and the Ti6Al4V alloy are significantly difference. The difference of the tribological behaviors between the 45 steel and the Ti6Al4V alloy lies in the status of wear debris existing in the interface of the couple mainly.

5 – 5:30pm
**Impact of Steel Cleanness on Contact Fatigue**
*Technical Presentation Only.* IJ TC2012-61280
-Xiaolan Ai, The Timken Company, Canton, OH, United States

*Abstract*
Steel cleanness plays a critical role in improving contact fatigue life of a rolling element bearing. The ability to predict the impact of inclusions in bearing steel on bearing fatigue life is of great importance to bearing manufacturers and to the end-users. A bearing relative life model was developed based on inclusion distributions, stress field alterations, and the stress and fatigue life risk function. Influences to inclusion distributions due to manufacturing process were considered through flow line tracking during metal forming process. Monte Carlo simulations were conducted to study the statistic nature of inclusion distribution variation from bearing to bearing. Simulation results were compared with experimental results to demonstrate the validity of life prediction model.
wall slip at the fluid-surface interface occurs for between well defined layers). On the other hand, ordered states), to maxima (at the transitions oscillates from minima (in correspondence with ordered states), to maxima (at the transitions between well defined layers). On the other hand, wall slip at the fluid-surface interface occurs for smooth, non-wettable surfaces: the shear stress is limited to a low, constant value. Nanorough surfaces cause a disordered state in the lubricant, and frustrate the occurrence of wall slip: hence, high friction ensues.

Finally, the absolute maximum in friction is reached when the solid bodies come into contact and the adhesion forces between atoms of the metal surfaces are dominating.

Molecular dynamics simulations are used to analyze the local tribological behaviour of n-hexadecane confined between metal oxide surfaces under high pressure and shear rates. The number of lubricant molecules in the contact zone is then progressively reduced in order to achieve the direct contact between the atoms of the walls. Furthermore, the influence of the surface wettability and geometry (smooth versus nanorough surfaces) is studied.

A particular focus is placed on the analysis of the structure and dynamics of the confined fluid. Results show that, in the case of smooth surfaces, two possible configurations can be reached: in some cases, a well-defined structure is formed by the lubricant molecules, with an integer number of layers having equal density and low bridging. Between these ordered states, transition zones can be observed: the central layers merge together, and a disordered state is achieved in the center of the film. Finally, the ordering inside the fluid is always frustrated when nanometer scale roughness is present.

Surface nature and geometry have a significant effect on the dynamics of the confined lubricant and friction. In the case of smooth wettable walls the lubricant is locked to the surfaces and shearing occurs between layers. Shear stress is then related to the degree of organization within the fluid: it oscillates from minima (in correspondence with ordered states), to maxima (at the transitions between well-defined layers). On the other hand, wall slip at the fluid-surface interface occurs for
existence of Mo-S-P as the composition of tribochemical films. The Raman spectroscopy analysis of tribofilms showed significant difference (such as formation of poly-molybdates) in chemical information of nanolubricants and tribofilms, which is an indication of the formation of friction polymer [4]. Additionally, phosphates and oxides, acting as components of surface protecting layer of tribofilms, have been found on surface by XPS technique. Moreover, MoS2 nanoparticles are found to navigate into surface asperities to protect the contacting surfaces. The results (information about the chemical states of the tribofilm) obtained from different characterization techniques can be used to explain the mechanism of friction and wear reduction associated with MoS2 multi-component nano lubrication system that has been reported in the literature.

The contact area between probe tip and lubricant film was observed by using an optical microscope. For the microscopic observation, the substrate where the lubricant film was coated must be transparent. In this study, we used a silicate glass plate as a substrate and perfluoropolyether (Fomblin Z-35) as a liquid lubricant. The thickness of lubricant film was about 5 nm. The probe tip was also made from silicate glass. Theoretically, light reflectance at glass-lubricant interface decreases by 65% compared with that at glass-air interface. Therefore, we can observe the contact area as a dark region on probe tip surface. By using the bright field microscope, however, we could not obtain high-contrast images because of the background noise mainly from reflection at glass-air interface of substrate, which was the other side of the substrate where the lubricant film was not coated. To reduce the noise, we used differential interference contrast (DIC) microscopy. In the optical system of DIC, the background noise was removed by polarizing plate. In the verification experiment, the probe tip was initially set at more than 100 nm from the surface of the sample. When the gap between probe tip and sample was decreased at a constant rate, the dark region on the probe tip suddenly appeared at a certain point. At the same time, the friction force was detected. This result indicates that we succeeded in the simultaneous measurement of friction force and a contact area during the shearing of the nanometer-thick liquid lubricant film.

10 - 10:30am – BREAK

10:30 – 11am

Mechanisms of Entrapment and Release of Fluid Droplets from Nano-Scale Surface Features

Extended Abstract. IJ TC2012-61201

-William Chong, Loughborough University, Loughborough, United Kingdom
-Mircea Teodorescu, UC Santa Cruz, Santa Cruz, CA, United States
-Ashlie Martini, UC Merced, Merced, CA, United States
-Homer Rahnejat, Loughborough University, Loughborough, United Kingdom

-Engineering surfaces are never perfectly flat. They contain micro and nano-scale features on multiple length scales. Predicting the amount of fluid trapped in these minute surface crevices and its controlled release could benefit a variety of practical applications. In a sliding contact, the released fluid could create an ultra-thin film, reducing the direct contact and consequently the boundary friction. Transdermal patches are the least invasive of available subcutaneous drug delivery techniques. The drug is stored in a micro-reservoir and it is released to the skin either through a permeable membrane or through a series of micro needles. The aim of the current paper represents the first attempt to investigate whether a modeling approach encompassing two complementary simulation techniques in an integrated framework can be used to predict the volume of fluid stored in a nano-scale surface feature. Molecular dynamics (MD) simulation could provide accurate modeling of fluid behavior at nano-scale, and statistical mechanics (SM) could provide a fast prediction.

11 - 11:30am

Temperature Distribution of Plasma Generated In Gap of Sliding Contact Under Dry Sliding

Technical Presentation Only. IJ TC2012-61233

-Keiji Nakayama, Chiba Institute of Technology, Chiba, Japan
-Fumio Yagasaki, Ken Automation Inc., Yokohama, Japan

-Previously, one of the authors reported that plasma, i.e., triboplasma is generated in the rear gap of a sliding contact under dry sliding and oil lubrication. It is well-known that there exist two kinds of plasma from the points of view of the temperature, i.e., low temperature plasma and high temperature plasma. In the case of triboplasma, the plasma is generated by attack of high energy of electrons accelerated by the intense electric fields.
caused by tribocharging to the air molecules. As the mass of the electrons are too small to raise the temperature of the air molecules, it is expected that the overall plasma temperature should be extremely low. Namely, triboplasma should be low temperature plasma. However, the temperature of the plasma has not yet been measured so far.

In this paper we tried to measure the temperature distribution of the plasma generated in the rear gap of sliding contact while a diamond pin sliding against a sapphire disk under dry sliding in an ambient air using a highly sensitive infrared camera. The tip radius of the diamond pin was 4 mm and the thickness of the sapphire disk was 1 mm. The temperatures were measured in two directions from the sideward almost parallel to the disk flat surface and vertical through the sapphire disk under the normal force of 1 N and 2 N, respectively at different rotational speeds of the disk of 10 rpm, 20 rpm, 50 rpm, 100 rpm and 155 rpm at a wear track diameter of 40 mm.

We succeeded to measure the temperature distribution of the ionized plasma gas. The temperature increase of the ionized gas in plasma was below 1.0° for the overall rotational speed tested. Namely, triboplasma was not a high temperature plasma, but low temperature plasma as expected. We also succeeded to take the movie of the flow of the plasma gas at the two directions, from the sideward and vertical ward. The movie measured from the sideward showed that the gas flow was laminar at low rotational speed range, whereas at and beyond a critical rotational speed, the gas flow condition transited from the laminar to a turbulent flow. The plasma flows along the wear track at low rotational speed, but with the increase of the rotational speed, the flow shifted from the wear track direction to the circumference direction due to the centrifugal force.

**3B - TRACK 3 Engineered Surfaces**

Track Chair: Daniel Nelias, INSA-Lyon, CNRS, Villeurbanne, France

**3-3 - ENGINEERED SURFACES III**

8am - Noon - Molly Brown

Session Chair: David Philippon, Laboratoire de Mécanique des Contacts et des Structures - INSA de Lyon, VILLEURBANNE, France

**8 - 8:30am**

In Situ Study of PTFE Nanocomposites: Relating Transfer and Wear

Technical Presentation Only. IJ TC2012-61252

Jiaxin Ye, Harmandeep Khare, David L. Burris, University of Delaware, Newark, United States

Polytetrafluoroethylene (PTFE, Teflon®) has a unique combination of low friction, large thermal range, and chemical inertness, but its use as a tribological material has been limited by its exceptionally high rate of wear. Certain nanofillers have been shown to reduce the wear rate of PTFE by up to four orders of magnitude. Although the mechanisms responsible for this dramatic improvement remain unclear, there is substantial evidence that transfer films play a dominant role.

In this study, we use a wear resistant PTFE nanocomposite reported previously in the literature by two independent groups. This material is known to exhibit a period of transient wear that is followed by a transition to steady state. In-situ observations at the friction interface give some insights into causal relationships and the mechanisms of transfer film development and wear reduction.

**8:30 - 9am**

Formation of Periodic Ripple Patterns during Slurry Jet Erosion of Polyurethane Elastomers

Technical Presentation Only. IJ TC2012-61257

Mikhail Gelfer, Phil Atthey, David Reuschle, Dow Chemical, Freeport, TX, United States

Erosive wear of polyurethane elastomers by a slurry jet (SJE) containing 10 [wt%] of quartz sand was investigated using scanning electron microscopy (SEM), laser profilometry, and other techniques. A random collection of depressions and ridges formed early in the erosion process evolved into well-defined periodic ripple patterns as erosion progressed. Unexpectedly, the wavelengths of the patterns were 25-50 times smaller than the average diameter of erodent particles, also the characteristic dimensions of a ripple pattern were shown to depend on the hardness of eroded polymers. Formation of periodic surface patterns was attributed to the combination of plastic flow and fatigue-induced fracture occurring under the influence of repeated particle impacts.

**9 - 9:30am**

Isolating the Effects of Water, Oxygen, And Temperature On MoS2 Tribology

Technical Presentation Only. IJ TC2012-61235

Harmandeep Khare, David L. Burris, University of Delaware, Newark, DE, United States

Extreme operating conditions in extra-terrestrial environments coupled with the mechanical complexities of autonomous systems presents unique challenges to any potential bearing material. Molybdenum disulfide has been used as a space solid lubricant due to its low friction coefficients in vacuum; however, friction and wear can increase by an order of magnitude or more in the presence of moisture or cryogenic temperatures which can lead to component or system failure. Despite decades of research on MoS2 tribology, the underlying mechanisms responsible for these important phenomena remain topics of scientific debate. For example, it is unclear 1) if water increases friction directly or by promoting oxidation; 2) to what extent surface adsorption and bulk absorption impact the response; 3) if increased temperature reduces friction through thermally activated slip or desiccation. In the present study, we use a combination of time, temperature, and moisture control to isolate these effects and better understand the causal relationships involved in MoS2 tribology.
Friction and wear characteristics of selected chlorinated compounds, dissolved in mineral oils, were tested on Four Ball machine at several loads (up to 2200 N). Chlorinated materials were used at 1 to 5% wt. and included quaternary ammonium chloride, dichloroethylene, dichlorobutane and chlorinated C10-16 paraffins. With progressively higher loads, the friction remained the same until a pronounced increase was observed. Blends with higher concentrations of chlorinated additives tolerated higher loads, despite often producing more wear. Variation of alkyl chains of quaternary ammonium chloride can produce specifically tailored Extreme Pressure additives. These new composites with low friction coefficient and sufficient wear resistance are suitable for the application as surface lubricating film to run under a boundary lubrication condition.

8:30 - 9am
The Influence of Antiwear and Extreme Pressure Oil Additives On Scuffing And Pitting Of WC/C Coated Tribosystems
Technical Presentation Only.  IJ TC2012-6105
-C. Boniatian, A. Pogosian, W. Saroyan
(State Engineering University of Armenia, Yerevan, Armenia)

Keywords: tribology, additive, lubricant, boundary lubrication, chlorinated compounds.
While exploiting machines and mechanisms the most vulnerable are the units, where heavy modes of boundary lubricated friction are realized, the serviceability of which depends on the ratio of two processes going on during the contact a formation and destruction of surface layers (films) of contacting bodies. The purpose of additives to lubricating oils in such a case is to provide the restoration of destroyed superficial layers before the following destruction occurs by the chemical modification of contacting surfaces in the conditions of high specific loads and temperatures generated by friction. The studies show that this role could be carried out more effectively by multi-component additives. Therefore the molecules or the products of their decomposition are capable to demonstrate incremental activity on the juvenile surfaces of contacting bodies, along with increasing severity of friction conditions.

Metal forming Tribology: Interaction between hard coatings and additives
Technical Presentation Only.  IJ TC2012-61071
-C. Peuker, AC2T, Wiener Neustadt, Austria, Ewald Badisch, Ac2t Res Gmbh-austrian Ctr, Wiener Neustadt, Lower Austria, Austria

-Thread forming is a well-established and often used process in a wide range of applications. High process security, the efficient use of material and economical benefits lead to a wide spread distribution especially in automotive industry. The advantage compared to cut and milled threads are
the chipless production, the strain hardened material and reduced rejections due to inaccurate produced parts. On the other hand the demand on the tribological system due to increased loads is rising. The lifetime of the tool strongly depends on the wear of the hard coating and the applied load. The loading on the tool consists of the normal load due to the material resistance and the shear stress due to the friction between the tool and the work piece. Previous investigations have shown that mixed friction is present in the contact zone. The contact pressure is in the order of magnitude of GPa, furthermore temperatures up to 200°C and relative movement up to 1 m/s can be observed. The maximum of the load on the tool strongly depends on the adhesive properties of the contact materials and the ability of the lubricant to prevent adhesion.

The aim of this work is the investigation of the adhesion properties of PVD-hard coatings (TiN, TiCN, CrAlN and DLC) during thread forming of zinc-coated steel in mixed friction regime. In the first step non additivated paraffinic oils were used to show the adhesion properties for constant fluid solid friction ratio. Furthermore the interaction of commonly used commonly used metalworking additives (EP, PEP, AW and FM) with hard coatings were systematically investigated. The results indicate, that especially Extreme Pressure additives (EP) have a huge impact on adhesion between the hard coating and the work piece. It can be assumed that the highest impact of the additives in the forming process depends on the chemical interaction on the zinc-coated sheet metal.

The results can be used to select the best fitting lubrication for a specific coating or the best fitting coating for a specific lubrication for metal forming applications.

9:30 - 10am
Proteins, Polysaccharides, Polyalcohol and Phospholipids as Lubricant Additives in Water.
Technical Presentation Only. IJT2012-61229

-Daniel Tang, Connor Myant, Imperial College, London, United Kingdom, Philippa Cann, Imperial College Tribology Sec, London Snt2b, United Kingdom

-The lubrication properties of biomolecules (protein, polysaccharides, phospholipids, polyalcohol) were tested as dilute additive solutions (0.1% w/w) in water. Coefficient of friction was measured over a range of sliding speeds for steel ball and disk configuration. At the end of the test the wear scar diameter on the ball was measured. Lubrificant film thickness was studied in a glass/steel contact using optical interferometry. The results were compared to film thickness calculated using measured viscosities of the solutions.

10 - 10:30am - BREAK

10:30 - 11am
Tribological Properties of Oxidized Vegetable Oils Used in Metal-working Applications
Technical Presentation Only. IJT2012-61207

-Selim Erhan, Polartech Additives Inc., Bedford Park, IL, United States, Steven Anderson, Polartech Limited, Manchester, United Kingdom, Carl Bennett, Afton Chemical Corporation, Richmond, VA, United States, Mark Devlin, Afton Chemical Co, Richmond, VA, United States

-In order to develop environmentally friendly lubricants for metal-working applications, oxidized vegetable oils have been used in place of Chlorinated compounds. These oxidized oils have comparable performance as Chlorinated compounds in standard metal-working tests. To better understand the mechanism by which oxidized oils perform in metal-working applications, the film formation and frictional properties of the oxidized oils have been determined. These properties have been measured under environmental conditions similar to those observed in metal-working applications. The tribological properties of oxidized oils are compared to those for Chlorinated compounds to better show the differences and similarities between the activity of these two types of lubricants.

11 - 11:30am
A Quantitative Model and Experimental Investigations of Measurement of Wall Shear Stress Using Liquid Crystal Coating Technical Presentation Only. IJT2012-61039

-Songpeng Zhang, Xiangjun Zhang, Yu Tian, Yonggang Meng, Tsinghua University, Beijing, Beijing, China

-Measurement of wall shear stress (WSS) has important significance in many fields such as drag reduction of solid-liquid interface, spacecrafts surface flow visualization, intelligent skin, boundary lubrication mechanism?etc. With the rapid development of micro and nano technology, various measuring methods have been invented, including MEMS sensor technology, oil film interference technology, liquid crystal coating technology. The liquid crystal coating technology is mainly based on two kinds of liquid crystals. One is the nematic phase with the advantage of a clear theoretical understanding of its molecular responds under shearing. The other is the cholesteric phase whose advantage is its colorful visualization to identify the distribution of shear stress. However, the latter is limited by its complicated optical measuring system and calibration process. This paper focuses on the measurement of WSS by using nematic liquid crystal coating.

When the liquid crystal coating is under shear stress, the nematic molecules will rotate correspondingly. This rotation will cause formation of a helix structure. When a polarized light is transmitted through the liquid crystal layer, the plane of polarization will be changed. The rotating process and final state of the molecules are both related to the wall shear stress. Then the information of shear stress can be obtained by measuring optical signal.

For the nematic liquid crystal coating under an electric field, its molecular direction equation was built when the system free energy approaches minimum balance, then analogously the molecular direction equation under mechanical shear stress was proposed which includes shear stress, twist.
The shearing induced by the transverse component to match the kinematics imposed by the skew and longitudinal slide power losses as well as the spin of the velocity impacts the viscosity and thus the overall magnitude of the velocity field increases due to the new orientation of the fluid inertia effects compared to the viscous effects. In these situations, a set of three simplified Navier-Stokes equations, generally named bulk flow equations, must be solved to obtain the pressure and fluid velocity fields. When the fluid regime is turbulent, methods to consider roughness are well developed. However, this is not the case for laminar flow regime. Indeed, usual methods such as flow factors cannot be transposed to the bulk flow equations.

In the present work, a new model based on an artificial viscosity is presented. This stochastic model is derived from a theoretical approach and coefficients are empirically determined with direct numerical simulations. It provides a simple way to consider roughness effect in the bulk flow equations.

The 3D - TRACK 5 Fluid Film Lubrication session is scheduled for 8 - 8:30am and features presentations on Thermoelastohydrodynamic Spinning Contacts by Thomas Doki-Thonon, Nicolas Fillot, Philippe Vergne, Guillermo Morales Espejel, and Philippe En Baroeul, France.

Lubrication is a key factor in the performance and longevity of mechanical systems. The investigations described in the paper intend to propose a better understanding of the physical phenomena occurring in spinning contacts under skewing. Experimental investigation is done in a unique test rig called TRIBOGYR, dedicated to large size contacts with spinning kinematics, which allows both film thickness and friction measurement.

When the skew angle is large enough, both experimental and numerical analysis show the formation of a dimple (local increase of film thickness inside the contact area) caused by a viscosity gradient due to high shear in the transverse direction.

When the skew angle is large enough, both experimental and numerical analysis show the formation of a dimple (local increase of film thickness inside the contact area) caused by a viscosity gradient due to high shear in the transverse direction.

8:30 - 9am Roughness Effect In Laminar Inertial Fluid Films Technical Presentation Only, IJ TC 2012-61097 -Noel Brunetiere, Institut Pprime, Futuroscope chasseneuil, France

-This paper presents a new method to include roughness effects in fluid films when the fluid inertia is significant. In many applications, the Reynolds equation is no more relevant because of thick fluid films, high speeds, and low viscosity lubricants leading to important fluid inertia effects compared to the viscous effects. In these situations, a set of simplified Navier-Stokes equations, which are usually transposed to the bulk flow equations, must be solved to obtain the pressure and fluid velocity fields. When the fluid regime is turbulent, methods to consider roughness are well developed. However, this is not the case for laminar flow regime. Indeed, usual methods such as flow factors cannot be transposed to the bulk flow equations.

In the present work, a new model based on an artificial viscosity is presented. This stochastic model is derived from a theoretical approach and coefficients are empirically determined with direct numerical simulations. It provides a simple way to consider roughness effect in the bulk flow equations.


-This paper presents a hybrid mobility solution approach to the analysis of dynamically loaded misaligned journal bearings. Mobility data obtained for misaligned bearings (calculated from a finite element representation of the Reynolds equation) are compared with existing curve-fitted mobility maps representative of a perfectly aligned bearing. A relative error analysis of mobility magnitude and direction provides a set of misaligned journal bearing configurations (midplane eccentricity ratio and normalized misalignment angle) where existing curve-fitted mobility map components based on aligned bearings can be used to calculate the resulting journal motion. For bearing configurations where these mobility maps are not applicable, the numerical simulation process proceeds using a complete finite element solution of the Reynolds equation. A set of numerical examples representing misaligned main and connecting rod bearings in a four-stroke automotive engine illustrate the hybrid solution method. Substantial savings in computational time are obtained using the hybrid approach over the complete finite element solution method without loss of computational accuracy.
**Effects of 3D Surface Roughness and Lubricant Shear Thinning and Viscoelastic Properties on Transient-Thermohydrodynamic Behavior of a Big-End Bearing**

Extended Abstract. IJ TC2012-61128

T Nagaraju, K. M. Jagadeesha, P. E. S. College of Engineering, Mandya, Karnataka, India

The combined influence of 3D surface roughness, shear thinning and viscoelastic behavior of lubricant on transient thermohydrodynamic response of a big-end journal bearing is studied. A time dependent form of modified average Reynolds equation is developed to include the effects of surface roughness, variation of fluid viscosity across and along the fluid-film as well as the angular speed of bearing bush relative to crank pin of big-end journal bearing. The expressions for the simulation of cylinder gas pressure, engine dynamic load components and their time derivatives required for the inclusion of viscoelastic property of lubricant are presented. The coupled solution of the modified average Reynolds, energy and heat conduction equations is obtained using finite element method and appropriate iterative schemes. The influence of roughness orientations and roughness characteristics of opposing surfaces on transient performance of big-end journal bearing is studied by considering thermal and shear thinning and viscoelastic properties of lubricant.

10 - 10:30 am - BREAK

10:30 - 11am

Evaluation of Angular Stiffness in a Large Tilting Pad Thrust Bearing Technical Presentation Only. IJ TC2012-61238

Srikanth Duriseti, JNTUH, Hyderabad, Andhra Pradesh, India

A finite difference procedure to solve the Reynolds and energy equations for the pressure and temperature distribution across the film is described. The film temperature takes viscosity variation and hot oil carryover into consideration. A coupled finite element method using ANSYS determines the important pad deformation. Torques for pad positions 1 and 2 are calculated. The angular stiffness pertaining to the 2x1 pair is calculated for 0.5-20% variation of ho. The values of Kt converge asymptotically. The novel interpretation of a single pads angular stiffness results to determine the characteristics of the bearing are highlighted. Unlike in earlier studies this analysis is helpful in understanding the factors causing pad flutter and dynamics of the bearing elements in hydrogenerators.

3E - TRACK 10 Symposium on Biomimetics and Green Tribology

Track Chair: Michael Nosonovsky, University of Wisconsin Milwaukee, Milwaukee, WI, United States

Track Co-Chair: Bharat Bhushan

**-SYMPOSIUM ON BIOMIMETICS AND GREEN TRIBOLOGY I**

8am - Noon - Lawrence B

8 - 8:30am

Energy Efficient Industrial Lubricants Technical Presentation Only. IJ TC2012-61020

David Blain, Angela Galiano-Roth, ExxonMobil Research and Engineering, Paulsboro, United States, Kevin Harrington, ExxonMobil Lubricants and Specialties, Fairfax, VA, United States, Rick Russo, ExxonMobil Lubricants and Specialties, Middletown, R.I., United States

-Global energy demand is predicted to be about 30 percent higher in 2040 compared to 2010 (1). Energy demand growth is projected to slow as economies mature, population growth moderates and efficiency gains accelerate. This paper will focus on the third factor: improving energy efficiency. The industrial sector consumes almost 48% of global energy, with the remainder being used for residential/commercial and transportation (1). Clearly, improvements in energy efficiency in the industrial setting can have a major impact on overall global energy use and resultant CO2 emissions.

There are multiple sources of lubricant-related energy loss in industrial equipment in general, and gearboxes in particular. These include frictional losses due to metal-to-metal contact, frictional traction losses under elasto-hydrodynamic lubrication conditions and windage or churning losses in the bulk oil. All three of these factors can be improved by using a properly formulated lubricant, with carefully selected base oils and additives to improve efficiency while maintaining good lubrication performance.

ExxonMobil has developed a series of industrial lubricants that can reduce energy usage by up to 4% relative to conventional lubricants. These savings have been documented in carefully controlled laboratory testing and validated in extensive evaluations in actual industrial equipment in the field. Experiments to measure lubricant-related energy efficiency benefits are inherently challenging. Valid determinations of these benefits require precise measurements and controls, meticulous attention to detail and appropriate statistical analysis. In addition to the energy efficiency benefits, these oils can reduce equipment operating temperatures, resulting in increased component and lubricant life. This leads to longer oil drain intervals, and less used oil disposal.

This paper will also describe how the new energy efficient lubricants provide sustainability benefits. Sustainability means different things to different people. For ExxonMobil, it means: balancing economic growth, social development and environmental protection, so that future generations are not compromised by actions taken today.

(1) ExxonMobil: 2012 The Outlook for Energy: A View to 2040
Formulation of a Biobased Gear Oil Utilizing Boron Technology

Ken Doll, NCAUR-ARS-USDA, Peoria, United States, Malgorzata Myslinska, Anderson Development Company, Adrian, MI, United States, Brajendra Sharma, ISTS-UUIC, Champaign, IL, United States, Glenn Heise, Anderson Development Company, Adrian, MI, United States

- A new additive was produced from a natural oil and boron. The synthesis involves the use of the epoxidized form of soybean oil which then undergoes a catalytic ring opening to produce the additive material. Due to their remaining triacylglycerol structure, the products are highly compatible with bio-based lubricants and due to their coherent boron attachments, show effective properties for the reduction of wear.

Some performance examples: Using a traditional 4-ball wear test, the scar diameter observed in a soybean oil lubricant could be reduced from 0.61 mm to 0.41 mm by the inclusion of 1% of the additive. A second generation additive, while not as effective at reducing wear, was able to increase the oxidation onset temperature of soybean oil under pressurized oxygen by 14°C.

Next, these additives were tested in a formulation of biobased gear oil composed of heat treated soybean oil and synthetic esters. In the best formulation, these additives were able to surpass the oxidation onset of a gear oil that was formulated with commercially available additives, while giving nearly as good of performance by wear scar analysis. This oxidation onset value, of 258°C, approaches that of off-the-shelf gear oils.

Overall, these new additives are strong performers which can be made using simple chemistry. Their properties combined with their high biobased content are valuable assets in the search for biobased lubricants and gear oils.
thermal insulation, self-healing, and sensory aid mechanisms are some of the examples found in nature which are of commercial interest. This talk will provide a broad overview of four selected objects of interest found in nature and applications under development or available in the marketplace. These will include Lotus Effect used to develop superhydrophobic and self-cleaning/anti-fouling surfaces with low adhesion3-6, Rose Petal Effect used to develop superhydrophobic surfaces with high adhesion3,7. Gecko Adhesion to develop surfaces with reversible adhesion3,8, and Shark Skin to develop surfaces with low fluid drag and anti-fouling characteristics3,9.

11 - 11:30am
Tribological Performance of Environmentally-Friendly Ionic Liquid Lubricants
Extended Abstract. IJ TC2012-61180
- Carlton Reeves, University of Wisconsin-Milwaukee, Milwaukee, WI, United States
-Sarah Garvey, University of Wisconsin-Milwaukee, Glendale, WI, United States
- Pradeep Menezes, University of Wisconsin Milwaukee, Milwaukee, WI, United States
- Mark Dietz, University of Wisconsin-Milwaukee, Evanston, IL, United States
-Tien-Chien Jen, Michael Lovell, University of Wisconsin-Milwaukee, Milwaukee, WI, United States

Increasingly stringent regulations regarding the use, containment, and disposal of petroleum-based lubricants, along with concerns arising from the depletion of crude oil reserves and the accompanying increases in oil prices, have led to growing interest in the development of environmentally-benign (green) lubricants derived from renewable resources. Although progress has been made in the development and application of natural oil-based lubricants, problems arising from the inherent irreproducibility of these materials make alternatives desirable. Ionic liquids (ILs), particularly those that are fluid at room temperature, represent a promising potential solution to many of the problems associated with both conventional lubricants and those based on natural oils. Moreover, their negligible vapor pressure, low combustibility, non-flammability, and lamellar-like chemical structure have attracted attention for their use as lubricants. These compounds, which typically consist of combinations of a bulky, asymmetric organic cation and an appropriate organic anion, exhibit a number of unique and useful properties that make them well suited as the basis of new families of lubricants. First, they have a consistent and easily tailorable set of properties that can be designed to be environmentally friendly. That is, both the cationic and anionic constituents can be chosen to be non-toxic. Also, in many instances, the ionic liquids can be prepared from renewable (i.e., non-petroleum) resources. Lastly, by proper selection of cation and anion, the room temperature ionic liquids (RTILs) can be rendered biodegradable, reducing or eliminating concerns regarding the disposal and environmental fate of used lubricant. Thus, a lubricant combining these properties would be of considerable interest in a wide range of applications. In the present investigation appropriately designed ionic liquids functioning as efficient lubricants and satisfying the variety of environmental, cost, and performance challenges that complicate the uses of conventional petroleum-based and natural lubricants are considered. In this study, friction and wear tests were carried out using a pin-on-disk tribometer under ambient and varying temperature conditions to characterize the performance of green ionic liquids as viable lubricants. More specifically ionic liquids consisting of salicylate, benzoate (common food additives) and saccharinate (an artificial sweetener) anions with conventional phosphonium cations are used as environmentally-benign lubricants. These green ionic lubricants were compared with petroleum-based lubricants and natural oils. The ionic liquids demonstrated better tribological performance when compared to the petroleum-based lubricants as well as natural oils. The mechanisms governing the chemical composition and tribological performance (friction and wear resistance) are discussed while highlighting possible industrial applications of this new class of lubricants.

11:30am - Noon
Two-dimensional Simulation of the Superhydrophobic behavior using Cellular Potts Model
Technical Presentation Only. IJ TC2012-61222
- Vahid Mortazavi, Michael Nosonovsky, Roshan M Dsouza, University of Wisconsin Milwaukee, Milwaukee, WI, United States

Cellular Potts model (CPM) has been successfully applied to problems where the dynamics is driven by energy minimization arising from interfacial tensions between different media. This model originally was introduced for biological tissues. In recent years, the model has been used in different studies to simulate grain growth, foam structure, coarsening, and drainage, fluid flow and reaction-advection-diffusion systems. In the current study, we extend the standard cellular superhydrophobic behavior of a droplet sliding over the patterned substrate. We also discuss dependency of the sliding velocity on parameters like the solid fraction of contact and contact angle, and contact angle hysteresis based on the results obtained by CPM.

4A - TRACK 1 Nanotribology
Track Chair: Ashlie Martini, UC Merced, Merced, CA, United States

1-2 - NANO TRIBOLOGY II
2 - 6pm - Lawrence A
Session Chair: Emil Sandoz-Rosado, Columbia University, New York, United States

2 - 2:30pm
Atomic Friction on Imperfect Surfaces
Technical Presentation Only. IJ TC2012-61010
-Ashlie Martini, UC Merced, Merced, CA, United States
Friction at the atomic scale is typically characterized on ideal surfaces, i.e., those with repeating and easily characterized surface features. However, if the new understanding gained from such fundamental studies is to ultimately be translated to frictional sliding in general we need to move beyond ideal surfaces. Here we take a significant step towards that goal by characterizing the effect of imperfections, reconstruction, and other measurable surface features on atomic-scale friction. We use atomistic simulation to study sliding between materials with quantifiable atomic-scale surface features such as crystalline metals and Carbon-based materials. The models provide insight into the connection between those features and their effect on frictional behavior.

2:30 - 3pm
Nanotribological Performance of Ultra-thin Al2O3 Films Prepared by Atomic Layer Deposition
Technical Presentation Only. IJTC2012-61055
-Zhimin Chai, Xinchun Lu, Tsinghua University, Beijing, Beijing, China
-The nanotribological performance of ultra-thin alumina (Al2O3) films prepared by atomic layer deposition (ALD) was investigated. The films were deposited by sequential exposures of trimethyl aluminum (TMA) and water on Si substrates. Deposition was carried out in viscous flow reactor at ~7Pa and 200?, with N2 as a carrier gas. The film thickness which is in the range of 0.8-5nm was measured using Optrel Multiskop-ellipsometry. The microstructure was probed by transmission electron microscopy (TEM). The TEM results demonstrate that the Al2O3 films are amorphous. The films become continuous and dense at thickness of 1.5nm, while at 0.8nm the films are discontinuous. Surface morphology of the films and nanotribological experiments were achieved by scanning probe microscopy (SPM). The objectives of the study were to identify the thinnest films that exhibit good wear-resistance and to understand failure mechanisms of such ultra-thin coating during wear. The results show that the films with thicker thickness exhibit better wear resistance due to the improved load carrying capacity.

3 - 3:30pm - BREAK

3:30 - 4pm
Atom-Scale Interrogation of the Scanning Probe Tip Subjected To Nanotribological Testing
Technical Presentation Only. IJTC2012-61099
-Christopher J. Tourek, Sriram Sundararajan, Iowa State University, Ames, IA, United States
-While atomic force microscopy (AFM) based techniques have proved very useful in investigating nanotribological phenomena, a detailed assessment of the material structure and chemistry of the near apex region of the AFM tip can provide further insights. We present our investigations utilizing 3D atom probe tomography to successfully study the near apex regions of an AFM tip at the atomic scale. We also report our observations on the change in chemistry and structure of an AFM tip when subject to nanotribological sliding experiments. When a commercially available Si tip is subjected to dry sliding against Cu, Cu is found to transfer onto the Si tip beyond a critical normal load. Cu atoms are found to transfer even in the absence of discernible wear tracks on the Cu sample. Finally, initial observations in analyzing DLC coated tips subjected to similar wear experiments are also reported. The technique opens up a new avenue of investigation for AFM-related nanotribology research.

4 - 4:30pm
Determination of Adhesion Forces Between Smooth And Structured Solids
Extended Abstract. IJTC2012-61132
-Hartmut R. Fischer, Edwin R.M. Gelinck, TNO, Eindhoven, Netherlands
-With the increasing quality in surface finish for many components and systems on the one side and on miniaturization in mechanical components as well as in demanded precision of positioning of parts in high-end equipment machines and systems, the tendency of smooth surfaces to stick spontaneously to each other is becoming a serious problem. Surfaces tend to be made smoother in order to gain flatness or in order to fulfill the need for more precise and reproducible positioning of parts. Adhesion or even sticking of the surfaces is a major showstopper for these applications.

There are several measures that can be taken in order to reduce spontaneous adhesion. Quantification of the effectiveness of the chosen solution is most often done using an AFM with probes varying from 1nm to 8 micron of contact diameter. A serious disadvantage in measuring adhesion by sharp tips is the wear of the tips. Sharp tips wear easily, resulting in undefined contact areas. When the real area of contact is not well defined, the quantification of the adhesion force is not significant.

In the current study results of AFM measurements from literature with different tip diameters of colloidal probes are compared with AFM cantilevers with a plateau tip and using probes from large spheres using an alternative setup (UNAT). These methods give results that are in good agreement with values found in literature. Large contacting surface areas. When the real area of contact is not well defined, the quantification of the adhesion force is not significant.

Another part of the study deals with a deliberately roughening of smooth surfaces to minimize (spontaneous) adhesion. Good agreement has been found with existing results.

For the use of larger surfaces it is important that the surfaces to be tested are extremely clean. Particles on smooth surface do influence the measurements quite easily. Especially for larger areas the possibility of encountering particles on the surface are more likely, when particles are present. For the measurements in this study a lot of care has been taken therefore to remove organic contamination.

4:30 - 5pm
The Wear Characteristics of Graphene as an Atomically-Thin Protective Coating
Extended Abstract. IJTC2012-61135
-Emil Sandoz-Rosado, Elon Terrell, Columbia University, New York, United States
- Lamellar atomically-thin sheets such as graphene (and its bulk equivalent graphite) and molybdenum disulfide have emerged as excellent solid lubricants at the macro scale and show great promise as protective coatings for nanoscopic applications. In this study, the failure mechanisms of graphene under sliding are examined using atomistic simulations. An atomic tip is slid over a graphene membrane that is adhered to a semi-infinite substrate. The impact of sliding velocity and substrate rigidity on the wear and frictional behavior of graphene is studied. In addition, the interplay of adhesive and abrasive wear on the graphene coating is also examined. The preliminary results indicate that graphene has excellent potential as a nanoscale due to its atomically-thin configuration and high load carrying capacity.

5 - 5:30pm
In-Situ Calibration of Lateral Forces in AFM-Nanotribology
Technical Presentation Only. IJTC2012-61258
-Harmandeep Khare, David L. Burris, University of Delaware, Newark, DE, United States
-Solid lubricants have been shown to form ultra-thin (~10 nm) tribofilms at sliding interfaces which are thought to consistently accompany and impact low wear and low friction sliding. Scanning Probe Microscope (SPM) based lateral force measurement techniques are suited to characterize surface mechanical properties of tribofilms at the relevant length scales. However, inherent difficulties with existing calibration and measurement methods in lateral force microscopy present challenges in the repeatable and quantitative assessment of such forces in an absolute sense. These often arise due to the combination of instrument characteristics and the choice of calibration method themselves. The present research proposes modifications to existing lateral force calibration, measurement and analysis procedures with an aim to reduce experimental complexity and measurement uncertainty. Representative measurements with the new method within the context of solid lubricants are also presented.

5:30 - 6pm
Optimization of Roughness for Minimum of Friction and Adhesion in Micro/Nanocontacts
Technical Presentation Only. IJTC2012-61232
-Zygmunt Rymuza, Warsaw Univ Of Tech, Warsaw, Poland, Lukasz Ocyra, Dominik Nolbert, Warsaw University of Technology, Warsaw, Poland, Hiroaki Kawata, Yoshihiko Hirai, Osaka Prefecture University, Osaka, Japan
-The roughness plays very important role in friction and adhesive interactions. It relates in particular to the mold/resist interfaces in nanoinprint lithography (NIL) as well as in MEMS/NEMS contacts of moving components. The aim of the experimental studies accompanied by advanced modelling and computer simulations was to indentify the optimum roughness of contacting surfaces to minimize the friction and adhesion which are both important in particular in NIL mold/resist contacts.

The experimental studies have been performed with the use of Atomic Force Microscopy (AFM) on the fabricated by etching silicon samples with various roughnesses and also on imprinted (copied) polymeric resist samples using the silicon samples as NIL molds. The experimental studies have been followed by the advanced modelling and computer simulation of frictional/adhesive contacts between the silicon mold and polymeric imprints. The properties of the real samples measured with the use of the same AFM have been used in the modelling and simulations. The comparison of the experimental studies and the results of the simulations will be discussed in the paper.

4B - TRACK 4 Boundary and Thin Film Lubrication
Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

4-4 -BOUNDARY AND THIN FILMS 3
2 - 6pm - Horace Tabor
Session Chair: Antonius Lubrecht, Insa De Lyon, Villeurbann 69621, France
Session Co-Chair: Bhavesh Kachhia, GE India Technology Center Pvt Ltd, Bangalore, Karnataka, India

2 - 2:30pm
A Fluid-Structure Interaction Modeling Approach of Lubricated Bearing-type Sliding Contacts
Technical Presentation Only. IJTC2012-61193
-Jeremiah N. Mpazzehe, C.F. Higgs III, Carnegie Mellon University, Pittsburgh, PA, United States

-in many tribological applications, such as journal bearings and gears, a fluid film is used to accommodate velocity between moving surfaces. To model the behavior of this film and to predict its ability to carry load, the Reynolds equation is predominantly employed. As computational processing power continues to increase, there has been a trend towards using computational fluid dynamics (CFD) to predict the fluid behavior in lubrication environments. Using CFD is advantageous in that it can provide a more general approximation to the Navier-Stokes equations than the Reynolds equation. Moreover, using CFD allows for the simulation of multiphase flows as could occur during bearing contamination and bearing exit conditions. Because the bearing surfaces move relative to each other as they obtain equilibrium with the fluid pressure, there is a need to model the moving CFD boundary which is a non-trivial task. In this work, a fluid-structure interaction (FSI) technique is explored as an approach to model the dynamic coupling between the bearing surfaces and the lubricant. The benefits of using an FSI approach are discussed and the results from its implementation in a lubricated sliding contact model are presented.

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Un-Steady Piston Skirts EHL Modeling at Idling Speed Initial Engine Start Up

- Syed Adnan Qasim, National University of Sciences and Technology (NUST), Rawalpindi, Pakistan, M. ShoaiB Ansari, National University of Sciences and Technology (NUST), Islamabad, Pakistan, M. Afzaal Malik, Air University, Islamabad, Islamabad, Pakistan

An internal combustion (IC) engine starts up at a low speed and under the low-load conditions. It runs at an idling speed before attaining the desired operating conditions. During the process the small but significant secondary piston displacements occur, which are transient in nature. In an engine start-up at an idling speed the elastohydrodynamic lubricating (EHL) film is absent and the unsteady squeeze exposes the interacting surfaces of the piston skirts and cylinder liner to adhesive wear. This work numerically models the hydrodynamic and EHL of the piston skirts by considering the steady-state wedging and un-steady squeeze effects at an idling speed in the initial engine start up. The second-order changes in the transverse piston displacements as a function of the 4-stroke cycle are incorporated in the skirts lubrication models. A fairly viscous engine lubricant is considered at a small piston-to-bore radial clearance in the lubrication models. The 2-D average Reynolds equation is solved numerically to determine the hydrodynamic pressures and film thickness profiles under the transient conditions. An appropriate finite difference scheme is used to generate the hydrodynamic pressures and film thickness profiles. The profiles of the rising pressures and an EHL film are generated by defining the pressure-viscosity relationship, incorporating the elastic surface displacements, and using the inverse solution technique. The simulation results show the secondary piston eccentricities and velocities as a function of the 720 degree crank rotation cycle. The 3-D fields of the hydrodynamic pressures generated over the surface of the piston skirts are plotted to study their effects on the corresponding film profiles in the respective lubrication regimes. The analysis of the results shows that at an idling speed engine start up the un-steady squeeze produces an insignificant effect initially in the induction stroke but attains dominance during the expansion stroke of the piston. The squeeze action produces some beneficial effects by improving the thickness of the film and the load-carrying capacity of the lubricant at an idling speed in the initial engine start up.

Film Thickness Prediction for Isoviscous Visco Elasto Hydrodynamic Lubricated Point Contacts

- Florian Mora, Michelin, Villerurbanne, France, Philippe Sainsot, Université de Lyon, INSA de Lyon, LaMCoS, CNRS UMR 5259, Villerurbanne, France, Yohan Le Chenadec, Michelin, Ladoux, Select State/Province, France, Antonius Lubrecht, Insa De Lyon, Villeurbanne 69621, France

To correctly model and predict the behaviour of vehicle tires and oil seals it is essential to account for the viscoelastic material properties. Several models of viscoelastic lubricated contacts exist in the literature. Salant et al [1], Thatte and Salant [2], Leeuwen and Stakenborg [3] and A Elsharkawy [4] have studied the line contact viscoelastohydrodynamic lubricated problem with smooth or rough surfaces using the Patir and Cheng flow factors. The goal of this work is to model a point contact problem, including transient and viscoelastic parameters. The generalized Zener model is applied, enabling a large range of viscoelastic properties. Its impact on the lubricated contact behaviour is studied, showing time dependent behaviour even in smooth conditions, like waves in the contact zone. During its operations, the material is stressed dissimilarly along the contact radius, changing elastic modulus and creating pressure fluctuations. Moreover, with increasing time, the elastic modulus decreases at the contact center, creating a local pressure decrease. This work tries to give a general prediction of the central film thickness as a function of all viscoelastic and lubrication parameters.

4 - 4:30pm

Modeling Low-Viscosity 1st Compression Ring EHL at Large Radial Clearance in Initial Engine Start Up

- Syed Adnan Qasim, National University of Sciences and Technology (NUST), Rawalpindi, Pakistan, Rashid Naseer, Abdul Ghafoor, National University of Sciences and Technology (NUST), Islamabad, Islamabad, Pakistan, M. Afzaal Malik, Air University, Islamabad, Islamabad, Pakistan

During the normal operation of an internal combustion (IC) engine the 1st compression ring plays a crucial role in sustaining the thermal loads effectively. The low-speed initial engine start up is a critical occasion when the ring has to act as an effective seal against the thermal loading in the absence of a fully established elastohydrodynamic lubricating (EHL) film. The absence of an EHL film and the secondary translations of the piston assembly at a large ring-to-bore radial clearance make the 1st compression ring vulnerable to adhesive wear in a few cold initial engine start up cycles. This study develops the numerical models of the isothermal hydrodynamic and EHL of the parabolic-faced 1st compression ring at a relatively large radial clearance. The secondary dynamics of the piston assembly are incorporated in the ring lubrication models by considering a low-viscosity grade engine lubricant at a low initial engine start up speed. In the hydrodynamic lubrication model the Reynolds equation is solved to generate the hydrodynamic pressures over the circumferential length at the critical ring positions in the 4-stroke
cycle. In the 1st compression ring EHL model the inverse solution technique is employed to generate the rising EHL pressures after incorporating the elastic displacements of the ring and the liner. The simulation results show the secondary displacements and velocities of the 1st compression ring as a function of 720 degree crank rotation cycle. The film thickness profiles and pressure fields are plotted in the hydrodynamic and EHL regimes. The analysis of the simulation results suggests that a relatively large ring-to-bore radial clearance affects the secondary eccentricities and lubrication of the 1st compression ring when a low-viscosity grade engine oil is used as a lubricant.

4:30 – 5pm
On the Prediction of Cavitation in EHL Point Contacts Using a Mass-Conservative Algorithm
Technical Presentation Only. IJ TC2012-61398
-Bhavesh Kachhia, GE India Technology Center Pvt Ltd, Bangalore, Karnataka, India
Daniel Nelias, INSA-Lyon, CNRS, Villeurbanne, France

-The Floberg-Jakobsson-Olsson cavitation theory with mass-conservative algorithm is implemented for the EHL point contact problem. An attempt is made to obtain accurate estimate of the cavitation boundary by solving the Reynolds equation with the fractional film content parameter introduced by Elrod. The multigrid technique is used to enhance the convergence. Emphasis is made on the numerical method to eliminate the instabilities caused by the binary switch function. Results are compared with the classical EHL point contact solution obtained with Reynolds cavitation boundary conditions.

4C - TRACK 5 Fluid Film Lubrication
Track Chair: Daejong Kim, University of Texas at Arlington, Arlington, United States

4C - FLUID FILM LUBRICATION IV
2 - 6pm - Tabor Auditorium
Session Organizer: Bart Raeymaekers, University of Utah, Salt Lake City, UT, United States

2 - 2:30pm
Experimental Investigation On The Thermal Effects In A Taper Land Thrust Bearing
Extended Abstract. IJ TC2012-61025
-Yann HENRY, Jean BOUYER, Institut Pprime - CNRS - University of Poitiers - ENSMA, Chasseneuil du Poitou, France
-Michel Fillon, Institut Pprime - CNRS - University of Poitiers - ENSMA, Chasseneuil, France

-An experimental study on a taper land thrust bearing has been performed on an original test rig designed at PPrime Institute. The results are presented for an eight pads fixed geometry thrust bearing. The test rig allows a precise evaluation of several parameters such as the friction torque, the minimum film thickness as well as pressures and temperatures at the film/pad interface. Indeed, the temperature field is determined on two pads equipped with thirteen thermocouples each while the pressure field is measured on two other pads by using twelve pressure transducers. The temperature at half-thickness and at the back of the pads is also measured.

The test was conducted with an ISO VG 46 mineral oil supplied to the bearing under operating conditions which were kept constant throughout the test: the nominal supply temperature was fixed at 40°C and the nominal feeding pressure at 0.1 MPa. Two other supply configurations were performed at higher supply temperatures: 50°C and 60°C at 0.1 MPa. The effect of supply pressure has been analyzed too: 0.05 MPa and 0.15 MPa at 40°C. The experiments were carried out for operating conditions close to those existing in industry: the rotational speeds ranged from 2,000 up to 10,000 rpm (up to 36.6 m/s) and the nominal loads ranged from 1,000 up to 8,000 N (specific pressure up to 2MPa).

The results are in agreement with other literature surveys. However, the defaults of the active surface during machining of the thrust bearing can generate measurement dispersion through different pads. For a better understanding, two additional tests were performed in order to measure temperature and pressure fields on the same pad. The results are presented as a function of the flatness defects of the pad. It is found that the performance of the thrust bearing is most likely affected by the variation of the supply temperature and weakly affected by the variation of the supply pressure. Moreover, it is surprising to note that the displacement of the peak pressure towards the inner radii for high loads can be attributed to thermal and mechanical deformations of the thrust bearing components.

2:30 – 3pm
Behaviour of Magnetic Fluid Based Rough Rayleigh Step Bearing
Extended Abstract. IJ TC2012-61058
-Ashok Patel, Vishwakarma Government Engineering College, Ahmedabad, Gujarat, India
-Gunamani Deheri, Sardar Patel University, Anand, Gujarat, India
-Paresh Patel, Institute of Science, Nirma University, Ahmedabad, Gujarat, India

-The Rayleigh step bearing is considered in one dimensional geometry. It is a well established fact that the roughness has a significant effect on the performance of the hydrodynamic lubrication of a slider bearing. An attempt has been made to study and analyze the effect of transverse roughness in the presence of a magnetic fluid for a Rayleigh step bearing. The bearing surfaces are assumed to be transversely rough. The roughness of the surfaces has been characterized by a random variable with non-zero mean, variance and skewness. The stochastically averaged Reynolds equation is solved with suitable boundary conditions to obtain the pressure distribution in turn, which is used to get the load carrying capacity. The results presented in graphical form indicate that the effect of transverse roughness is significantly adverse. However, this article establishes that there exist sufficient scopes for improving the performance of the bearing system.
in the case of negatively skewed roughness especially, when negative variance is involved, in spite of the fact that the standard deviation introduces a negative effect. Besides, the performance of the bearing system improves significantly owing to the presence of the magnetic fluid lubricant. The adverse effect of roughness can be minimized by the positive effect of magnetization at least in the case of negatively skewed roughness. Therefore, this investigation offers some measures even from bearings life period point of view.

3 – 3:30pm - BREAK

3:30 - 4pm
Non-Iterative Finite Element Scheme for Combined Annular-Thrust Porous Aerostatic Bearings Analysis
Extended Abstract. IJ TC2012-61088
Polina V. Khan, Kamchatka State Technical University, Petropavlovsk-Kamchatsky, Russia, Pyung Hwang, Yeungnam University, Gyeongsan, Gyeongbuk, Korea (Republic)

The paper deals with the problem of static analysis of the combined annular-thrust porous aerostatic bearings. The flow is essentially three dimensional, compressible, and is governed by two equations: one based on the Darcy's law for the porous bulk and another one is the Reynolds equation for the lubrication film. The common approach involving non-linear system solution and iterative unification of the porous bulk and lubrication film pressure values is time-consuming. In the present paper the two governing equations are combined into one, by using the integration by parts in Petrov-Galerkin formulation for the mass conservation law. The combined equation is linearized considering low rotation speed. The resulting scheme requires only two matrix inversions while the common approach requires hundreds of them. The effect of the dimensionless permeability onto the load carrying capacity in radial and thrust directions is analyzed, and the optimal permeability value is found.

4 - 4:30pm
An Investigation of the Steady-State Performance of a Wave Aerodynamic Thrust Bearing for High Speed Applications
Extended Abstract. IJ TC2012-61187
Nicoleta M Ene, Florin Dimofte. The University of Toledo, Toledo, OH, United States

The wave geometry bearings were successfully analyzed and tested as journal bearings with both liquids and gas lubricants since 90s. The same geometry can be used to support axial loads. Thus, a stationary disk with a waved surface on the side that faces a rotating flat disk can support unidirectional axial loads. If two waved disks are placed on both sides of a runner disk, then the thrust bearing can carry axial loads in both directions. In addition, the double thrust bearing can be used to axially position the rotor.

A double thrust wave bearing lubricated with air was developed to support axial loads up to 200 N at rotational speeds up to 100,000 RPM. The steady-state performance of this bearing (the load capacity, stiffness, friction power loss, etc.) was analyzed for various running regimes. The influence of the wave bearing parameters on its steady-state performance was also studied.

One side of the double thrust wave bearing was experimentally tested to validate the theoretical analysis. A special test rig was built for this purpose. The rotating disk of the thrust bearing was attached to the shaft of a ball bearing spindle that is driven by an air turbine. The stationary disk of the thrust bearing is supported by an air journal bearing. A load cell attached at the end of the air journal bearing is used to measure the axial load. Because the stationary disk floats on an air layer, both the axial (thrust) and the rotating friction of the thrust bearing support are minimized. A load cell that is set offset from the centerline measures the thrust bearing friction torque. The clearance between the thrust bearing disks is controlled with a precise micrometric screw with 200 threads per inch (approximately 0.127 mm pitch). The experimental measurements were in good agreement with the numerical predictions, validating the computer code.

4E - TRACK 9 Wind Turbine Tribology
Track Chair: Gary Doll, The University of Akron, Akron, OH, United States

9-1 -WIND TURBINE TRIBOLOGY
2 - 6pm - Lawrence B

2 - 2:30pm
Improved Reliability and Maintainability of Wind Machines Through Proper Lubrication
Technical Presentation Only. IJ TC2012-61137
-Chad Chichester, Dow Corning Corp., Midland, United States, Roman Vanecek, Manfred Jungk, Dow Corning GmbH, Wiesbaden, Germany

Wind power sustainability requires improvements in wind machine reliability and maintainability. Many efforts are on-going to improve wind system reliability, and maintainability through system design and optimized maintenance practices, both aimed at increasing uptime, and reducing total cost of ownership. Proper lubrication is included in these efforts. Wind machine components require different lubricants forms, including oils, greases, and/or assembly pastes. Each of these lubricant forms offers unique solutions to known reliability issues. Special solid lubricant packages included in some greases and pastes can help prevent vibration-induced fretting corrosion, or riffling that occurs in Pitch/Yaw bearings designed to carry high loads and operate at variable speeds. Oils with improved viscosity-temperature performance can help main bearings and gears operate reliably in the Boundary/Mixed friction regime, while at the same time reducing the effects of viscous drag due to the oil viscosity being too high. This can help achieve improved power output efficiency. Threaded connections used to assemble components need to
be lubricated, in order for a consistently low coefficient of friction to be achieved. This helps to insure the required pre-tensioning, and subsequent clamping force is equally applied to each threaded connector, while at the same time optimizing the amount of applied torque required to achieve proper fastener elongation. Shrink discs connecting the main shaft to the gear box are frictional connections, thus require ultimately low frictional coefficients in boundary friction at assembly, as well as disassembly to optimize the assembly and maintenance processes. Brakes are used to quickly prevent over speeding and to lock the shaft during maintenance operation. Reduction of friction between the back plate and jacks on each side of the caliper is required to allow safe operation, and even wear profiles. This presentation will explore bench test results that were used to develop special solid lubricant packages for greases and pastes, as well as test data used to examine alternative lubricating fluid chemistries for use in Lubed for Life+ wind turbine gearboxes. All aimed at improving wind machine reliability and maintainability to optimize asset utilization through reduced downing events.

2:30 - 3pm
Oil and Grease Analysis from Wind Turbine: A Complete Condition Monitoring Approach
Technical Presentation Only. IJ TC2012-61208
-Steffen Bots, Oelcheck GmbH, Brannenburg, Bavaria, Germany

Taking oil samples on a regular basis as part of the maintenance strategy is state of the art for wind turbine main gearboxes. The oils are being tested regarding their condition, possible contaminations and to evaluate the wear situation. The lab results and the evaluation made by experienced engineers support the identification of upcoming component failures, proof whether maintenance actions like filtration or dehydration work properly and finally oil drain intervals can be set up condition based.

But there is a different picture when it comes to greases. In the past continuous, trend based grease monitoring was not a common practice, although the major part of installed bearings is grease lubricated and these machinery parts have often an essential impact on the reliability of the whole equipment. But there seem to be a change in the philosophy and a trend towards more routine grease analysis which has been driven by technical issues and is supported by the positive experiences with oil analysis programs. Additionally there exist many examples from the field in the meantime where grease analysis has proven that it reads important information out of the grease like:

- Amount of wear
- Contaminations
- Consistency of the grease
- Bleeding out behaviour
- Condition of base oil and additives

Often grease properties change significant during operation. The information about contaminations and wear is concentrated within a relatively small volume and is not affected by filtration or diluted by a huge oil reservoir. As a result grease analysis can be a very effective condition monitoring tool.

This paper will introduce state of the art test methods for the analysis of oil and grease samples. Related on different components and the deduced demands it is shown that the optimal combination of tests, performed as trend analysis, avoid many common problems or answers special questions. The presentation provides some examples from the field giving an overview about typical oil and grease analysis results and provides general evaluation guidelines. Finally the setting up limit values will be demonstrated.

3 - 3:30pm - BREAK

3:30 - 4pm
Lubricant Rheology and Its Affect on Contact Starvation
Technical Presentation Only. IJ TC2012-61240
-Paul Shiller, The University of Akron, Akron, United States

-Lubrication of mechanical contacts depends on the film forming properties of the lubricant. This action presupposes that enough lubricant can be brought into the contact area. The flow of lubricant into the contact area relies directly on the rheology of the lubricant. If the lubricant is Newtonian then the introduction of lubricant into the contact area is straightforward. There is enough lubricant carried into the contact area in the boundary layer to satisfy the needs of the film formation; i.e. fully flooded. If the lubricant is non-Newtonian then the introduction of lubricant into the contact area is not so simple. What would happen if the lubricant were shear thinning? Or shear thickening? What about the normal forces on the lubricant in the inlet to the contact area? The contact may actually be starved for lubricant if the rheology of the lubricant is not correct.

Oils are normally shear-thinning fluids. Experiments were carried out in which solid particles were added to an ISO VG 68 lubricating oil to induce shear thickening behavior. The particles used were all solid lubricants; C, BN, PTFE, and Clay. The materials were tested in a ball on ring configuration to determine the point where the friction increased, indicating metal-to-metal contact, as the slide to roll ratio was increased using two different entrainment velocities. It was found that the increase in friction occurred sooner at the higher entrainment velocity. The higher entrainment velocity was expected to produce the larger lubricant film. This observation is an indication that the lubricant could not be carried into the contact area fast enough to prevent metal-to-metal contact; it was starved for lubrication. This presentation will discuss possible reasons for starvation from a rheological viewpoint.
4 – 4:30pm
**Micropitting of Steel Surfaces in Wind Turbine Gearbox Oils**
*Technical Presentation Only.*  IJTC2012-61241

-Gary Doll, Paul J. Shiller, The University of Akron, Akron, OH, United States

Low cycle micro-pitting is one of the life-limiting wear mechanisms of roller bearings that are used in wind turbine gearboxes. Micro-pitting can occur on the raceways of roller bearings when the bearings operate in low lambda conditions, and experience a significant amount cycle shear stresses arising from roller/raceway sliding. Surface treatments like WC-DLC and black oxide on bearing elements are employed to address this life-limiting wear mode. In this study, we have applied tribological experiments designed to produce micro-pitting wear on steel surfaces to study this wear mode on three surfaces (nascent steel, WC-DLC, and black oxide) in three of the most used commercial gearbox oils.

4:30 – 5pm
**Rolling Element Bearing Failure In Wind Turbine Applications**
*Technical Presentation Only.*  IJTC2012-61244

-David L. Burris, Benjamin Gould, University of Delaware, Newark, DE, United States

- On average, wind turbine gearboxes survive approximately 5-7 years of a 20 year design life. Gearbox failures are currently a leading cause of wind turbine downtime and significant reliability improvements are needed to make wind power economically competitive with other power sources. The cause of the reliability problem is currently unknown, but recent work indicates that the low speed and high speed bearings are the likely initiation sites. We are working as part of the Atlantic Offshore Wind Consortium to better understand the challenges specific to the wind turbine gearbox application, especially as they relate to the offshore environment. In this paper, we report our initial efforts to create properly scaled laboratory experiments to study the evolution of surface failure of rolling element bearings in the presence of water and particulate contamination.

5 – 5:30pm
**Wind Turbine Tribology - A Brief**
*Technical Presentation Only.*  IJTC2012-61261

-Shuangwen Sheng, Jonathan Keller, National Renewable Energy Laboratory, Golden, CO, United States, Aaron Greco, Argonne National Laboratory, Argonne, IL, United States, Robert Errichello, GEARTECH, Townsend, MT, United States

-Wind power is presently the fastest growing renewable energy source. However, the industry still faces reliability challenges, which are highly dependent on tribological issues associated with blade pitch systems, main shaft bearings, yaw systems, gearboxes, and generators. Many of the failure modes that occur in these systems such as Hertzian fatigue, adhesion, abrasion, corrosion, fretting corrosion, polishing, electric discharge, and scuffing are influenced by tribology. Lubricant base oil, additives, and cleanliness must be correctly specified for each of these systems to achieve their design life.

A Wind Turbine Tribology Seminar was convened by the National Renewable Energy Laboratory (NREL), Argonne National Laboratory (ANL), and the U.S. Department of Energy (DOE) to explore the state-of-the-art in wind turbine tribology and lubricant technologies, raise industry awareness of this complex topic, present the science behind the technologies, and identify possible R&D areas for improvements. The seminar was held at the Renaissance Boulder Flatiron Hotel in Broomfield, Colorado, on November 15-17, 2011. This presentation will give a brief recap of materials presented at the tribology seminar. In details, several topics, such as tribological damage modes, factors influencing surface failures, and recommendations for future research and development (R&D) activities, will be touched on. The objective is to provide lubrication engineers and tribologists with up-to-date information on wind turbine tribology challenges and opportunities. As a result, needed lubrication and tribology research can be conducted to improve wind turbine gearbox reliability and help the wind industry lower the cost of energy.
8 - 8:30am
Tribological effects of BN and MoS2 nanoparticles added to polyalphaolefin oil in piston skirt/cylinder liner tests
Extended Abstract. IJ TC2012-61062
-Nicholaos Demas, George Fenske, Elena V. Timofeeva, Jules Routbort, Argonne National Laboratory, Argonne, IL, United States

The dispersion of nanoparticles in liquid lubricants is a relatively recent idea. Difficulties associated with the synthesis of many nanoparticles and their stability in solutions have only recently been addressed, and today descriptions of various kinds of nanoparticles suspended in solutions can be found in literature. While well-known solid lubricants such as graphite, h-BN, and transition metal dichalcogenides owe their lubricity to a unique layered structure, solid nanoparticles are believed to provide additional lubrication mechanisms. In this work, the friction and wear of poly-alpha-olefin (PAO 10) base oil with 3 wt. % boron nitride (BN), and molybdemen disulfide (MoS2) nanoparticles added were studied. The formulations were tested using cast iron cylinder-liner segments reciprocating against aluminum alloy piston-skirt segments at 20, 40, and 100°C. The results showed that at a load of 250 N and reciprocating frequency of 2 Hz BN did not lower friction whereas MoS2 nanoparticles were very effective at reducing both friction and wear, compared to the base oil. The viscosities of both formulations were similar to the base oil, which allowed for a direct comparison between them. Raman spectroscopy showed the formation of an aligned MoS2 layer on the cast iron liner surface, which functions as a tribofilm. In the case of the cast iron liner tested with BN nanolubricant there were no traces of BN that could be related to tribofilm formation. The effect of surfactants was also studied and it was found that some surfactants were not only beneficial in dispersing the nanoparticles in oil, but also produced some reduction in friction and wear even as stand-alone additives in PAO10.

8:30 - 9am
Mechanistic and Structural Study of Friction Polymer Based Tribo-chemical Lubricant Film
Technical Presentation Only. IJ TC2012-61120
-Wenyang Zhang, Muhammad P. Jahan, Ajay P. Malshe, University of Arkansas, Fayetteville, AR, United States

-In recent years, to meet the growing need of lubrication in multi-purpose industrial requirements, the application of multi-component nano-lubrication systems have been reported [1-3]. The MoS2 based nanolubrication system was found to provide excellent lubricating performance under severe boundary lubrication conditions [1-3]. The aim of the present study is to investigate the reasons behind the superior tribological performance of the developed nano-lubrication system from the mechanical and structural point of view. Different characterization techniques such as: nanoindentation, atomic force microscopy (AFM), focused ion beam (FIB) and transmission electron microscopy (TEM) have been employed to study several mechanical and structural properties of the tribofilm, namely the film strength, thickness, roughness, and crystalline structure. The AFM surface roughness results clearly showed that the nanolubricants could protect the mating surfaces, since the wear track roughness of base oil sample is much higher than that of nanolubricant sample. Moreover, tribofilms with 40-60 nm thickness have been observed by the AFM analysis. The mechanical strength of the film has been studied by nanoindentation technique. In addition, the FIB-TEM cross-sectional analysis of the tribofilms reveals that the structure of boundary tribo-chemical lubrication film partly remains as crystalline structure to reduce friction, whereas the multicomponent nano-lubrication system partly converts into amorphous friction polymers under severe boundary lubrication.

9 - 9:30am
Effect of the Modified Silica Abrasive Particles on Nano-Sized Particle Deposition In Final Polishing Of Silicon Wafers
Extended Abstract. IJ TC2012-61122
-Zhonghua Gu, Tsinghua University, Shenzhen, Guangdong, China, Guoshun Pan, Tsinghua University, Beijing, Beijing, China, Hua Gong, Chunli Zou, Tsinghua University, Shenzhen, Guangzhou, China

-The content of the deposited nano-sized particles is an important indicator to evaluate the final polishing slurry of silicon wafers. Some undesirable detects, such as haze and scratch, will be caused by deposition of nanoparticles, which is mainly related to the effect of charges on the particle and wafer surface. Thus, reduction of the deposition of particles in the final polishing process of silicon wafer is an urgent task to achieve a high-quality silicon wafer surface.

In this work, silane coupling agent and polymers are proposed to change the electrical properties of the nanoparticles surface. The surface roughness of polished silicon wafers and the deposition of particles on silicon wafer surface are measured by Atomic Force Microscope (AFM). When the silicon wafer is polished by basic final polishing slurry, the material removal rate (MRR) and the roughness (Ra) are 0.204mg/min and 0.817nm, respectively. Fortunately, when the basic final polishing slurry is amended by Silane Coupling agent KH550, Pacific Alaska Airways (PAA), Polyacrylamide (PAM), or Polyethylene Oxide (PEO), the values of Ra reduce remarkably and the values are 0.054, 0.279, 0.327, and 0.097nm, respectively. Among the four materials, KH550 and PEO are much better than PAA and PAM.
The Tribological Behavior of Paraffin Liquid with Nanodiamond

Hyunsoo Kim, Sungkwan Univ., Suwon, Korea (Republic), Ilyoung Kim, Jinwhak Park, Sungkyunkwan Univ., Suwon, Korea (Republic), Jungsuuk Lee, Neoenbiz, Incheon, Korea (Republic), Youngze Lee, SKK University, Suwon, Korea (Republic)

In the Matrix synthesis method, nanodiamond is dispersed in paraffin liquid. This method is a unique technique of the team. Scuffing life and wear amount were tested at the sliding tester using paraffin liquid with nanodiamond and carbon steel in order to investigate its tribological behavior. The tribological tests were conducted in two ways. First, the load was increased gradually at the scuffing test. Second, the immediate loading tests were conducted at constant time and load. As a result, nanodiamond dispersed paraffin liquid was found to have a good tribological behavior and this characteristic leads to a long scuffing life and low wear rate.

5B - TRACK 4 Boundary and Thin Film Lubrication

Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

4-5 - BOUNDARY AND THIN FILMS 6 8am - Noon - Horace Tabor

Session Chair: Marc Ingram, PCS Instruments, London, United Kingdom
Session Co-Chair: Patrick Dougherty, Carnegie Mellon University, Pittsburgh, PA, United States

8 - 8:30am

Wear Of Graphitic Cast Iron In Seawater Technical Presentation Only. IJ TC2012-61224

Connor Myant, Shi Lin Oh, Imperial College London, London, United Kingdom, Philippa Cann, Imperial College Tribology Sec, London, United Kingdom

In the marine industry grey cast iron is extensively employed in the manufacture of bearings for shaft-driven propeller ships where fully lubricated conditions are often impossible to maintain. Any ship setting sail with a defective stern tube bearing is in breach of the seaworthiness regulations and thus culpable should there be a casualty or loss of propulsion. To repair malfunctioning motor assemblies exorbitant costs are incurred whenever a vessel is dry-docked and disassembled, added to the loss of revenue suffered by the company as long as the vessel stays out of operation. Typical losses may amount to several million pounds depending on the type of vessel. In order to prevent catastrophic failure as well as to optimise the maintenance schedule of each marine vessel, it is important to be able to accurately predict the onset of wear and the wear rate of cast iron in seawater. For this reason there is terrific interest within the marine industry into how graphitic cast iron wears in contact with steel.

The objective of this study was to conduct experiments simulating the real life situation to measure the wear rates for cast iron rubbing against steel. A pin-on-disc tribometer was employed for all wear tests and the experimental parameters matched to the actual operating conditions for marine cargo vessels. The wear tests were performed under different lubricating conditions, distilled water, sodium chloride (NaCl) solution with concentrations of 25 g/l and 35 g/l and model seawater at varying temperatures. Wear of the cast iron pin and friction coefficient were measured during each test and plotted as a function of sliding distance.

Two distinct temperature dependent wear behaviours were observed which can be attributed to the formation and oxidation of different surface oxides early on in the wear test. At low temperatures with higher dissolved oxygen content, iron (III) oxide formed rapidly and protected the metallic surfaces from further oxidation. At high temperatures, the dissolved oxygen content is lower; consequently green rust compounds formed which are less stable and easily removed. The corrosive wear process is accelerated by the constant removal and formation of these green rusts.

8:30 - 9am

Scuffing Resistance Evaluation of High Quality Gear Oils Technical Presentation Only. IJ TC2012-61260

Marc Ingram, Richard Baker, PCS Instruments, London, United Kingdom, Hugh Spikes, Imperial College London, London, United Kingdom

Scuffing can occur between sliding surfaces, during a complete breakdown of any hydrodynamic and boundary film. This leads to unprotected metal-
metal contact and subsequent catastrophic wear. The current scuffing evaluation methods are not able to accurately capture between gear oils containing high levels of EP additives. A testing method has been designed that utilizes a high pressure counter rotating contact. This accelerates the onset of scuffing by limiting lubricant entrainment while maintaining high sliding speeds. The occurrence of scuffing is easily identified by a large change in the measured friction coefficient, and can then be classified in terms of the sliding speed or applied load at failure, which can be increased stepwise or linearly. The new testing method is fast, repeatable and allows the differentiation of gear oils that contain a high concentration of EP additive.

9 - 9:30am
Adaptive Solid Lubricant Transfer Films for Conductivity and Oxidation Control
Extended Abstract. IJ TC2012-61157
-Patrick Doughtery, Cecily Sunday, C.F. Higgs III, Carnegie Mellon University, Pittsburgh, PA, United States
-The success of solid lubricants to exhibit ultralow friction and wear behaviors in oil-prohibitive environments, has led to a major effort to optimize their performance and enhance their applicability. Depending on the operating conditions, solid lubricants may take on a plethora of forms including fabricated composite coatings, thick quasi-hydrodynamic films, nano-particle additives for hard surfaces or liquid lubricants, and self-replenishing transfer films. One of the benefits of the latter, in addition to its self-replenishing characteristic is its freedom from complex deposition techniques required for most other solid lubricant systems. In this work, the adaptive natures of self-replenishing transfer films were augmented through the use of composite powders for both electrical conductivity and oxidation control. MoS2, WS2, and Graphite Powders were mixed in varying composition with Cu, Sb2O3, and BO3 additives and compacted to form tunable or adaptive self-replenishing transfer films. Relationships between friction, wear, electrical resistance, tribol-induced oxidation and powder composition, will be presented in order to investigate the potential of hybrid property optimization for lubricious, highly conductive, and oxidation resistant transfer films.

9:30 - 10am
Thin Liquid Film Lubrication Under the Influence Of External Electrical Fields
Technical Presentation Only. IJ TC2012-61094
-Guoxin Xie, Jianbin Luo, Dan Guo, Tsinghua University, Beijing, China, Chenhui Zhang, Tsinghua Univ, Beijing 100084, China, Jinjin Li, Liran Ma, Tsinghua university, Beijing, China
-The problems of the film formation and failure behaviors of nanoscale thin lubricant films under external electric fields are one of the current focuses in the tribological research field. The competition between the EEF effect and the intermolecular interaction between lubricant molecules on the behaviors and mechanisms of the film formation properties has been still unclear. In this presentation, the film formation properties of oil-based lubricants under EEFs have been investigated. The equations of the lubrication film thickness were determined by determining the elastohydrodynamic lubrication regimes of these lubricants. Then, the effective viscosities of the nanoscale thin lubricant films were calculated, and the mechanisms were analyzed on the molecular level. The variation trends of the effective viscosities of liquid aliphatic compounds under EEFs with the type of the headgroup and the alkyl chain length in the molecule were revealed. A molecular rotation model was constructed to calculate the mean relaxation time necessary for the molecular alignment along the EEF direction, and the theoretical analyses were compared with the observed phenomena. In addition, the result suggested that proper amount of polar additives could increase the resistance capacity of lubrication failure of charged oil lubricant films.

10 - 10:30am · BREAK
10:30 - 11am
Mechanisms of Friction Reduction of Glycerylmonooleate
Technical Presentation Only. IJ TC2012-61237
-Sophie Campen, Imperial College London, London, United Kingdom, Jonathan Green, Gordon Lamb, BP Global Lubricants Technology, Reading, United Kingdom, Hugh Spikes, Imperial College London, London, United Kingdom
-The additive glyceryl monooleate (GMO) has been widely used as an organic friction modifier in lubricants, and also to enhance the lubricity of diesel fuel. Despite its widespread use it is not yet clear how GMO reduces boundary friction, whether by direct adsorption from solution to form low shear strength monolayers, as is believed to occur with long chain fatty acids, amines and other surfactants, or whether it decomposes in rubbing conditions to form a lubricious decomposition product, either a free carboxylic acid or glycerol. This talk reviews the existing literature and describes new friction measurements on GMO and related materials in both sliding and rolling-sliding contact conditions, with the aim of understanding further how glyceryl monooleate contributes to reducing boundary friction.
round region. Small droplets have been observed to turn round in the turn-round region, with a diminishing droplet-size distribution. Moreover, by employing two different feeding modes, we have demonstrated a surprising discovery diametrically opposed to the traditional concept. The film formation has been detected to be distinctly enhanced under an insufficient feeding condition compared to the situation under a sufficient feeding condition. The unusual performance leads to a strong evidence of the reemulsification concept. Here, we demonstrate, directly from experimentally observations of emulsion behaviors, that the film formation of emulsion is significantly affected by the droplet behavior.

11:30am - Noon
Track Patterns in Grease Lubricated Rolling Contact
Technical Presentation Only. IJTC2012-61247
Jing Chen, Kyushu University, Fukuoka, Fukuoka, Japan, Hiroyoshi Tanaka, Joichi Sugimura, Kyushu Univ, Fukuoka, Fukuoka, Japan

This paper describes experimental study of behaviors of greases in rolling contact track and their relationship with rheological properties of the greases. Patterns produced by flow of several different types of greases at and around rolling contact track are observed on an optical microscope. The tested greases range from lithium soap greases and urea greases with the base oils of poly alpha olefin and poly esters, to perfluoro poly ether greases and silicone greases. In addition to rolling contact tests, rheological properties of the greases were determined with a cone-on-plate rheometer.

The grease lubricated tracks exhibited different features at the track and at the sides of the tracks. Firstly, the tracks looked uniform or non-uniform depending on deposition of grease, or grease thickeners, on the tracks. Secondly, the flow pattern of grease at the sides of the track showed clear or unclear patterns depending on the combination of the thickeners and base oils. The difference in the patterns is shown to be related with some particular characteristics found in their viscoelastic properties described by storage and loss moduli and stress strain relationship.

5C - TRACK 5 Fluid Film Lubrication
Track Chair: Daejong Kim, University of Texas at Arlington, Arlington, United States

5-5 - FLUID FILM LUBRICATION V
8am - Noon Tabor Auditorium
Session Organizer: Stephen Boedo, Rochester Inst Of Tech, Rochester, NY, United States

8 - 8:30am
Non-Linear Analysis of Floating Ring Annular Seals
Extended Abstract. IJTC2012-61147

-Mihai Arghir, Institut Pprime, Université de Poitiers, Futuroscope, France

-Carbon floating rings are used as efficient annular sealing devices enabling reduced leakage in rotating machinery. Low leakage is ensured by the small clearance of the annular gap between the floating ring and the rotor. Under normal operating conditions, the ring must be able to float on the rotor in order to accommodate its vibration. Impacts between the ring and the rotor are prohibited. The only contact occurs on the nose of the floating ring that is pressed against the stator by the pressure difference. If the vibration of the rotor and the trajectory of floating ring are both uniform whirs with the same angular speed but different amplitudes then the equations of motion of the floating ring have a quasi-analytic solution that was presented in a previous paper. The stability of the motion of floating ring following the whirling rotor was not addressed yet. The present paper starts by investigating this stability problem. The equations of motion of the floating ring describe a dynamic system with periodic coefficients. The stability is addressed by constructing the monodromy matrix and by analyzing its eigenvalues (the Floquet multipliers).

A full non-linear model of the floating ring is also developed. The non-linear model uses transient hydrodynamic forces between the floating ring and the rotor and transient friction forces between the nose of the floating ring and the stator. Impacts between the floating ring and the rotor can also be accommodated. The non-linear model is first used for verifying the results of the stability analysis. The model then enlightens many possible solutions for the floating ring trajectory beyond the stability limit. The trajectories which don’t contain impacts between the floating ring and the rotor can be considered as acceptable operating conditions.
chromium coated glass disk and a steel ball. Also only transient speed and load were taken into account. The method used to measured film thickness was thin film colorimetric interferometry. An high-speed digital camera was used in combination with high power xenon lamp to capture rapid changes of film thickness in the contact area. Servomotors and piezo-actuator were used to control the speed of contact surfaces and also the load of the contact during experiment.

The experimental results show that the change of speed has great impact on film behavior during sequences where opposite sliding or zero entrainment speed is involved. It was found that shallow grooves can behave as a reservoir of lubricant which can supply the contact area and increase the film thickness during above described transient phenomena.

9 - 9:30am
Nano-Texturing for Expansion of Hydrodynamic Lubrication Regime Technical Presentation Only. IJTC2012-61146
Tomoko Hirayama, Doshisha Univ, Kyoto J, Japan, Yusuke Tanaka, Doshisha University, Kyoto, Japan, Mitsutaka Ikeda, Doshisha University, Kyoto, Japan, Takashi Matsuoka, Doshisha University, Kyoto, Japan, Hiroshi Sawada, Kusuke Kawahara, Shunji Noguchi, Canon Machinery, Shiga, Japan.

To effectively reduce the friction in machines operating under lubrication, the sliding surfaces should be fully fluid-film lubricated. Under the full fluid-film lubricated conditions, the upper surface is completely supported by the lubrication film formed in the gap between the surfaces, resulting in the low friction and no wear. Surface texturing is a promising ways to modify the tribological properties of the sliding surfaces, and a technique for fabricating surface textures with a nanometer-order depth using a femtosecond laser can be used to easily and quickly produce periodic grooves in metal surfaces. It can thus be applied to industrial sliding surfaces to improve their tribological properties. The purpose of the study is to verify the effect of surface textures fabricated using femtosecond laser to reduce friction under lubrication. As the result, the two disks continued to operate under full fluid-film lubricated conditions even when the bearing clearance became quite small, less than 200 nm. Our testing showed that grooves with a nanometer-order depth can support a higher load than ones with a micrometer-order depth, and we proved that nano-texture can expand the full-lubricated condition.

9:30 - 10am
Friction in Starved Hydrodynamic Contacts Technical Presentation Only. IJTC2012-61234
Nans Biboulet, Universite de Lyon, INSA-Lyon, LaMCoS, CNRS UMR 5259, Villeurbanne, France, Antonius Lubrecht, Insa De Lyon, Villeurbanne 69621, France.

The hydrodynamic friction coefficient, which determines the friction coefficient at high Sommerfeld numbers (viscosity*velocity/load) has a unique solution for the fully flooded case. As such the friction coefficient can be predicted as a function of the above number.

As shown by Cameron [1] the friction coefficient in the fully flooded regime increases as the square root of the Sommerfeld number. For very low Sommerfeld numbers, theasperity interaction causes the friction coefficient to increase when entering the mixed lubrication regime.

Even though a unique (and low) friction coefficient exists in the fully flooded regime, the situation is more complex in the starved regime.

First of all the friction coefficient is higher in the starved regime, and secondly the coefficient depends on the degree of starvation.

As a consequence the friction coefficient for starved conditions is dominated by the Couette term.

The current paper analyses the friction coefficient evolution as a function of starvation for line and circular contact conditions.

10 - 10:30am - BREAK

10:30 - 11am
Squeeze film flow analysis using Moving Particle Semi-Implicit calculation Extended Abstract. IJTC2012-61161
Nobuyuki Hirooka, Elon J. Terrell, Department of Mechanical Engineering Columbia University in the City of New York, New York, NY, United States.

We have presented an application of the modified Moving Particle Semi-implicit (MPS) method for squeeze film flows. In addition to calculating the flow field of a squeeze film using the full Navier-Stokes equations, this method has the advantage of being meshless, which gives it the capability of analyzing dynamic and/or highly transient squeeze films by discretizing the domain as a series of particles and numerically analyzing inter-particle interactions. Although past literature has indicated the MPS method in its original form to be unstable in terms of its calculation of pressure, a modified algorithm was implemented to provide agreement between the numerical results and the analytical solutions.

11 - 11:30am
A Mixed Lubrication Based Wafer Scale Model for Chemical Mechanical Polishing
Technical Presentation Only. IJTC2012-61170

-Gagan Srivastava, Carnegie Mellon University, Pittsburgh, United States

Chemical mechanical polishing (CMP) is a material removal process that involves rubbing a workpiece under a load against an elastic polishing pad, in the presence of a chemically active abrasive slurry. The mechanical action in CMP involves hydrodynamic lubrication, solid contact and abrasive wear. A liquid slurry is entrained into the interface between the pad and wafer forming a lubricating film, which is modeled here using two dimensional Reynolds' Equation for average flow in cylindrical polar coordinates. The contact mechanics are modeled using a Winkler elastic foundation. At each time step, the resulting slurry hydrodynamic pressure distribution and contact stress are used to determine the equilibrium configuration of the system in the form of a nominal clearance, and roll and pitch angles. Local and wafer scale material removal rate (MRR) is predicted by assuming a normal distribution of particle sizes. Comparisons with previous studies show similarity in the MRR and hydrodynamic pressure profiles.

The current model provides a faster solution compared to previous models and higher accuracy as compared to wafer scale models. Potentially, it can provide high resolution solutions very quickly. Because of this, the model can prove to be more useful in an integrated framework for semiconductor design for manufacturing simulations which require fast, physics-based models.

11:30 - Noon
Two Dimensional Modified Reynolds Equation including pressure dependent viscosity effect

Extended Abstract. IJTC2012-61174

-Jung Gu Lee, Alan Palazzolo, Texas A&M University, College Station, United States

For the fluid film bearing analysis, the Reynolds equation plays an important role to predict pressure distribution in the fluid film. One of the assumptions on the Reynolds equation is that the viscosity is independent of pressure. This assumption is still valid for most fluid film bearing applications, in which the maximum pressure is less than 1 GPa. In elastohydrodynamic lubrication (EHL), the lubricant is subjected to extremely high pressure, however, the pressure independent viscosity assumption should be reconsidered. With considering pressure-dependent viscosity, the 2D modified Reynolds equation is derived in this study. The solutions of 2D modified Reynolds equation is compared with that of the classical Reynolds equation for the plain journal bearing and ball bearing cases. The pressure distribution obtained from modified equation is slightly higher pressures than the classical Reynolds equations.

6-3 - MACHINE COMPONENTS

TRIBOLOGY III

8am - Noon - Continental B

Session Chair: Joichi Sugimura, Kyushu Univ, Fukuoka, Fukuoka, Japan

8 - 8:30am

Diesel Engine Turbocharger Stabilized with Novel Tilting Pad Bearing Design

Extended Abstract. IJTC2012-61041

-R. Gordon Kirk, Virginia Polytechnic Inst, Blacksburg, VA, United States, Matthew Enniss, Daniel Freeman, Andrew Brethwaite, Virginia Polytechnic Institute and State University, Blacksburg, VA, United States

Many high speed turbochargers operate with limit cycle vibration as a result of fluid-film instability. This problem has been under investigation for the past seven years. Only now has a turbocharger with fluid film bearings been run to full speed and loaded, with essentially no bearing induced subynchronous vibration. The goal of this research was to have a stable synchronous response with a minimum of non-synchronous contribution excited only by the engine dynamics and exhaust pressure pulsations. Previous papers have documented experimental results of the fixed geometry bearing designs. This paper documents a new, modified tilting pad bearing concept that has replaced the fixed geometry bushings with minimal modifications to the stock bearing housing. The summary of the on-engine testing over the past year is documented in this paper.

8:30 - 9am

Polycrystalline Diamond Thrust Bearing Testing and Qualification for Application in Marine Hydrokinetic Machines

Extended Abstract. IJTC2012-61061

-Brent Lingwall, US Synthetic Bearings, Orem, UT, United States, Craig H. Cooley, Ussynthetic Corp, Orem, UT, United States, Tim N. Sexton, US Synthetic Corp., Orem, UT, United States

Polycrystalline diamond (PCD) bearings are designed for use in extreme environments; this includes process-fluid-lubricated applications such as those in oil and gas drilling turbines and marine hydrokinetic (MHK) energy machines. Past uses of PCD bearings in oil and gas down-hole tool applications have proven them to be robust, long lived, and rugged. To be effective in MHK machines, PCD bearings must demonstrate adequate bearing efficiency and life in a submerged marine environment not nearly as severe as an oil well bore or a gas well bore. This paper discusses the advantages PCD bearings could provide when used in underwater MHK energy machines. Laboratory test results are presented that can help predict the performance of PCD in these MHK applications. Results from three types of tests are presented including tests that measure bearing capacity, those that observe and qualify hydrodynamic properties during testing, and those that evaluate diamond wear rates through a test representing the life time of a bearing in a MHK energy application. Failure tests conducted to
improved algorithm is employed to analyse the effects of compressibility, piezoviscosity and shear-thinning on the lubricant properties. This formulation of the Reynolds equation using the concept of complementarity is suitably extended to measure bearing capacity revealed the PCD bearing could well endure conditions found in MHK applications, and coefficient of friction (COF) tests demonstrated the PCD ability to move from a boundary lubrication regime, to mixed mode lubrication, and then become hydrodynamic. The PCD wear test was designed to simulate years in the life of a tidal stream power generator, an MHK energy machine, and showed the PCD life is more than adequate for the MHK application. Bearing capacity, COF, and wear observed during laboratory testing illustrate that PCD thrust bearings can provide a robust, long lasting, and low maintenance effect.

-Kei Somaya, Toru Yamashita, Japan / Tokyo university of science, Tokyo Japan, Shigeka Yoshimoto, Tokyo University Of Science, Tokyo 162-8601 Japan

-Foil bearings have been attracting considerable attention for their applications to micro turbomachinery, such as blowers and compressors, because of their excellent stability at high speeds and durability in high-temperature environments. This paper investigates experimentally and numerically the high-speed instability of a rotor supported by small aerodynamic foil journal bearings. Two types of foil journal bearings were prepared: a first-generation bump-type foil bearing and a dimple-type foil bearing; these consist of a top foil and a support foil with bumps or dimples, respectively. The dynamic characteristics of a support foil using the frequency response and the threshold speed of instability at high speeds were measured experimentally. Furthermore, the numerical threshold speed of instability was obtained using the nonlinear orbit method. It was confirmed experimentally and numerically that a 6 mm diameter rotor with a mass of 4.7 g supported by either of the two types of foil journal bearing treated in this paper could rotate stably at speeds of more than 760,000 rpm.

9:30 - 10am
Experimental and Numerical Investigation of the High-speed Instability of Aerodynamic Foil Journal Bearings for Micro Turbomachinery
Extended Abstract. IJ TC 2012-61130

9:30 - 10am
Experimental and Numerical Investigation of the High-speed Instability of Aerodynamic Foil Journal Bearings for Micro Turbomachinery
Extended Abstract. IJ TC 2012-61130
-Young-Kwan Lim, Jong-Min Lee, Chong-Sub Jeong, Korea Institute of Petroleum Management, Chungbuk, Korea (Republic)

-The engine oil is an oil used for lubrication of various internal combustion engines. Recently, the vehicle and engine oil manufacturers have been investigating the possibility of using used engine oil to reduce the cost of driving by frequent oil change. In this study, we investigate the various properties for engine oil. The authors is capable of predicting the performance of journal bearings in the unsteady regime, where cavitation and reformation occur several times. Moreover, the effects of the pressure and the shear rate on the density and on the viscosity of the lubricant are taken into account.

9 - 9:30am
Analysis of the Lubrication Regimes at the Small End and Big End of a Connecting Rod of a High Performance Motorbike Engine
Extended Abstract. IJ TC 2012-61087
-Luca Bertocchi, Matteo Giacopini, University of Modena and Reggio Emilia, Modena, Italy, Daniele Dini, Imperial College London, London, United Kingdom

-In the present paper, the algorithm proposed by Giacopini et al. [1], based on a mass-conserving formulation of the Reynolds equation using the concept of complementarity is suitably extended to include the effects of compressibility, piezoviscosity and shear-thinning on the lubricant properties. This improved algorithm is employed to analyse the performance of the lubricated small end and big end bearings of a connecting rod of a high performance motorbike engine. The application of the algorithm proposed to both the small end and the big end of a con-rod is challenging because of the different causes that sustain the hydrodynamic lubrication in the two cases. In the con-rod big end, the fluid film is mainly generated by the relative high speed rotation between the rod and the crankshaft. The relative speed between the two races forms a wedge of fluid that assures appropriate lubrication and avoids undesired direct contacts. On the contrary, at the con-rod small end the relative rotational speed is low and a complete rotation between the mating surfaces does not occur since the con-rod only oscillates around its vertical axis. Thus, at every revolution of the crankshaft, there are two different moments in which the relative rotational speed between the con-rod and the piston pin is null. Therefore, the dominant effect in the lubrication is the squeeze caused by the high loads transmitted through the piston pin. In particular both combustion forces and inertial forces contribute to the squeeze effect. This work shows how the formulation developed by the authors is capable of predicting the performance of journal bearings in the unsteady regime, where cavitation and reformation occur several times. Moreover, the effects of the pressure and the shear rate on the density and on the viscosity of the lubricant are taken into account.

Reference papers
**Technical Presentation Only.** IJ TC2012-61242

- **Surajit Ghosh**, The Institution of Engineers (India), Kolkata, West Bengal, India, **Swarup Paul**, P.K. **Bose**, National Institute of Technology, Agartala, Tripura, India, **Bijan Sarkar**, Jadavpur University, Kolkata, West Bengal, India

- The fault diagnostic monitoring system of compression ignition (C.I.) engines always involves various conventional techniques, which sometime may not be supervised properly at micro level. To overcome this kind of situation, the procedure like lubricant analysis is quite an approachable methodology for health diagnosis system. It will help for predictive maintenance strategy of C.I. engines, which is also an economically feasible process. Nowadays, the fast and reliable diagnosis of engines has become a primary requirement for any organization. Apart from the traditional method, the C.I. engines are also quite accustomed with the non conventional fuel like biodiesel. In this technique, the level of pollution is not more than the conventional fuel. In the present work, the authors have tried to investigate the health diagnosis of C.I. engines through trito-analysis of used biodiesel. In this work, mainly wear particle analysis of C.I. engine has been given priority through which health diagnosis has been performed. A case study on C.I. engine has been done using biodiesel where vegetable oil with diesel blend have been utilized and after a fixed time interval, the used fuel has been collected for ensuring the severity of wear. Apart from the severity, the images of wear particles have also been thoroughly examined for wear characterization. The fractal mathematics has also been used for wear characterization. Finally, the authors have tried to explore the possibility of making decision on maintenance strategy of biodiesel C.I. engine.

11:30am - Noon

**Experimental and Numerical Investigation on Torsion Fatigue of Bearing Steel**

Technical Presentation Only. IJ TC2012-61263

- John A.R. **Bomidi**, Purdue University, WEST LAFAYETTE, IN, United States, Nick **Weinzapfel**, Purdue University, Lafayette, IN, United States, Farshid **Sadeghi**, Purdue University, West Lafayette, IN, United States

- Recent experimental and numerical modeling efforts reveal that a fundamental understanding of torsion fatigue of bearing steel is pertinent to rolling contact fatigue (RCF) investigations and bearing life predictions. This paper presents the results of experimental and numerical investigation on torsion fatigue of bearing steel. A Torsion Fatigue Test Rig (TFTR) was designed and developed with custom grip features to evaluate torsion fatigue life and failure mechanism of bearing steel hourglass specimen. A 3D finite element model was also developed to investigate fatigue damage in torsion and to account for crack initiation and propagation. Static and fatigue tests were conducted on the TFTR to obtain ultimate strength in shear (Sus) and Stress cycle (S-N) curves for torsion fatigue of bearing steel. Evaluation of the fatigue specimens indicate shear driven crack initiation followed by normal stress driven propagation, resulting in a helical crack path. In the numerical model, Continuum Damage Mechanics was employed in a Delaunay triangulated mesh of the hourglass specimen to provide unstructured inter-element paths for fatigue damage accumulation and crack evolution. Additionally, a new damage evolution procedure was implemented to capture the change in fatigue failure mechanism from shear to normal stress assisted crack growth, as observed in experiments. The progression of fatigue failure and the stress-life results obtained from the fatigue damage model are in good agreement with the experiments.

5E - TRACK 7 Contact Mechanics

Track Chair: **Jeffrey Streator**, Georgia Tech, Atlanta, United States

7-3 -CONTACT MECHANICS III

8am - Noon - Continental A

Session Chair: **Ivan Iordanoff**, 12M UMR CNRS 5295 Département DuMAS, Talence 33405, France

8 - 8:30am

**Excitation Model by Dynamic Transmission Error and Dynamic Characteristics for Helical Gear Pair**

Technical Presentation Only. IJ TC2012-61059

- Wenliang Li, Harbin Institute of Technology, Harbin city, China, Liqin Wang, Harbin Institute of Technology, Harbin, China

- This paper adopt the Monte Carlo method to calculate the manufacturing error and installation error of every meshing point along the time-varying contact line for helical pair. The meshing error is determined on the every contact point clearly. The flexural-torsion-axis dynamic model coupled is established and solved by the perturbation method, which make it possible to compute real dynamic tooth loads. The transmission error formulation is analyzed, which make it possible to introduce meshing excitations. The results about the maximum dynamic transmission error, maximum meshing force and maximum dynamic factor are calculated under the different speed, external loads and damping factor. The conclusions provide the theoretical basis for the gear design especially in tooth profile correction.

8:30 - 9am

**Molecular Dynamics Simulation Of A Rigid Sphere Indenting A Copper Substrate**

Extended Abstract. IJ TC2012-61079

- Ding Jia, Longqiu Li, Harbin Institute of Technology, Harbin, Heilongjiang Province, China, Andrey Ovcharenko, Western Digital Corporation, San Jose, CA, United States, WENPING SONG, Harbin Institute of Technology, China and University of California, San Diego, La Jolla, CA, United States, Guangyu Zhang, Harbin Institute of Technology, Harbin, Heilongjiang, China
It is of great interest to understand the elastic-plastic contact behavior in nanoscale for MEMS/NEMS devices. A lot of experimental work has been done on nanoindentation to investigate mechanical properties of materials on micro- and nano-scales. The molecular dynamics (MD) tool is a viable alternative to the traditional experimental approach and is an effective way to study the effects of various indentation conditions. In this work, molecular dynamics simulation is used to study the atomic-scale indentation process of the spherical diamond tip in contact with a thin copper (001) substrate. During the simulation, the diamond tip is considered as a rigid sphere and the substrate is assumed to be deformable. A controlled displacement method for normal loading and unloading, is employed in MD simulation. The embedded atom method potential is adopted to express the interaction between copper atoms, and the Morse potential is employed for the interaction between copper and carbon atoms, respectively. The load-displacement curve is obtained during MD simulation and is used to compare with the modified Hertz solution during elastic contact. The contact area as a function of the indentation depth is also investigated. During loading and unloading processes, the elastic-plastic behavior under different maximum indentation depths is analyzed to investigate elastic and plastic deformation. We observe that the load-displacement curve obtained from the MD simulation is in good agreement with the modified Hertz solution and the contact area is nearly proportional to the indentation depth.

9 – 9:30am
Effect of Surface Roughness and Lubricant on Scuffing
Extended Abstract. IJ TC 2012-61096
-Young Han, University of Turabo, Gurabo, P.R., United States
- Qian Zou, Oakland University, Rochester, MI, United States
-Scuffing failure generally occurs at oil film breakdown and large amount of metal-to-metal interaction between the contacting surfaces, where the role of surface roughness and lubricant becomes prominent. In order to evaluate the effect of surface roughness and lubricant on scuffing, scuffing simulation was carried out using contact mechanics and plasto-elastohydrodynamic lubrication model (MixedPEHL) by taking into account the plastic deformation in the contact area. The evolution of pressure, film thickness, contact area ratio, and subsurface effective plastic strain (EPS) was performed with three types of surface roughness and two different lubricants. Comparisons of pressure distribution, film thickness distribution, film thickness to surface roughness ratio (? ratio), and contact area ratio were described to investigate the effect of surface roughness and lubricants on scuffing behavior. A better understanding on the effect of surface roughness and lubricant on scuffing processes was obtained through research work.

9:30 – 10am
Direct Observation of Surface Transition during Scuffing in Dry Condition
Extended Abstract. IJ TC 2012-61139
-Kazuyuki Yagi, Naoya Ikeda, Kyushu University, Fukuoka, Japan
-Joichi Sugimura, Kyushu Univ., Fukuoka, Fukuoka, Japan
-Seiji Kajita, Toshihide Ohmori, Toyota Central R&D Labs., Inc., Aichi, Japan
-Takatoshi Shinyoshi, Atsushi Suzuki, Toyota Motor Corporation, Aichi, Japan
-This study investigates surface changes during scuffing in a dry condition. In tests a ball-on-disc apparatus was used, in which a rotating sapphire disc was loaded to a stationary steel ball. The contact area was directly observed and recorded by a digital camera attached to a microscope during the test. The variations in frictional force were synchronously measured with the capturing of images of the camera. After the test, the hardness of the scuffed steel ball were measured at different points in the contact area. The direct observation of the contact area shows that areas of macro plastic flow appeared from the trailing side of the contact area with a dramatic increase in frictional force. The macro plastic flow areas were changed, resulting in a dramatic expansion of the contact area. During the dramatic expansion, the friction coefficient kept a high constant value of about 0.4. The hardness distributions of the scuffed steel ball showed that the hardness was smaller at the trailing side of the contact area, in which macro plastic flows started, than that at the leading side. On the other hand the temperature rise calculated by a simple temperature estimation model was insufficient to cause the hardness reduction.

10 – 10:30am – BREAK

10:30 – 11am
Single Particle Interaction Properties: Investigations on the Coefficient of Restitution and Coefficient of Friction
Extended Abstract. IJ TC 2012-61165
-Martin C. Marinack Jr., Patrick Dougherty, C.F. Higgs III, Carnegie Mellon University, Pittsburgh, United States
-Understanding granular flows has always been important for predicting natural phenomena such as avalanches, rockslides, and soil erosion, as well as industrial processes such as coal-based fossil fuel systems, solids processing, and food manufacturing. As such, it becomes important to understand granular flows from both a classical granular flow and tribological perspective. Inherently important in the study of granular flows is the study of the individual particle-level interactions, which in turn define the global behavior of the flow. Two essential interaction (collision) parameters are the coefficient of friction (COF) and the coefficient of restitution (COR), which provides a way of accounting for the kinetic energy lost during the collision of materials. Accurate measurements of COR and COF are especially vital in order to obtain reliable particle-level data for discrete modeling approaches such as the discrete element method and cellular automata. The fidelity of these discrete modeling approaches hinges on the accuracy of particle-level physics defined by the COR and COF parameters. The current work examines both the COR and COF for various material combinations. The coefficient of restitution parameter for particle-boundary type collisions is studied through both experiments and
explicit finite element modeling of falling spheres colliding with thin stationary plates over a range of impact velocities. Characterization experiments are performed on various sphere-plate material combinations which include several tribologically relevant materials, such as low carbon steel, tungsten carbide, and NITINOL 60. Coefficient of friction and wear investigations are performed for various individual particle-disk material combinations using a pin-on-disk tribometer equipped with a linear variable differential transformer (LVDT).

**11:30am - Noon**

**Analysis of Contact Conditions Leading to Onset of Smearing in Concentrated Contacts**

**Technical Presentation Only.** IJ TC2012-61268

-A. Kadiric, Imperial College Of Science, London Sw7 2bx, United Kingdom

-Smearing damage most often occurs in large, slow rotating rolling element bearings during the roller entry into the loaded zone of the bearing when a significant amount of sliding between the element and raceways can take place. This investigation utilises existing contact mechanics models in combination with a unique smearing test rig to study contact conditions that may lead to onset of smearing.

The test rig simulates roller passage through loaded and unloaded zones of the bearing via an idealised set-up, where a free rotating barrel roller is repeatedly pinched between two driven bearing rings at a prescribed maximum load. The variation of roller rotational speed, acceleration, instantaneous slide-roll ratio and varying load is recorded. Contact mechanics models are used to predict the prevalent contacts conditions when smearing was observed and therefore attempt to provide suitable criteria for prediction of smearing onset. In particular, the contact pressures and deformations, heat flux and resulting temperature distributions are calculated and their importance on prevalent lubrication conditions and the likelihood of smearing are considered.

**5F - TRACK 8 Magnetic Storage Tribology**

Track Chair: Jeffrey Streator, Georgia Tech, Atlanta, United States

**8am – Noon - Magnetic Storage Tribology I**

Session Chair: Frank Talke, Univ Of California, La Jolla, CA, United States

**8 – 8:30am**

**Surface Properties of Magnetic Recording Media under Pulsed Laser Application in HAMR Technology**

**Technical Presentation Only.** IJ TC2012-61026

-Chang-Dong Yeo, Sungae Lee, Shahrukh Niazie, Texas Tech University, Lubbock, TX, United States

-The effects of laser heating on surface properties of magnetic recording media were systematically investigated through novel experiments and analytical simulations. When controlled laser pulses were applied onto the surface of a perpendicular magnetic recording (PMR) media, the measured values of surface roughness, surface free energy,
and surface adhesive force were significantly increased with the number of the applied laser pulses. The heat transfer modeling and simulation was performed to evaluate the change in surface temperature of PMR media by the pulsed laser. The resulting temperature was not high enough to affect the carbon film and the underlying magnetic materials, but it could change the properties of the molecularly thin lubricant film on the media surface. Based on the thermal stability of the perfluoropolyether (PFPE) lubricant, it was found that the change of surface properties in experiments could be attributed to the thermal degradation of the lubricant through desorption process.

From the experimental and analytical results, it could be concluded that the applied laser pulses gradually deteriorate the PFPE lubricant on the PMR media, and its surface properties dramatically change after a critical number of laser pulses. Therefore, if not correctly controlled, the laser heating can significantly change the surface properties of magnetic recording media, which thus can lead to unexpected tribological failures in head disk interface.

**8:30 - 9am**

**Experimental Study of Thermal Stability of Nanometer-Thick Diamond-Like Carbon Films in Thermally Assisted Magnetic Recording**  
**Technical Presentation Only.** IJ TC 2012-61027

-Norio Tagawa, Hiroshi Tani, Kansai University, Suita, Osaka, Japan

-In this study, experiments were performed to understand the thermal stability of 3-4 nm-thick CVD and FCVA films in thermally assisted magnetic recording. Disks coated with diamond-like carbon (DLC) films were heated up to 400-500 °C for 600 s using a conventional heater. The thermal stability of these films was studied by Raman spectroscopy and ESCA. In addition, the surface free energy of the DLC films was investigated. The results indicated that the change in I(D)/I(G) of DLC thin films was investigated. The results indicated that the measurement of the refractive index of heated disk substrates would be a simple and easy evaluation technique for studying heat-induced structural changes in DLC thin films because the refractive index and structural changes had a very good correlation. The refractive index-based method was also used to investigate the effect of the heating duration on the structural changes in the DLC thin films, and the associated results are discussed in this paper.

**9 - 9:30am**

**Flying Height Control Using Dual Thermal Protrusions in Heat Assistant Magnetic Recording (HAMR)**  
**Extended Abstract.** IJ TC 2012-61083

-Shaomin Xiong, Liping Li, UC-Berkeley, Berkeley, CA, United States, David B. Bogy, University of California, Berkeley, Berkeley, CA, United States

-Thermal flying height control technology has been used to approach sub-5nm flying height for higher storage areal density in the past few years. The slider dynamics behavior with a single thermal protrusion underneath the magnetic transducer has been widely investigated both experimentally and theoretically. In this paper, an air bearing slider with dual thermal protrusion is introduced to reduce the flying height modulation (FHM) and attenuate the external disturbance around the air bearing resonance frequency. This new scheme can be used in the HAMR systems, because the laser heating will result in an additional thermal protrusion around the magnetic transducer, while FHM protrusion is still necessary for flying height control.

Numerical simulation is conducted to investigate the feasibility of the dual thermal protrusion in HAMR. The air bearing system is simulated as a 2 degree of freedom (DOF) mass-spring model, and the disk waviness is regarded as a disturbance to the systems equilibrium flying state. The protrusions provide additional force and torque excitation to the slider, which can be regarded as a feedback loop to compensate the disturbance. The gain of the feedback loop depends on the stiffness of the protrusion, which is determined by the protrusion height and position. The pressure and normal force under the protrusion are obtained for various protrusion heights to calculate the stiffness around the protrusion by a CML Dynamic Simulator.

The FHM of the dual protrusion slider is reduced significantly when the protrusion height and location are optimized. The external disturbance induced FHM can be suppressed by tuning the height of TFC protrusion while keeping the laser induced protrusion unchanged, thus eliminating the need to change the power of the laser in the HAMR slider during the writing process. This scheme can benefit HAMR because it will provide a more consistent flying height and more freedom to compensate the external disturbance.
9:30 - 10am
Experimental and Numerical Investigations of the Light Contact Dynamics of Thermal Flying-Height Control Sliders
Technical Presentation Only. IJTC2012-61084

-Yung-Kan Chen, University of California at Berkeley, Berkeley, California, United States
-Jinglin Zheng, University of California at Berkeley, El Cerrito, CA, United States
-David B. Boggy, University of California, Berkeley, CA, United States

-Owing to the demand for ever increasing magnetic data storage needs, the air bearing sliders in hard disk drives now perform the read/write process with only a few nanometers separation away from the disk surface to achieve higher areal densities. Under such a challenging spacing some contact may occur between the slider and the surface of the lubricant that coats the disk is inevitable. Furthermore, a widely adopted technology using thermal flying-height control (TFC) on sliders brings the spacing between the slider and the disk surface at the read/write transducer down to the sub-nanometer regime. Therefore the understanding of the light contact dynamics is essential for designing a reliable slider/lubricant interface. In this paper, we report our experimental and simulation findings using multiple in-situ measurement techniques to identify distinct dynamical phases during the light touchdown process between the flying head and the ultra-thin perfluoropolyether (PFPE) lubricant layer in Angstrom-level. During the light touchdown process, we found three distinct dynamical phases as the power supplied to the heater increased, and they are termed as the states of flying, bouncing and surfing. Simulation results using a complete head-gimbal-assembly finite element model that incorporates the air bearing slider explains the frequency content seen in the experiments and suggests that a suspension-air-bearing coupled mode gets excited in the touchdown process. The surfing state is characterized by relatively low acoustic emission (AE) sensor and laser Doppler vibrometer (LDV) signals and by a distinct frequency content. Carefully calibrated optical surface analyzer (OSA) readings strongly suggest that the state of surfing occurs in the mobile layer of the ultra-thin PFPE lubricant. Experimental and simulation results indicated that the dynamics in light contacts are significantly affected by the sliders air bearing design, heater design and the property of the mobile layers of lubricant. It is concluded that the design mechanism of the mobile layers of lubricant are crucial for the stability of head-disk interface.

10 - 10:30am - BREAK

10:30 - 11am
Lubricant Flow and Evaporation Model for Heat Assisted Magnetic Recording Systems Including Reactive End-Group and Thin-Film Viscosity Effects
Extended Abstract. IJTC2012-61167

-Joanna Bechtel, David B. Boggy, University of California, Berkeley, Berkeley, CA, United States

- The lubricant applied to the disk in a hard drive is a critical component for head-disk interface reliability. In Heat Assisted Magnetic Recording (HAMR), the heat supplied to the disk by the laser will add new thermal considerations to lubricant performance. Experimental investigations of lubricant depletion under HAMR conditions are currently limited to relatively large laser spot sizes of approximately one micron in diameter and fairly long durations of irradiation on the order of microseconds. Investigations into how the lubricant behaves at the smaller time and length scales (nanoseconds and nanometers) seen in HAMR systems need to be conducted numerically. Published works on HAMR lubricant modeling have considered only the van der Waals contribution to disjoining pressure, commonly called the dispersive component. However, lubricants with reactive end groups such as Fomblin Zdol are widely used. These reactive end groups interact with the disk surface to cause oscillations in the disjoining pressure, meaning the lubricant-air interface can be attracted or repelled from the disk depending on the film thickness. In addition, published HAMR lubricant models do not consider the film thickness dependence of viscosity. Both effects are important to include in simulations of a monolayer polar lubricant. As the lubricant thins, more energy is required to move molecules past each other in viscous flow and also to excite a lubricant molecule into the vapor phase. Thus lubricant property film thickness dependencies beyond the van der Waals contribution to disjoining pressure should be considered in order to capture lubricant thin film behavior.

We have developed a simulation tool that incorporates experimentally determined thickness dependencies of evaporation, viscosity and disjoining pressure into a continuum lubrication model. While molecular simulation methods are limited to domain sizes of only a few molecules due to computational costs, continuum-based simulations with thin film effects are able to simulate system-scale domains so the whole track width can be considered. We investigate the effect of initial thickness on lubricant flow and evaporation under HAMR write conditions considering both components of disjoining pressure and thin film viscosity. Simulation results indicate the effect of including polar disjoining pressure depends on the initial lubricant thickness. The inclusion of viscosity thickness dependence does not affect simulation results under scanning laser conditions but will be important in reflow simulations.

11 - 11:30am
Evaluation of Head Wear Durability from Analysis of Asperity Contact and Replenishment Speed of Submonolayer Lubricant
Technical Presentation Only. IJTC2012-61197

-Kyosuke Ono, Tokyo Institute of Technology, Tokyo, Japan

-To achieve a high density recording above 1 Tb/in^2, near contact recording at a flying height of ~1 nm or on-demand contact recording will be needed. For this purpose it is important to develop a design methodology of reliable head-disk interface...
conditions allowing intermittent asperity contacts. This paper presents an evaluation method of head wear durability in relation to wear scar caused by asperity contact and the effective replenishment speed of sub-monolayer lubricant. Real asperity contact stress is numerically analyzed for a contact model between a spherical TFC head and disk considering sub-nanometer surface roughness and intermolecular attractive pressure. Possible wear scar width is evaluated in relation to asperity radius and height. The replenishment speed of sub-monolayer lubricant into the wear scar caused by asperity contact is analyzed by using two-dimensional long wave equation on the basis of continuum mechanics. The effect of the wear scar width and the effective thickness and physical properties of the mobile lubricant layer on the replenishment speed are discussed. An identification method of the effective properties of submonolayer lubricant is proposed. From some experimental data of the surface roughness of current magnetic disk and replenishment velocity to wear scar, head wear reliability and possibility of on-demand contact recording are discussed.

5G - TRACK 11 Symposium on Condition Monitoring
Track Chair: Mohsen Nakhaeinjad, University of Texas at Austin, Austin, United States

11-1 -CONDITION-BASED MONITORING AND MAINTENANCE
8am - Noon - Lawrence B

8 - 8:30am
Crack Detection in a Rotor Dynamic System by Vibrating Monitoring - Analytical and Experimental Results
Extended Abstract. IJ TC2012-61076
-Philip Varney, Georgia Institute of Technology, Atlanta, GA, United States, Itzhak Green, Georgia Inst Of Tech, Atlanta, GA, United States

As the power to weight ratio demand on rotodynamic systems increases, susceptibility to transverse fatigue cracking of the shaft increases as well. The ability to detect cracks in an early stage of progression is imperative for minimizing off-line repair time. A vibration monitoring system proposed prior is developed herein, employing the 2X harmonic response component of the rotor tilt as a signature indicating a transverse shaft crack. To effectively capture the 2X response, the crack model must include the local nature of the crack, the depth of the crack, and the stiffness asymmetry inducing the gravity-forced 2X harmonic response. The transfer matrix technique is well-suited to incorporate these crack attributes due to its modular nature. Two transfer matrix models are proposed to predict the 2X harmonic response. The first model applies local crack flexibility coefficients determined using the strain energy release rate, while the second incorporates the crack as a rectangular notch to emulate a manufactured crack used in the experiments. Analytic results are then compared to experimental measurement of the rotor tilt gleaned from an overhung rotor test rig originally designed to test seal face dynamics. The test rig is discussed, and experimental 2X harmonic amplitudes of the rotor tilt are provided for shafts containing manufactured cracks of depths between zero and 40 percent.

8:30 - 9am
Engine Oil Acidity Detection Using Solid State Ion Selective Electrodes
Technical Presentation Only. IJ TC2012-61011
-Mostafa Soleimani, University of Southampton, Southampton, UK, United Kingdom

-Engine oil quality monitoring has attracted considerable interests from industries and public over the years. Lubricating oil of moving parts is a critical factor for the performance and longevity of cars and industrial engines. In order to maximise the engine efficiency and useful life, lubricant oil change intervals should be optimised. If oil changes are left too late, the protective properties of oils start degrading and hence increase engine wear and even result in damage. On the other hand, premature oil changes should be avoided due to environmental and economical issues. Currently, automotive and lubricant industries are pursuing sophisticated and accurate approaches for real-time (on-line) monitoring of oil condition, by developing sensors for oil properties such as temperature, viscosity, acidity, etc. Many single physical and electrical property oil sensors as well as indirect methods (e.g. algorithm based) have been developed. However, due to the complexity of oil composition and degradation process, there have not been any reliable on-line sensors for monitoring the chemical properties of oil and changes in TAN and TBN values. Recently for chemical properties, attempts on miniaturising IR spectroscopies and Chronopotentiometric sensors based on solid-state devices have been reported for TAN (Total Acid Number) and TBN (Total Base Number) measurements.

This paper summarises the investigation in the feasibility of measuring oil acidity (i.e. TAN value) using ion selective electrodes fabricated utilising thick film technology. Thick-film (screen printing) technique is a very good means for mass production of rugged, compact and disposable sensors as many such devices can be printed at the same time making them very cost effective to manufacture. For monitoring the acidity of the oil samples, thick film ruthenium oxide (RuO2) pH sensitive electrodes (i.e. working electrodes) were used against silver/silver chloride (Ag/AgCl) reference electrodes as well as a commercial glass Ag/AgCl reference electrode. An array of the working electrodes and its compositional materials/layers is illustrated in Figure 1. The potentiometric sets of electrodes were initially calibrated in pH 4, 7 and 10 standard aqueous buffer solutions in a cyclic manner and the voltage was recorded. Graphs of voltage against pH were plotted while the gradient of the graph can provide the sensors sensitivity (Fig. 2). The experiments were carried out using seven artificially degraded oil samples, by adding different amount of nitric acid to Castrol Magnatec Fully Synthetic 5W30 engine oil, and six oil samples obtained from Shell Global Solutions. Shell oil samples are fresh Motiva Star 6
base oils (API Group II) which had already been oxidised at different time intervals (fresh, 2, 4, 16, 20 and 24 hours). For the experiments, the oil samples were heated to 50°C and 80°C in order to study the temperature effects on the oil samples.

9 – 9:30am
Condition Monitoring Enters a Holistic Stage
Technical Presentation Only. IJ TC2012-61169
Jack Poley, Kittiwake-Americas, Miami, FL, United States

-Oil analysis (OA) as a condition monitoring (CM) tool has existed for more than sixty years, but for more than forty years oil analysis was not able to join its sister primary non-destructive tool, vibration analysis (ca. 1970), to participate in real time condition monitoring.

Sensors developed previously were simply not robust enough to withstand the punishment from immersion in hot, often-contaminated oil. Although earlier electronics had performance and service issues, too, even when these circuits provided good information, the sensor would be highly susceptible to premature failure from construction quality issues.

Condition Monitoring (CM) has come of age in the 21st Century, where it is now possible to monitor machinery health from anywhere in the world, including where the machinery operates. Technology has followed demand for real-time information on machinery health, resulting in the development of an array of products and services with capabilities to fulfill such demands.

Real-time information must necessarily come from sensors, however, sensor data alone do not always have all the answers, any more than a blood pressure measurement in a doctor’s office can be considered a complete physical checkup. The components of a holistic CM program now consist of:

- Online Testing: Oil Parameter & Vibration sensing at the machine
- Onsite Testing:
  - Basic oil condition investigation, e.g., VIS, AN, BN, Soot (diesels), Water, Ferrous debris near the machine
  - Ancillary instrumentation, such as thermographic imaging
- Offsite Testing: Additional, comprehensive testing to supplement Online/Onsite results using traditional fixed-base laboratories
- Expert, automated evaluation and prompt delivery of results
- Statistical data rating (result Severity)
- Detailed, comprehensive commentary as to Actions and Reasoning for such actions
- A report delivered via the Internet to appropriate Stakeholders.

Enough time has elapsed that some case histories are beginning to build up, demonstrating:

- The vast improvements in Onsite test kits specifically configured for given types of applications and venues
- The virtual necessity of computerized assistance in sifting through all the data to

This paper will show some concepts and practical results from the inclusion of all three OA testing tiers, and the addition of an Intelligent Agent to perform the necessary data assessments and maintenance advisories to provide practical solutions for maintenance and other Stakeholders.

9:30 – 10am
Condition Monitoring and Fault Diagnosis of Antifriction Bearings via Vibration Measurement and Analysis - A Comprehensive Review and Some Case Studies
Technical Presentation Only. IJ TC2012-61067
Ramchandra Desavale, Annsaheb Dange College of Engineering & Technology, ASHTA, India, Venkatachalam Rapur, National Institute of Technology - Warangal, Warangal, Andhra Pradesh, India, S.P. Chavan, WCE, Sangli, Sangli, India

-Vibration monitoring and analysis of rotating machines give very important information about malfunctions those occur with machinery. It helps to judge health condition of machine as well as detects the faults. It also enables the maintenance department to plan the preventive action. This study highlights the conditioning monitoring and fault diagnosis of antifriction bearings, through vibration measurement and analysis.

6A - TRACK 4 Boundary and Thin Film Lubrication
Track Chair: David L. Burris, University of Delaware, Newark, DE, United States

4-6 -BOUNDARY AND THIN FILMS 5
1:30pm - 5:00pm - Horace Tabor
Session Chair: Thomas Zolper, Northwestern University, Evanston, IL, United States

1:30 – 2pm
Not All Silicone Fluids Are Created Equally
Technical Presentation Only. IJ TC2012-61136
Chad Chichester, Dow Corning Corp., Midland, United States, Andreas Stammer, Dow Corning Europe S.A., Seneffe, Belgium, Herbert Stoegbauer, Dow Corning GmbH, Wiesbaden, Germany

-Silicone fluids are known to have high Viscosity Indices (VI), and high Oxidation Onset Temperatures (OOT). Silicone VI and OOT characteristics make those fluids appealing for use as lubricants in high temperature applications, and where lubricant longevity is desired. Despite thermal and oxidative benefits, silicones lubricants have a reputation as being poor lubricants in metal-to-metal applications, and are typically only selected
for use in plastic applications. Most industrial knowledge about silicone lubricants is based on characteristics of PolyDiMethyl Siloxanes (PDMS), in which case, lubricity limitations do exist. However, there are other silicone based lubricating fluid technologies, that have been commercially available for decades, that far exceed known lubricity performance of PDMS, and in some ways can rival traditional synthetic hydrocarbon. Phenyl-Methyl Silicones (PMS), Fluoro Silicones (FS), and Alkyl-Methyl Silicones (AMS) can offer great performance, at high temperatures, due to the high VI and OOT, for which silicones are known, and their molecular structures enable improved lubricity as compared to PDMS, giving these unique silicones the combinatorial even in metal-to-metal applications. This paper will discuss and compare different silicone-based fluids, as well as some comparison to polyalphaolefins. Basic molecular structures will be reviewed, and comparative test data will shared. For example: SRV (Schwingungs-Reibungs und Verschleißtest) data, which is a test to quantify load carrying capacity of a lubricant film; 4-Ball wear scar data, a common measure of lubricant wear resistance; Viscosity Index, an indication as to how a lubricating fluids viscosity changes with temperature; and Differential Scanning Calorimetry (DSC), a measurement method used to identify temperatures, at which oxidation onset occurs. Following data sharing, a few ideas of potential applications examples will be presented.

2 - 2:30pm
Physical and Chemical Properties of Fatty Acids as Oiliness Additives
Technical Presentation Only.  IJ TC2012-61144

-Tomoko Hirayama, Masayuki Maeda, Doshisha Univ, Kyoto 610-0394, Japan
-Masato Nakashima, Doshisha University, Kyotanabe, Japan
-Takashi Matsuoka, Doshisha University, Kyotanabe, Kyoto, Japan
-Masahiro Hino, Kyoto University, Osaka, Japan

-Oiliness additives are commonly used in industrial machines, but the number of papers focusing on the properties of these additives is still relatively limited because of the difficulties involved in the analysis of layers that less than several nanometers. Our goal is to clarify the physical and chemical properties of oiliness additives by analytical techniques such as neutron reflectometry (NR), quartz crystal microbalance with dissipation monitoring (QCM-D), and infrared reflection-absorption spectroscopy (IR-RAS). In this investigation, some kinds of fatty acids were prepared as oiliness additives and mixed into a base oil. NR profiles were collected from metal surfaces in air, in the base oil and in the base oil with a deuterated acid using an angle-dispersive neutron reflectometer SUIREN at JAEA. The fringe interval in the profile from the surface in the base oil with deuterated acid was clearly narrower than that seen in the other profiles. This result supports the presence of an adsorbed additive layer on the surface. Fitting the curve using Parratt's theory showed that the layer thickness was almost same with the single chain length of acid. The mass of the adsorbed additives on metal surfaces was determined by means of QCM-D. The mass increased upon increasing the additive concentration in the base oil. The calculated layer thickness was similar to the value estimated from neutron reflectometry.

2:30 - 3pm
Siloxane Lubricants Utilizing Temporary Shear Thinning
Technical Presentation Only.  IJ TC2012-61077

-Thomas Zolper, Northwestern University, Evanston, IL, United States, Manfred Jungk, Dow Corning GmbH, Wiesbaden, Germany, Tobin Marks, Yip-Wah Chung, Qian Wang, Northwestern University, Evanston, IL, United States

-This work studies the rheological properties, elastohydrodynamic film, and friction coefficients of several siloxane-based polymers in order to examine their performance as lubricants. The molecular structures and masses were determined by means of nuclear magnetic resonance and gel permeation chromatography, respectively. The density and viscosity were measured at temperatures from 303 to 398K using a constant temperature bath with microprocessor control. Elastohydrodynamic film thickness and friction data of the fluids were obtained at loads and speeds representative of boundary, mixed and full film lubrication regimes. The results indicate that the shear characteristics of these siloxane lubricants can vary significantly with polymer length.

3 - 3:30pm - BREAK

3:30 - 4pm
Traction Fluids Utilizing Siloxanes with Ring-Shaped Branch Structures
Technical Presentation Only.  IJ TC2012-61159

-Thomas Zolper, Northwestern University, Evanston, IL, United States, Manfred Jungk, Dow Corning GmbH, Wiesbaden, Germany, Tobin Marks, Yip-Wah Chung, Qian Wang, Northwestern University, Evanston, IL, United States

-The molecular structures, rheological properties, and friction coefficients of several siloxane-based polymers were studied in order to evaluate their potential use as traction fluids. The molecular structures including branch content were determined by means of nuclear magnetic resonance. The molecular mass distribution of the samples was obtained with gel permeation chromatography. Density, viscosity, elastohydrodynamic film formation and friction were investigated over a temperature range of 303 to 398K. Film thickness and friction measurements were studied under the conditions that are representative of boundary, mixed and full film lubrication regimes. The friction measurements were made at several slide-to-roll ratios over an entrainment speed range of 0.025 to 5.00 m/s. The correlation of the molecular structures to the rheological properties and friction reveals how structural features affect the load and traction capacity of a siloxane film.

64
4 - 4:30pm
Spontaneous Change in Effective Viscosity of a Liquid Crystal by Surface Anchoring in an EHD Contact
Extended Abstract. IJ TC2012-61195
-Chiharu Tadokoro, Ken Nakano, Yokohama National University, Yokohama, Japan

The optical film thicknesses of a 0.1 mass% solution of hexadecanoic acid (HDA) in a nematic liquid crystal (i.e., 4-pentyl-4-cyanobiphenyl (5CB)) were measured in an EHD contact by using ultrathin-film interferometry. Comparing with a 0.1 mass% solution of HDA in an ordinary isotropic liquid (i.e., polyalphaolefin), the optical film thickness of the solution was increased at middle entrainment speeds (i.e., in the mixed lubrication regime). This shows that the effective viscosity of 5CB was increased with decreasing the entrainment speed, by the surface anchoring of 5CB on the boundary films formed by HDA. Using this spontaneous change in the effective viscosity, it is believed that a smart lubrication system can be realized, which optimizes the viscosity of a liquid crystal lubricant autonomously so that the friction coefficient is minimized when the entrainment speed is changed. It should be noted that this method does not need any pretreatments of contact surfaces and any external fields (e.g., an electric field or magnetic field).

6B - TRACK 5 Fluid Film Lubrication
Track Chair: Daejong Kim, University of Texas at Arlington, Arlington, United States

5-6 - FLUID FILM LUBRICATION IV
1 - 5pm - Tabor Auditorium

1 - 1:30pm
Misalignment Effects in Compliant Tilting Pad Journal Bearings
Technical Presentation Only. IJ TC2012-61186

-Matthew Cha, Sergei Glavatskih, KTH Royal Institute of Technology, Stockholm, Sweden

The influence of misalignment effects (static and dynamic) on compliant tilting pad journal bearings with different pad support geometries and loading configurations are investigated. Two different pad support geometries are considered; line and ball-socket pivots for load between pivot (LBP) and load on pivot (LOP) configurations. Tilting pad journal bearings can decrease the misalignment moment (reduce maximum oil film pressure and increase minimum oil film thickness) compared to fixed geometry bearings. Compliant liner can further improve the bearing static and dynamic performance. Ball-socket pivot can even further decrease misalignment effects by providing self-adjustment to the load in the axial direction.

Different taper geometries are implemented at the pad sides to reduce the misalignment effects.

1:30 - 2pm
Determination of dynamic coefficients in a hydrodynamic journal bearing based on the 3-D Navier-Stokes equations and considering cavitation effects
Extended Abstract. IJ TC2012-61192

-Changhu Xing, Utah State University, Logan, UT, United States, Minel Braun, University of Akron, Akron, United States

-Dynamic coefficients are very important for the stability of the journal bearing. In order to determine the stiffness, damping and added mass coefficients of the hydrodynamic bearing, the finite perturbation method around its stabilization position was employed. Based on the Reynolds equation with Gumbel cavitation algorithm, the maximum magnitude of the perturbation was judged by comparing results from finite perturbation to those from infinitesimal perturbation as well as theoretical analysis. With the determined perturbation, the full three-dimensional Navier-Stokes equations in CFD-ACE+ were used to evaluate coefficients from an actual lubricant and compared to those obtained with Reynolds equation. Finally, a homogeneous gaseous cavitation algorithm is coupled with the Navier-Stokes equation to establish the pressure distribution in the bearing. When gas concentration was varied, the pressure distribution as well as the dynamic coefficients changed significantly.

2 - 2:30pm
Effect of Surface Microstructure on Friction and Torque in a Rotating System
Technical Presentation Only. IJ TC2012-61203

-Frank Horvat, Minel Braun, University of Akron, Akron, OH, United States

-This presentation investigates the effect of surface texturing in a rotating system containing a journal and a partial bearing whose contact surface is machined for different microstructure where the depth and density of the imprinted profiles are parametrically changed. The basic choice shape is a diamond format which is precisely burned into the lucite surface of the partial bearing.

The system is instrumented with Schaevitz LVDT with a precision measurement capability of ±10-4 in and a Omega 25lb load cell with a bias error of ±0.1lbf. This allows for simultaneous determination of fluid film thickness and resulting forces. The journal powering the system is connected through a Himmelstein torquemeter (0-350 in.lb) to a 5 HP variable speed DC motor. The journal and the pad are immersed in a bath which part of an overall enclosure. The working fluid is a light oil of 6-8 cP and thermocouples measure its temperature changes during operation.

A National Instruments data acquisition system is used for controlling and monitoring the operation.

The results include force, torque and friction graphs presented as a function of journal speed, film thickness and type of microstructure used.
Influence of Water-In-Oil Mixture as a Lubricant on Hydrodynamic Bearing Performance

Elias Harika, Institut Pprime - CNRS - University of Poitiers - ENSMA, Chasseneuil du Poitou, France

Extended Abstract.

It is well-known that water has better thermal characteristics than the oil. Even though, in the world of bearings, the use of water as a lubricant is still restricted to some applications, where water is the only possible lubricant, like in marine applications for example. For all the other bearings, the presence of water in lubricant circuits is a dangerous anomaly. The literature shows well the damaging effects of this contamination, but studies are commonly based on analysis of results obtained after the failure of bearings. This paper presents a study of the effects of the water-in-oil mixture on hydrodynamic lubrication for significant levels of water concentration, up to 10% by mass. The aim of the work is to identify the conditions for which the presence of water can be detrimental. If not, the effects on lubrication of water-in-oil mixture worth to be studied, in order to test the possibility of finding new lubrication concepts. Thus, the rheological behavior and thermal characteristics of the mixture (density, specific heat, thermal conductivity) have been numerically modeled and simulations of bearings operating with this mixture were performed. Only the case of fine emulsion (droplet diameter less than 20µm) was considered, while the continuous phase was a mineral oil containing no additives. The lubrication characteristics were experimentally measured on a tilting pad thrust bearing, showing the same effects than those obtained numerically. The presence of water has a slight effect on lubrication. Moreover, this effect is an improvement of the lubrication characteristics. Indeed, it is found that pure oil could be replaced by a water-in-oil emulsion having the same viscosity. In this case, the film thickness and the friction coefficient will be weakly modified whereas the bearing will run with a lower temperature.

3 - 3:30pm - BREAK

Performance Evaluation of Journal Bearings used in Sugar Mills using Taguchi Method

Muzakir S M, Hirani Harish, Indian Institute of Technology, New Delhi, India

The Indian sugar mills use journal bearings to support the cane crushing rollers. These bearings are used continuously for a season (lasting about four to six months) and often encounter premature failures. This premature failure of the bearing is due to the mixed lubrication condition that exists due to very high operating loads and slow speeds of rollers. It will be valuable to use an experimental optimization method to establish the correlation between the operating parameters of load, speed, clearance and lubricating oils. In the present research experimental Taguchi method has been employed. A set of 16 bearing were fabricated (at a reduced scale of 50 mm) with radial clearances varying from 30 to 50 microns and grouped into eight categories. The controlled experiments on reduce scaled bearing are to be conducted. The experimental results indicating the effect of varying the clearance and lubricating oils on the wear rate and frictional force will be analysed and reported.

Development of a New Jet Test Machine on Slurry Erosion

Jixin Zhang, Janchun Fan, Laibin Zhang, Xin Jiang, China University of Petroleum, Beijing, China

Erosive wear of materials encountered in multiple phase flow is a very complex process that can be affected by many factors including the properties of multiple phase flow and target material. Although more and more researchers pay attention to erosion phenomenon and a few impact wear testing structures were already proposed, they presented major limitations and the stress-loading of the test sample usually has not been considered. In petroleum industry, casing, coiled tubing, fracturing manifolds usually bear large pulling force and slurry erosion depredation of materials inner surface. So research on materials erosion wear resistance under tensile stress state should be indispensable.

A new type of test machine was developed to simulate the erosive wear behavior of material caused by the multiphase fluid such as drilling mud, slurry or other fracturing fluid in the oil and natural gas production. In this paper, a tribo-system model for materials sample, solid particles in the multiphase fluid and the slurry is presented and the tribological interaction relationships are analyzed in detail. The framework of the test rig is introduced based on the system model; the structure and the principle of the test rig are demonstrated. Furthermore, the control methods of key test conditions such as specimen stress condition, fluid velocity, and impact angle are illustrated. The on-line detection measure of the specimen erosion wear is described. Finally, some preliminary test results obtained by this test rig are...
shown. Wear patterns on the specimens reveal that multiphase flow is similar to that predicted theoretically. By means of applying different pull load on the specimen, the effect of the stress on erosive wear can be investigated, the results reveal that the stress condition on specimens have a remarkable effect on the erosive wear, meanwhile the sensitivity for the test results to small variations in the dimensions of specimen or specimen position can be overcome.

2 - 2:30pm
The Importance of Extreme Pressure Cyclic Load in Molybdenum Disulfide Greases Using 4 Balls Wear Tests
Extended Abstract. IJ TC2012-61005
-gabi nehme, University of Balamand, Lebanon North, EL-KOURA, Lebanon
-Grease is a product consisting of several additives and ingredients that can interact synergistically or antagonistically. Molybdenum Disulfide greases have been in use for the past decades and have found application extensively in extreme pressure situations.

In this study, Design of Experiment approach will be used to analyze the cyclic load vs. different speeds and different time to examine the lithium base grease wear behavior with and without molybdenum disulfide (MoS2). The 4 ball wear tests were conducted to examine the extent of wear in greases following ASTM 2266 standard to predict the wear behavior. The grease is heated to 75°C and the test was run using several DOE conditions and the wear scar was measured at the end of the specified period. Design of Experiment (DOE) was used to analyze several factors, since the traditional approach of examining one factor at a time (OFAT) is time consuming. The limitation of OFAT is the large number of experiments that are needed to evaluate products and multifactor interactions to reach high desirability. DOE approach systematically varies the test conditions such as applied load, duration of the test and speed to examine the outcome in the wear tests. It is also possible to determine the interaction between several factors simultaneously.

The goal of this study was to examine the cyclic load conditions and their influences on the wear properties of lithium base grease under a variety of conditions such as different rpm speeds and different time durations. Two compositions of this grease with 3% MoS2 and without MoS2 were developed to address the importance of cyclic load applications.

2:30 - 3pm
Research on Erosion Wear of High Pressure Elbow in Hydraulic Fracturing Operation
Technical Presentation Only. IJ TC2012-61184
-Jixin Zhang, Jianchun Fan, Laibin Zhang, Xin Jiang, China University of Petroleum, Beijing, BEIJING, China
-Erosive wear of materials encountered in multiphase flow is a very complex process that can be affected by many factors including the properties of multiple phase flow and target material. The fracturing fluid with solid particles (fracturing proppants) in the process of high-speed injects to high pressure pipe manifolds will cause serious erosion damage lead to serious material loss and equipment failure, especially on elbow area. Thus the prevention of erosive wear on high pressure pipeline is regarded as one of the most important problems in practical engineering. In this paper, Computational fluid dynamics (CFD) analysis has been successfully used to predict erosion behavior in high pressure manifolds geometries that are highly susceptible to erosion. A new type of test machine was developed to simulate the erosive wear behavior of the high pressure pipe manifolds specimens caused by the multiphase fluid to study the erosion failure mechanism by various influencing factors including the velocity of multiphase flow, solid particles of fracturing proppant and impact angles, etc. Results from the study of typical failure high pressure pipe manifold geometries used for oil and gas production and the macroscopic erosion experimentation are compared with the CFD analysis techniques to study the solid particle erosion process showing good agreement. Finally, the microscopic surface testing was also used to analyze the erosion failure mechanism for metal materials used for high pressure pipe manifold.

3 – 3:30pm – BREAK

3:30 - 4pm
Influences of Trace Water in Hydrogen and Argon on the Tribological Properties of Pure Iron
Extended Abstract. IJ TC2012-61204
-Kanao Fukuda, Malaysia-Japan International Institute of Technology, Kuala Lumpur, Malaysia, Masaaki Hashimoto, Kyushu University, Fukuoka, Fukuoka, Japan, Joichi Sugimura, Kyushu Univ, Fukuoka, Fukuoka, Japan
-The authors have studied the influences of a hydrogen environment on tribological properties of various materials because of the increasing interest on hydrogen as an energy carrier for renewable energies. The studies have revealed some influences of hydrogen on tribological properties and the influences implied several mechanisms with which hydrogen influence the tribological properties. One of the findings was that trace impurities i.e. water and oxygen which are inevitably involved in a practical hydrogen environment influence tribological properties substantially and often even govern them. Further study was carried out using a newly developed pin-on-disk apparatus equipped with a devised gas replacement system to separate the influences of water and oxygen. The study clarified that only water with virtually no oxygen in a hydrogen environment gives obvious influence on the tribological properties of pure Fe sliding on the same material.

In this study pure Fe sliding was investigated in an argon environment with different water concentration ranged between 1 to 10,000 ppb and virtually no oxygen i.e. less than 7 ppb. The experimental conditions including environmental conditions used for this study are same as those for the previous study except for a main experimental gas which is altered from hydrogen to argon. By comparing experimental data obtained in argon with
our previous data obtained in hydrogen the difference between these two environments are found as follows. The coefficient of friction of pure Fe in hydrogen is almost constant at around 1.0 for the variation of water concentration while that in argon decreases with increase of water concentration. The scattering of data is found larger in argon especially for low water concentration. The specific wear rate of a disk specimen in argon is obviously larger than that in hydrogen and those in both gas environments show little variation for different water concentrations. The specific wear rate of a pin specimen show almost same value and variation in hydrogen and argon. The rates in both gases decrease with increase of water concentration and those at around 10,000 ppb become one tenth of those at around 2 ppb. The comparison described above suggest that both a hydrogen gas and trace water which is involved in either hydrogen or argon have lubricity for pure Fe, however, whether hydrogen and water have synergy effect on tribological properties was not clarified. 

4 - 4:30pm
Self-organization and Friction during Sliding

Extended Abstract. IJ TC2012-61219

- Pradeep Menezes, University of Wisconsin Milwaukee, Milwaukee, WI, United States
- Kishore Kailas, Indian Institute of Science, Bangalore, Karnataka, India
- Satish Vasu Kailas, Indian Institute of Science, Bangalore 560012, Karnataka, India
- Michael Lovell, University of Wisconsin-Milwaukee, Milwaukee, WI, United States

-Friction and wear are irreversible processes which normally lead to material deterioration. Under certain circumstances, friction can lead to self-organization or increased orderliness when various secondary structures are formed at the frictional interface. In the self-organized process, the surfaces adjust to each other, leading to a more ordered state demonstrating friction-induced self-organization. In this study, various kinds of textures, unidirectional, 8-ground and random, were attained on the steel surfaces. For a given texture, roughness of the surfaces was varied using different grits of emery papers or polishing powders. Then pins made of pure Mg were slid against prepared steel surfaces at various numbers of cycles using pin-on-plate reciprocating sliding tester. Tests were conducted at a sliding velocity of 2 mm/s in ambient conditions under both dry and lubricated conditions. A normal load of 35 N was applied in the test. The morphologies of the worn surfaces of the pins and the formation of transfer layer on the counter steel surfaces were observed using a scanning electron microscope. Roughness parameters of the steel surfaces were measured using an optical profilometer. In the experiment, it was observed that the coefficient of friction and transfer layer formation depend on the surface textures under both dry and lubricated conditions. Irrespective of initial surface textures, all surfaces self-organize to a particular kind of surface texture after certain number of sliding cycles. As regards to friction under lubricated conditions, the coefficient of friction decreases for unidirectional and 8-ground surfaces while for random surfaces it increases with number of cycles. Under dry conditions, the coefficient of friction increases with increasing number of cycles for all kinds of surface textures. The variation in the coefficient of friction under both dry and lubrication conditions is attributed to the self-organization of surfaces during sliding.

6D - TRACK 7 Contact Mechanics

Track Chair: Jeffrey Streator, Georgia Tech, Atlanta, United States

7-4 - CONTACT MECHANICS IV
1:30 - 5:00pm - Continental A
Session Chair: Jeffrey Streator, Georgia Tech, Atlanta, United States

1:30 - 2pm
Friction Force Distribution along Time-varying Contact Line in Helical Gear System

Extended Abstract. IJ TC2012-61031

- Wenliang Li, Harbin Institute of Technology, Harbin city, China
- Liqin Wang, Harbin Institute of Technology, Harbin, China

-Over recent decades, many attempts have been made by so many authors to establish the models in order to simulate the dynamic behaviour of gears pairs. The different mathematical models to date have generally neglected the contribution of tooth friction force in gear system. Recently, sliding friction between gear teeth has been recognized as a potentially significant excitation and its powerful influence on the vibro-acoustic behaviour of gears has been demonstrated by Vaishya and Houser. The helical gear was divided into infinite slices, every slice was deemed to be a spur gear. The elastic potential of a spur gear were composed with bending component , the compressive component and the shear component .Based on the theory of energy minimization, a numerical algorithm was developed to calculate friction force distribution along the time-varying contact line in helical gear system. The elastic potential is a function of profile geometric parameters. The friction force acts on the contact line, the friction force varies with the variation of contact line. In this paper, we adopt the coulomb friction factor to calculate the tooth friction force .The friction force was calculated on every meshing point of time-varying contact line via the algorithm. The results show that the friction force distribution varies with the instantaneous position of the meshing point and the length of contact line. The friction force becomes larger from the tooth root to the pitch point and becomes smaller from the pitch point to the tooth tip. Due to this, there is a significant shock at the pitch point which will generate noise and vibration. The changing law of friction force distribution provides a fundamental theory for modification shape design and impact reduction.

2 - 2:30pm
Numerical Analysis of Distributed Inhomogeneities and Their Effect on Rolling Contact Fatigue Life

Extended Abstract. IJ TC2012-61156
3 - 3:30pm - BREAK

3:30 - 4pm
Variation of the Thermal Properties During Friction Under Shock Conditions
Extended Abstract. IJTC2012-61213
- Guillaume PEILLEX, CEA, Arpajon, Essonne, France, Patrick Le Tallec, Ecole Polytechnique, Palaiseau CEDEX, France.
Franck Dambaki zi, CEA, Arpajon, Essonne, France (Metro)
-During friction under shock conditions, interface is submitted to very strong heat flux. Thus, it may reach a temperature as high as melt temperature of one of the materials constituting the contact. As a consequence, the income and outcome of heat at the interface governs the friction and the contact behavior. This article exposes a model that resolves the non-linear heat equation in the vicinity of the interface. This way, it takes into account the variations of thermal properties of materials constituting the interface. First results indicate that such variations influence the tribological behavior of the contact.

4 - 4:30pm
Elasto-plastic Analysis of a Contact under Normal and Torque Loading
Extended Abstract. IJTC2012-61032
-Pengyang Li, Xi'an University of Technology, Xi'an, Shaanxi, China, Zhanjiang Wang, Chongqing University, Chongqing, China, W. Wayne Chen, Schlumberger, Houston, TX, United States, Xiaoqing Jin, Northwestern Univ, Evanston, IL, United States, Yan Li, Xi'an University Of Technology, Xi'an, Shaanxi, China, Qian Wang, Northwestern University, Evanston, IL, United States
Rolling contacts involving a spin load are commonly seen in engineering systems, such as railway wheel, rolling bearing, and ball drive mechanisms. The contact pressure and subsurface stresses may be high under certain conditions, which will cause plastic deformation in the contacting surfaces or the subsurface materials. Understanding the plastic flow problem of these contacts requires the modeling of contact subjected to spinning; and this paper presents a spinning rigid sphere pressed against an elasto-plastic half space under combined normal and torque loading.

A three-dimensional numerical model for simulating the spinning contact of a rigid sphere and an half space is developed. Elasto-plastic contacts were solved by using conjugate gradient method (CGM) and fast Fourier transform (FFT) technique for improving numerical efficiency. The effects of plastic deformation are included by superimposing the normal residual displacement to the geometry of plastic deformation. The elastic results based on present method are compared with analytical solution to validate the current model. The histories of stress, strain, residual displacement, and plastic strain volume integral (PV) are investigated in this paper. The results of the spinning contact obtained from four different hardening laws are presented. The effects of friction coefficient and the normal load on the spinning contacts are investigated. The surface pressure, subsurface stress, total Von Misses stress, the first yield point, plastic strain fields and evolution of the plastic region are further analyzed.

Results show that the application of the torque shifts the maximum Von Mises stress and plastic region in the half space closer to the surface; the whole plastic region also move near the surface. Moreover, the position of the first yield point also moves closer to the surface. Furthermore, the evolution of the plastic region, i.e., the yield maps, with increasing load are drawn, which shows more complex shapes than those from only under normal load conditions.

8-2 - MAGNETIC STORAGE
TRIBOLOGY II
1:30 - 5:00pm - Molly Brown
Session Chair: Kyosuke Ono, Tokyo Institute of Technology, Tokyo, Japan

1:30 - 2pm
A Thermo-Mechanical Finite Element Analysis of Light Sliding Contact at the Head-Disk Interface
Extended Abstract: IJ TC2012-61063
- Yuliang Liu, Harbin Institute of Technology & University of California, Berkeley, CA, United States, Jia Lou, Harbin Institute of Technology, Harbin, Heilongjiang, China, David B. Bog, University of California, Berkeley, CA, United States, Guangyu Zhang, Harbin Institute of Technology, Harbin, Heilongjiang, China

-As the data areal density has increased in hard disk drives, the head-disk clearance has been reduced to less than 5 nm by using thermal flying-height control (TFC) sliders. Under such a low flying height, some sliding contact, causing scratching of a TFC slider on a rotating disk in a hard disk drive (HDD), is inevitable, and the stability of the head-disk interface can be affected. So research into the effect of the magnetic recording layer thickness t and various sliding contact parameters (i.e. friction coefficient ?, normal load F) on the temperature variation and mechanical deformation at the interface of the contacting bodies is important for the design of a more reliable HDI.

In this paper a three dimensional finite element model of a rigid sphere lightly sliding over an elastic-perfectly plastic multilayered media under thermo-mechanical surface loading is developed in order to investigate the thermal and mechanical responses during the light sliding contact of a spherical corner of a slider with a rotating disk. The effects of the magnetic recording layer thickness t and sliding contact parameters on the maximum temperature Tmax at the slider-disk contact interface and maximum scratch depth h on the disk are analyzed for both glass and aluminum disks.

The results show that the magnetic layer thickness t has a small effect on the maximum temperature Tmax at the slider-disk contact interface and maximum scratch depth h on the disk for both types of disks, but the sliding contact parameters strongly affect the temperature variation and mechanical deformation of the HDI. Also, the temperature needs to be considered as a main influence factor for the glass disk. However, the mechanical deformation is more of a concern for the aluminum disk. Finally, in order to obtain good contact characteristics of the HDI, it is important to control the normal load F applied onto the slider, reduce the friction coefficient ? at the contact interface, and choose the appropriate disk type.

2 - 2:30pm
Bearing Forces in Mobile Molecularly Thin Lubricants for Magnetic Storage
Technical Presentation Only. IJ TC2012-61102

-Shahla Chowdhury, University of Illinois at Urbana Champaign, Urbana, IL, United States, Antonis Vakis, University of Cyprus, Nicosia, Nicosia, Cyprus, Jorge Hanchi, Seagate Technology, Minneapolis, MN, United States, Andreas A. Polycarpou, University of Illinois Urbana-Champaign, Urbana, IL, United States

-Mobile molecularly thin lubricant (MTL) layers under very high shear rate provide a certain amount of bearing resistance at the interface. This phenomenon is very important, for example, in the head-disk contact in magnetic storage to ensure that some of the contact may be sustained by the mobile lubricant layer. However, the amount of bearing resistance that the MTL layer can provide depends on several factors, with the most important being temperature, viscosity of the lubricant, sliding
velocity and radius of gyration of the lubricant molecules. In this work, a modeling investigation showed that viscosity has the greatest effect on the load bearing capacity of the MTL. Thus, by controlling the flash temperature and the ratio of MTL-to-bulk viscosity, the bearing load carrying capacity of the MTL can be controlled. This would allow for the contact to ratify within the mobile lubricant layer, avoiding solid contact so as to protect the diamond-like carbon coating. Such operation would reduce wear at the head-disk interface of hard disk drives.

2:30 - 3pm
Effects of Mechanical Contact Stress on Magnetic Properties of Ferromagnetic Film Poster Presentation Only. IJ TC2012-61103
-Chang-Dong Yeo, Sungae Lee, Muyang He, Texas Tech University, Lubbock, TX, United States
-Mechanical and magnetic degradation of ferromagnetic films under contact stress was systematically investigated through novel experiments. Permalloy (NiFe) film was deposited onto silicon substrate, and two different thickness of permalloy film (Sample A-50 nm and Sample B-300 nm) was examined in this study. For the two samples, the intrinsic magnetic strength (i.e., magnetization and coercivity) was obtained from B-H loop tracer hysteresis measurement, while the mechanical strength (i.e., hardness and elastic modulus) was measured using nanoindentation techniques. It was observed that the 50 nm thick permalloy film showed lower magnetization but higher hardness values. To apply mechanical contact stress on the permalloy film samples, nanoscratch experiments were performed using ramp loading and constant loading scratch profiles. Then, the resulting mechanical degradation (elastic to plastic deformation) was determined from Atomic Force Microscope (AFM) measurement, and the corresponding magnetic degradation was analyzed using Magnetic Force Microscope (MFM) measurements. It was found that the magnetic degradation was more sensitive to the applied contact stress than the mechanical degradation. Comparing the two thickness samples, it was observed that the 50 nm thick permalloy film showed more magnetic degradation under the same contact stress, which could be attributed to its intrinsic magnetic strength rather than the mechanical strength.

3 - 3:30pm - BREAK

3:30 - 4pm
Transient Thermo-mechanical Plowing Contact between Rigid Sphere and Elastic-plastic Sphere
Extended Abstract. IJ TC2012-61115
-WENPING SONG, Harbin Institute of Technology, China and University of California, San Diego, La Jolla, CA, United States,
-ANDREY OVCHARENKO, Western Digital Corporation, San Jose, CA, United States,
-LONGQIU LI, GUANGYU ZHANG, Harbin Institute of Technology, Harbin, Heilongjiang, China,
-FRANK TALKE, Univ Of California, La Jolla, CA, United States
-Transient thermo-mechanical contact between a rigid sphere sliding over an elastic-plastic sphere with a larger radius is studied using finite element analysis. Plastic deformation and temperature rise in the contact zone between the two spheres are investigated.

4 - 4:30pm
The Onset of Plastic Yielding in a Coated Spherical Shell Compressed by a Rigid Flat Technical Presentation Only. IJ TC2012-61188
-ZHENQIANG TANG, South China University of Technology, Guangzhou, China, LA JOLLA, United States,
-ANDREY OVCHARENKO, Western Digital Corporation, San Jose, CA, United States,
-WENPING SONG, Harbin Institute of Technology, China and University of California, San Diego, La Jolla, CA, United States,
-FRANK TALKE, Univ Of California, La Jolla, CA, United States,
-WEI XIA, South China University of Technology, Guangzhou, China, Guangzhou, Guangdong, China
-Contact between a spherical shell and a flat is a common problem in contact mechanics. A typical example for this situation is, for instance, the dimple/gimbal interface of a suspension in a hard disk drive. In order to improve the tribological properties of mechanical components, thin film coatings are widely used in industry, such as cutting tools, optical systems and hard disk drives. In particular, hard coatings, including diamond-like carbon coatings and ceramics coatings, have been used to reduce wear during intermittent contacts and continuous sliding. However, the selection of thin films is generally performed by trial and error, and fundamental research in the contact behavior of coated spherical shells loaded by a rigid flat is highly desirable. It was shown in recent studies of elastic-plastic spherical contact [1] that critical values at yield inception can be used to normalize contact parameters of elastic-plastic contacts in order to develop a universal dimensionless model.
-In this paper, the onset of plastic yielding in a spherical shell with a hard coating compressed by a rigid flat is investigated using finite element analysis. A non-dimensional solution is obtained for critical load, critical interference and critical contact area. The location of yield inception is analyzed and a universal dimensionless coating parameter is identified that controls the yield inception behavior of the coated spherical shell system. The effect of spherical shell geometry, coating thickness and material properties of both coating and substrate are investigated.

REFERENCES

4:30 - 5pm
Graded Carbon Embedding in the Magnetic Media for Better Tribological and Corrosion Performance Technical Presentation Only. IJ TC2012-61239
Carbon embedding using filtered cathodic vacuum arc technique with a graded structure in the top layer (~1.5 nm) of the magnetic media is evaluated for its tribological and anti-oxidation properties. Cobalt is used as the magnetic material. The surface modification is obtained by using ion energies of 60 eV and 90 eV successively to embed carbon in the top surface of the Co media. The developed technique showed promising results in terms of tribology and anti-oxidation, demonstrating its potential to be used in the surface modification of the media surfaces for higher areal densities.

Auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy are used to characterize the graded layer in terms of its thickness and chemical composition. Ball-on-disk wear tests and atomic force microscopy based scratch tests are conducted on the bare cobalt and modified cobalt surface to characterize the wear resistance. It is observed that the wear life and scratch resistance of the cobalt surface improved considerably after surface modification. Moreover, the modified cobalt surface with the graded structure showed a low coefficient of friction of ~0.2 when compared to the bare cobalt surface (~0.7) and a commercial media (~0.4) which has a carbon overcoat of 2-3 nm and a lubricant layer of 1-2 nm. AES and XPS analysis on the modified surface showed a significant improvement in the oxidation resistance of the surface when compared to the bare cobalt surface.
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