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MFPT
The Society for Machinery Failure Prevention Technology
Pursuing prognostics and health management capabilities for military and commercial systems

Assigned Session: A 1 Signal Analysis 1

Presenting Author: Domenic Boos **Ser:** 2

Organization: RWTH Aachen

Country: Germany

Paper Title: **Data Reduction Approach – Acoustic Emission (AE) Based Defect Analysis: Development of Burst Detector Algorithms**

Co Authors: F. D. Boos, R. Baltes, F. Toutounchi, K. Nienhaus, and S. Denault

Abstract:

Acoustic emission (AE) techniques offer the potential for new techniques of condition monitoring of bearings, especially for very large roller bearings with slow rates of rotation. Acoustic emission data processing must be carried out by a computer, necessitating algorithms to process recorded signals. One such algorithm is a burst detector, used to identify emission events. This paper deals with the design of a burst detector with the goal of improving upon existing algorithms. The algorithm has the benefit of detecting small amplitude and overlapping bursts, as well as supplying additional information about the decay portion of the burst.

Assigned Session: A 1 Signal Analysis 1

Presenting Author: Behrad Bagheri **Ser:** 29

Organization: Center for Intelligent Maintenance Systems (IMS), University of Cincinnati

Country:

Paper Title: **A Computational and Accuracy Based Evaluation of Automated Algorithms for Mechanical System Health Assessment and Fault Classification**

Co Authors: Behrad Bagheri, David Siegel, and Jay Lee

Abstract:

The increasing demand of using automated algorithms for fault diagnosis and health assessment in current industry is undeniable. Consequently, implementing emerging technologies such as cyber physical systems, cloud computing in prognostics and health management algorithms is inevitable. Due to these improvements and the emerging Big Data environment, optimizing algorithms for consuming less process and network bandwidth but generating high accuracy is important. Considering these factors, in this research, we propose a generic fault diagnosis framework for rotating machineries with variant methods and parameters for different steps of the algorithm. Methods, such as Fast Fourier Transform and Wavelet Transform for signal processing and Artificial Neural Networks and K-Nearest Neighbor for fault classification are considered in this study. This framework is applied to a gearbox and bearing system in order to evaluate the effect of simplicity in the overall performance of prognostic and health management algorithms. Finally, results of this paper shows that precise selection of methods and parameters will eliminate the requirement of using more complex and computationally expensive methods.

Assigned Session: A 1 Signal Analysis 1

Presenting Author: Bob Randall **Ser:** 58

Organization: University of New South Wales

Country: Australia

Paper Title: **Order Tracking under Run-up and Run-down Conditions**

Co Authors:

Abstract:

In recent years there has been considerable interest in the analysis of machine vibration signals in the presence of speed variations, sometimes over wide ranges. A typical application is to wind turbines, where the most efficient systems allow the speed to vary by ±30%. This amount of speed variation can just be accommodated by phase demodulation based order tracking techniques because it is at the limit of where the sidebands around the second harmonic of a tacho signal just start to overlap with those around the first (a range from 2/3 to 4/3 of the mean, or roughly 2:1). To analyse a complete run-up or run-down, however, obviously requires analysis with a speed range much greater than 2:1. This paper shows how it can be achieved by dividing the signal into overlapping segments, in each of which the speed range is less than 2:1. Complementary windows are used in the overlap sections, so that the processed signals can simply be added in those regions to give one continuous signal in the order domain. In the order domain, the highest frequency to be retained is proportional to the speed, and so at lower speeds the required sampling frequency can be reduced accordingly, as long as higher frequency components are first removed to avoid aliasing. The paper explains how this can be done in the most efficient way. The speed reference signal can be a once-per-rev tacho, a multi-pulse-per-rev encoder signal or can be extracted from the signal itself under certain conditions which are explained in the paper. The paper discusses the pros and cons of the different approaches, with respect to the possible applications of the results.

Assigned Session: A 1 Strategic Perspectives and Business Case Analysis

Presenting Author: Chris Hockley **Ser:** 24

Organization: Cranfield University, EPSRC Centre for Through-Life Engineering Services

Country: UK

Paper Title: **Identifying the True Cost of No Fault Found (NFF) within the United Kingdom Ministry of Defence (MOD)**

Co Authors: Chris Hockley

Abstract:

Availability is a key requirement for the Armed Forces yet the occurrence of faults where no attributable reason can be established still threatens to reduce the required availability and still causes nugatory maintenance effort. Such faults with no apparent cause are usually described in the UK as No Fault Found (NFF) and in USA as Retest OK (RTOK) or Can Not Duplicate (CND); their occurrence remains a huge and disruptive effect on the successful delivery of through-life customer support. Whilst commercially it causes huge loss of revenue, in the military environment, costs are often less obvious and hidden, yet may be much higher. This lack of visibility of the true cost is a worrying trend that must be tackled as the UK Armed Forces reduce in size as it will have a more significant operational and financial impact. A study of MOD's NFF occurrences has been conducted by the EPSRC Centre for Through-Life Engineering Services in order to establish more accurate costs and to establish the key reasons and causes. Whilst the study has so far concentrated on the air environment where information is most readily available, the research and lessons learned are applicable to other industries.

Assigned Session: A 1 Strategic Perspectives and Business Case Analysis

Presenting Author: Mike Roemer **Ser:** 4

Organization:

Country:

Paper Title: **Integrated Health and Contingency Management for Flight Critical Systems**

Co Authors:

Abstract:

The technology to be presented is based on a novel health monitoring and fault accommodative reconfigurable control architecture for autonomous vehicles with redundant control effectors. The primary components of this technology include: 1. A system identification module which is capable of identifying faults in critical components in real-time. This module is driven by a strong tracking online system identification technique which is based on a Regularized Recursive Least Squares algorithm. As an improvement for fast detection and tracking, a change detection scheme and a time varying forgetting factor have been developed. When a change in prediction residuals is detected, a smaller forgetting factor is utilized to discount 'old' data and place more weight on the latest measurements and identified model. The continuously identified model (changes as faults progress) is used not only for the fault detection scheme but also in the control algorithm itself to accommodate for fault conditions. 2. A reconfigurable control allocation method which compensates for degradation of the various control effectors by adjusting the manner in which the high level control signal is distributed to the individual effectors. For example, consider a multi-rotor helicopter UAV or redundant flight control system. High level control signals consist of force and moment commands, and the control allocation algorithm is a physics-based algorithm which takes into account the fixed geometry of the vehicle (i.e., the location of the motor/rotor assemblies on the UAV) and their variable health (i.e., ability to generate thrust).

Assigned Session: A 1 Strategic Perspectives and Business Case Analysis

Presenting Author: Ron Eshleman **Ser:** 33

Organization: Vibration Institute

Country:

Paper Title: **Some Reflections on Machinery Vibrations during Procurement and Acceptance**

Co Authors: Ronald Eshleman

Abstract:

The procurement process including selection, specification, and testing for acceptance for rotating machinery is described with emphasis on machine vibration. Several situations where things often go wrong are described.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Mohammad Azarbayejani **Ser:** 38

Organization: University of Texas-Pan American, Civil Engineering Department

Country:

Paper Title: **Implementing an Efficient SHM System into a Steel Model Bridge**

Co Authors: Mohammad Azarbayejani, Sebastian Salinas, David Renteria, and Francisco Cantu

Abstract:

Structure Heal Monitoring (SHM) systems have been implemented over the past decades to detect early damage caused by external forces and environmental effects acting on large-scale structures. An effective decision can be taken based on the evaluation of the damage in order to ensure a good performance of the current structure. In this paper, a SHM system is implemented on a model steel truss bridge; piezoelectric accelerometers are sending signal vibrations due to the traffic on the bridge to module NI 9234 of a NI Compact Rio - 9022 (cRIO). Field-programmable gate array (FPGA) housed in the cRIO process all the data information. Optical Sensing Interrogator sm125 system is connected to the cRIO to obtain strain measurement, Fiber optic Bragg Grating (FBG) which is connected to it facilitates this process. Three different scenarios are introduced on this investigation to present damage situations similar in a real bridge. Based on the data obtained at different states of the bridge and using the finite element model of the brisge, Monte Carlo simulation is implemented as the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. The method used on the model bridge can be implemented on real structures to enhance a damage detection process.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Brandon Van Hecke **Ser:** 23

Organization: The University of Illinois at Chicago

Country:

Paper Title: **A New Acoustic Emission Sensor Based Bearing Fault Diagnostic Technique**

Co Authors: Brandon Van Hecke, Yongzhi Qu, and David He

Abstract:

Bearing fault diagnosis by quantifying acoustic emission (AE) data has been an area of interest for recent years due to the numerous advantages over vibration based techniques. However, most AE based methodologies to date are data-driven technologies. This research takes a new approach combining a heterodyne based frequency reduction technique, time synchronous resampling (TSR), and spectral averaging to process AE signals and extract condition indicators (CIs) for bearing fault diagnosis. The heterodyne technique allows the AE signal frequency to be shifted from several MHz to less than 50 kHz, which is comparable to that of vibration based techniques. Then, the digitized signal is band pass filtered to retain the information associated with the bearing defects. Finally, the tachometer signal is used to time synchronously resample the AE data to allow the computation of a spectral average and the extraction of CIs for bearing fault diagnosis. The presented technique is validated using the AE signals of seeded fault steel bearings on a bearing test rig. The result is an effective physics based approach validated to diagnose all four fault types: inner race, outer race, ball, and cage.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Mike Scott **Ser:** 70

Organization: The Modal Shop

Country:

Paper Title: **Calibration of Industrial Vibration Protection Systems**

Co Authors:

Abstract:

Industrial machinery vibration protection systems are relied upon to ensure continued uptime and productivity while protecting the safety of those that work in and around the machines they monitor. How do we know these systems are functioning properly? Performing calibration and system checks on the plant floor is one method to ensure alert & alarm levels are functioning and data used to determine potential shutdowns and repairs is valid. A wide variety of sensing technologies and data acquisition options can be verified using back-to-back sensor calibration methods.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Michael Bryant **Ser:** 3

Organization: University of Texas at Austin

Country:

Paper Title: **Application of Information Theory's Channel Capacity as an Industry Machine Health and Diagnostic Metric**

Co Authors: Ted Costuros and Michael Bryant

Abstract:

A metric for degradation quantification, and assessment of machine health was constructed from an analogy between a machine and a communications channel. The metric is based on Shannon's channel capacity concept applied to the difference between measured signals (induced by faults) and baseline signals of a machine system response. Machine faults that hinder operation also alter signal flow through a machine system; the effects appear as a residual signal riding on a baseline signal. Similar to noise hampering data transmission, this residual signal can be viewed as noise within the context of information theory, permitting application of information theory to machines, resulting in a health measure for assessment of machine health.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Lim Meng Hee **Ser:** 16

Organization: Universiti Teknologi Malaysia

Country: Malaysia

Paper Title: **Machinery Fault Diagnosis Using Polar Wavelet Analysis**

Co Authors: Lim Meng Hee and Salman Leong

Abstract:

Most of the mechanical faults that occur in rotating machinery are repetitive in nature, of which the same forcing mechanism recur once per revolution. The ability to visualize these forcing mechanisms over a complete rotational cycle would provide crucial information about the characteristics of the faults and thus enables a more prudent fault diagnosis to be undertaken. The feasibility of using polar wavelet analysis to provide visualization of the cyclical forcing mechanism of faults in a rotor system is studied in this paper. An experimental study was conducted to simulate various machinery faults namely rotor eccentricity, stage rubbing and creep induced rubbing in a rotor system. Subsequently, polar wavelet analysis was applied to analyze the vibration response of the rotor. Experimental results showed that the characteristics of faults such as blade rubbing mechanism in the rotor could clearly be seen in the polar wavelet plots. Polar wavelet analysis is therefore deemed to be an excellence tool to visualize the cyclical force in a rotor and thus making fault diagnosis more intuitive and effective.

Assigned Session: B 1 Diagnostics 1

Presenting Author: Shuai Wang **Ser:** 11

Organization: State Key Laboratory for Manufacturing System Engineering

Country: P R China

Paper Title: **Statistical Analysis of the Vibration of Mistuned Centrifugal Compressor Impellers with Crack Damage**

Co Authors: Shuai Wang, Yanyang Zi, Minquan Zhang, and Zhengjia He

Abstract:

Statistical analysis of the effects of random mistuning on the nonlinear vibration of a cracked impeller of centrifugal compressor is presented and used to calculate the statistical characteristics of the forced response and the distribution of frequencies. Based on a finite element model, a hybrid interface method of component mode synthesis (CMS) is employed to generate a reduced-order model (ROM) of the cracked impeller. The degrees of freedoms on the crack surfaces are retained in the ROM so that the crack breathing effects can be simulated. Random mistuning is modeled by introducing small variations in Young's modulus of each blade. Then, the resulting nonlinear equations are solved by applying multi-harmonic balance method. Probability distributions of the forced response and frequencies of the mistuned impeller are obtained by a numerical Monte Carlo simulation and are used to calculate means and standard deviations. The results show that as the crack length grows, resonant frequencies tend to decrease, which is a potential feature for crack detection.

Assigned Session: C 1 Sensors

Presenting Author: Richard Roth **Ser:** 43

Organization: Etegent Technologies

Country:

Paper Title: **Mechanical Waveguide Vibration and Temperature Sensors for Monitoring Gas Turbine Engines**

Co Authors: Chris Larsen, Richard Roth, and Oleg Lobkis

Abstract:

Solid, mechanical waveguide sensors have been demonstrated for health-monitoring in the gas turbine environment. These sensors can be made of any material which conducts ultrasound; examples made of stainless steel, high-temperature aerospace alloys, and ceramics are presented here. Mechanical waveguides can be configured to measure temperature, pressure, heat flux, strain, and vibration. This paper presents results for two different waveguide-based sensors – a vibration sensor, and a temperature sensor. The waveguide vibration sensor was demonstrated for monitoring main-shaft bearings in a Rolls-Royce 501KB5+ industrial turbine engine. A high-temperature version was demonstrated in the exhaust of this engine for monitoring the #4 bearing at the turbine outlet; this requires survivability in the approximately 760°C (1400°F) exhaust stream. Additionally, a waveguide temperature sensor was demonstrated for turbine inlet temperature measurement in the same industrial turbine engine. This sensor provides accurate temperature measurement in combustion gases at over 1100°C (2000°F).

Assigned Session: C 1 Sensors

Presenting Author: Pratichi Vaidya **Ser:** 34

Organization: NTNU Norway

Country: Norway

Paper Title: **Smart Sensors for Technical Health Assessment of Subsea Oil and Gas Equipment**

Co Authors: Pratichi Vaidya

Abstract:

Life extension is becoming an important and highly discussed issue in the subsea oil and gas industry. Decision-making related to life extension is a multidisciplinary exercise and the primary factor that influences the decision is the remaining useful life. Models being used by nuclear and avionics industry for remaining useful life prediction are based on the operational data. In subsea oil and gas industry a lack of sufficient operational data does not make it possible to use similar models. Data acquisition from subsea equipment is a unique challenge due to remoteness of installations, water depth, and environmental conditions. Attempts for developing new techniques are being made by suppliers of sensors, subsea instrument, and subsea equipment. The challenge however is not only limited to technical enhancements of individual components but also to the need of interoperability among them. The paper gives an overview of the ongoing work on the development of smart devices and the common communication standards which will aid data transfer within the sea and from deep sea to a topside control room. Acknowledging that this is a big leap forward towards determination of remaining useful life, the paper especially focusses on the steps towards standardization, taken as a joint effort by subsea suppliers, contractors and operators. The paper explains how this technology will be useful in subsea oil and gas industry for technical health assessment.

Assigned Session: C 1 Sensors

Presenting Author: Harvey Niska **Ser:** 60

Organization: Honeywell Aerospace Co

Country:

Paper Title: **Measurement Systems and Sensors for Gas Turbine Engine Development**

Co Authors:

Abstract:

Standard instrumentation used today for the development and qualification of gas turbine engines rely on traditional sensors such as thermocouples, pressure sensors, strain gages, accelerometers, proximity probes, and others. The integration of new technologies into engine test will reduce development cost and accelerate schedules. The engine test community is currently focused on developing these new sensors and measurement technologies that will also address hot section measurements with improved sensor reliability. These measurements will provide data to address hot section hardware durability, engine reliability, and reduce mean time between overhaul (MTBO). Of prime interest are measurements of flow path dynamic phenomenon, hot section rotating component vibration, component temperatures, and mapping of gas path temperatures.

The OEM gas turbine engine community supports new test cell instrumentation sensors and systems maturity, and their transition into Engine Health Monitoring (EHM), Structural Health Monitoring (SHM), and integrated Vehicle Health Monitoring (i VHM). Optical sensors and systems are and will be playing a large part in the future of engine test. Health monitoring objectives will require reliable sensors and measurement systems with an order of magnitude improvement in life. Confirmation of computational fluid dynamics (CFD) models and improved engineering component and thermal design tools will result.

This presentation will explore current the TRL for sensor and measurements technologies that are being developed, matured, and deployed into engine development test and EHM.

Assigned Session: A 2 Prognostics 1

Presenting Author: John Lacontora **Ser:** 15

Organization: Drexel University

Country:

Paper Title: **Intelligent Maintenance Systems: Vehicle Health and Usage Tracking**

Co Authors: John Lacontora and Melvin Mathew

Abstract:

Over the last two decades, Intelligent Maintenance System (IMS) has emerged as an enabler for manufacturers and owners of complex systems to significantly increase their systems reliability and lower the overall cost of ownership. IMS health monitoring and analysis tools have the potential to determine the remaining useful life of components and subsystems resulting in a considerable reduction of operation and maintenance costs.

Assigned Session: A 2 Prognostics 1

Presenting Author: Thomas Lagö **Ser:** 54

Organization: QirraSound Technologies Europe AB

Country: Sweden

Paper Title: **Effective Accuracy Control for CBM Applications**

Co Authors: Thomas Lagö, Alan Boyer, and Valdi Ivancic

Abstract:

Controlling amplitude accuracy is an old concept. It is common to calibrate sensors to 2% and specify temperature drift and many other parameters for sound and vibration measurements. However, the sensor is typically not the main “error contributor.” Instead, measurement practices, algorithm errors and faulty data collection principles are the main error sources. One unfortunate thing with these errors is that they are deterministic and hence averaging does not make them go away or decrease. We strive for success concepts in CBM and we strive for a better understanding and clever strategies. However, the basic assumptions for the measurements and analysis principles used is sometimes forgotten or “ignored.” This can then lead to large amplitude errors and hence mislead the following analysis, classification and prognosis. This paper describes some of these errors and how incorrect conclusions and results may occur. By understanding these errors and why they exist, it is possible to mitigate and/or minimize their impact on the end results. Common challenges could be improper selection of anti-aliasing filters and/or sampling rate versus the filter bandwidth and roll-off rate. Another challenge is related to the fact that analyzed signals not obeying the required properties, may result in large amplitude errors. The background to the challenges is discussed, and typical solutions or strategies to avoid such errors are presented.

Assigned Session: A 2 Prognostics 1

Presenting Author: Jae Myung Yoon **Ser:** 21

Organization: University of Illinois at Chicago

Country:

Paper Title: **An Efficient Prognostic Estimator**

Co Authors: Jae Yoon, David He, and Paula Dempsey

Abstract:

In this paper, a new prognostic estimation technique for online gear health management system is proposed and demonstrated with real spiral bevel gear run-to-failure test data. Unlike conventional particle filter based prognostic estimation methods, the prognostic technique presented in this paper is a hybrid of the unscented Kalman filter and particle filter. It is designed to improve the processing efficiency whilst the state estimation accuracy is maintained. The unscented Kalman filter is utilized to obtain the “best estimate” of the states of a degrading nonlinear component and the particle filter l-step ahead prediction technique is employed to obtain the remaining useful life of the component. In addition, data mining techniques are applied to efficiently define the system dynamics model, observation model, and predicted measurement information for the prognostic estimator. At last, the feasibility of the presented prognostic estimator is demonstrated with satisfactory results using the actual oil debris mass and health index data obtained from a spiral bevel gear test rig at the National Aeronautics and Space Administration (NASA) Glenn spiral bevel gear test facility.

Assigned Session: A 2 Prognostics 1

Presenting Author: Thomas Lagö **Ser:** 55

Organization: QirraSound Technologies Europe AB

Country: Sweden

Paper Title: **New E-learning Systems for CBM Applications**

Co Authors: Thomas Lagö and Valdi Ivancic, and Alan Boyer

Abstract:

Today, there are multiple educational platforms for CBM applications like the simulators from e.g. SpectraQuest that can be used by individuals. For many students, it would be an advantage to include both sound and vibration like “touch and feel” in these simulator platforms. The Swedish company SenseGraphics [1] offer an open software platform that enables “touch and feel.” This is often referred to as “haptics” originated from the Greek words haptikos and hapthesthai, which means to grasp or to touch. They have already, together with partners, implemented simulators for medical, dental and multiple other applications. Qirra Sound has developed a platform for reinforced sound that is able to make sound so realistic that it does not feel like there are any loudspeakers. This technology would be very useful in educational simulators where even the sound and vibration aspect would be included. In Sweden, another project known as VISIR™ (Virtual Instrument Systems in Reality) was initiated together with National Instruments in the USA, to disseminate an online laboratory concept created using open source technologies in collaboration with other universities and organizations. The concept is about adding a remote operation option to traditional instructional laboratories to make them more accessible, irrespective of whether the students are on campus or mainly off campus. This paper will discuss an educational concept combining these technologies for CBM applications and how that would benefit students worldwide.

Assigned Session: A 2 Prognostics 1

Presenting Author: Shankar Sankararaman **Ser:** 45

Organization: SGT Inc., NASA Ames Research Center

Country:

Paper Title: **Significance of Uncertainty Quantification in Prognostics and Health Monitoring**

Co Authors: Shankar Sankararaman and Kai Goebel

Abstract:

This paper discusses the significance of uncertainty quantification in prognostics and health monitoring, which are important for failure prevention and risk-informed decision-making with respect to the operation of engineering systems. Since there are several sources of uncertainty that affect the future loading and operating conditions of these engineering systems, it is important characterize and quantify these sources of uncertainty, and quantify their combined effect on future prediction. Failure threshold levels are defined and used to quantify the remaining useful life, which is also uncertain due to the aforementioned sources of uncertainty. It is important to quantify the overall uncertainty in the remaining useful life using principles of probability, since this information is directly useful for risk-informed decision-making. Methods for such uncertainty quantification are discussed and illustrated using a numerical example.

Assigned Session: A 2 Prognostics 1

Presenting Author: Mark Friedrich **Ser:** 68

Organization: John Deere

Country:

Paper Title: **PHM Development and Implementation Challenges for the Off-Road Engine Market**

Co Authors:

Abstract:

PHM development and implementation for the off-road engine market presents a wide array of challenges, including some not seen in other industries. The John Deere Power Systems eBusiness and Service Information departments have developed and utilized new and unique capabilities to enable remote diagnostics for use by both the servicing dealers as well as internal development groups to overcome some of these challenges. This presentation will include a discussion on what those challenges are, how John Deere has overcome them, and some of the innovative and scalable capabilities developed to reduce problem recognition and resolution cycle times while improving returns and allowances, machine uptime, performance, and the customer experience.

Assigned Session: B 2 Data Management and Analysis

Presenting Author: Preston Johnson **Ser:** 39

Organization: National Instruments

Country:

Paper Title: **Big Analog Data™ Lessons Learned in Fleet Wide Asset Monitoring of Gas Turbines and Supporting Equipment in Power Generation Applications**

Co Authors:

Abstract:

The transition from route based measurements to a Fleet Wide Surveillance program touches many elements from sensors to networked data acquisition nodes to servers to historians and predictive technologies. At Duke Energy, installation costs, information technology strategies, and long term vision comes together to create higher machine reliability at lower operational cost and new automation in performance monitoring, diagnostics, and advisory generation. With automation, comes increased sensory data from pumps and turbines that require new tools for data management, mining, and transformation into actionable information. This case study reviews the open and extensible data architecture of the system deployed, the ongoing efforts, and current benefits delivered to Duke Energy.

Assigned Session: B 2 Data Management and Analysis

Presenting Author: Tik Sze **Ser:** 30

Organization: Dell

Country:

Paper Title: **The Merger of Field Sensory Data (Big Analog Data™) with Control and Semi-Structured and Un-Structured Data Breeds New Opportunities for Data Management including Hadoop™ and Application Specific File Formats**

Co Authors:

Abstract:

As machine fleet operators and suppliers take advantage of the InternetOfThings, more and diverse data comes together, promising enhanced decision making automation. To full-fill the automation of maintenance and operational decision making, data management provides the cornerstone for building intelligent information machines. This paper describes the use of Hadoop technologies coupled with machinery sensory data and business analytics that creates the environment for assisting and automating machinery diagnostics and maintenance decisions.

Assigned Session: B 2 Systems Engineering

Presenting Author: Michael Lipsett **Ser:** 42

Organization: University of Alberta

Country: Canada

Paper Title: **Design of a Modular, Cost-Effective Embedded Wireless Condition Monitoring System for Asset Management of Distributed Fleets of Light Commercial Vehicles**

Co Authors: Michael Lipsett, Stephen Dwyer, James Yuen, Nicolas Olmedo, Michael Mills

Abstract:

In an effort to improve the return on investment for assets, it is becoming increasingly important for companies to develop and implement techniques for more efficient asset management, particularly through condition monitoring. Improved reliability and productivity levels for technological assets such as fleet vehicles and material handling systems in factory and warehouse environments are key metrics for competitiveness. On a system such as a forklift fleet, distributed on-demand condition monitoring, combined with model-based fault analysis and prediction techniques, can raise productivity through more efficient maintenance schedules and reduced downtime. A small, customizable embedded sensor system is described for forklifts, with wireless connectivity and automatic status reporting for a set of condition indicators. Technical specifications are based on information flow for providing asset tracking of location, hours used, and machine condition. The system will be capable of logging and transmitting sensor data over a cellular network to a centralized server and database system capable of providing improved model-based condition monitoring reports to fleet owners and operators. An embedded system has been designed, prototyped, and demonstrated in field service using cell modems and a web-based reporting tool.

Assigned Session: B 2 Systems Engineering

Presenting Author: Juan Gamarra **Ser:** 41

Organization: Mechanical Solutions Inc

Country:

Paper Title: **Practical Heat Pumps in Cold Climates – An Enabling Technology**

Co Authors: Thomas Walter; presented by Juan Gamarra

Abstract:

The on-going development of a compact centrifugal compressor as a first stage or pre-compressor for cold climate operation of heat pumps is described. Positioned in the low pressure vapor portion of the refrigerant loop, this compressor will, on cold days, operate automatically to boost refrigerant pressure, in a manner similar to the way an automotive supercharger pressurizes air. The single stage motor driven centrifugal compressor runs on oil-free bearings. It is being configured to work in concert with a traditional heat pump compressor. The goal of this work is to enable air source heat pumps to efficiently extract heat from even the coldest ambient air without backup heat and without changing refrigerant type or the basic design of the positive displacement style compressors widely used in today's heat pumps. Doing so will allow air source heat pumps to operate effectively in virtually all major population centers. To date, a first article supercharger has been designed and built, and its performance mapped. Work to integrate it with a commercially available positive displacement (PD) heat pump compressor is underway.

Assigned Session: B 2 Systems Engineering

Presenting Author: Mike Roemer **Ser:** 5

Organization:

Country:

Paper Title: **Formal Validation and Verification of Flight Critical System Software using Modeling and Simulation**

Co Authors:

Abstract:

The presentation will cover the development of the necessary framework, models and algorithms that can be implemented to directly support formal compositional verification of highly integrated avionic systems. This will include exploiting simulation tools (Simulink), the Transport Class Model (TCM) and appropriate interfacing and other functionalities intended to test and assess the performance of flight critical components. The presentaion will also show simulation results based on dynamic, real-time models of flight critical components/systems, i.e. an Electro-Mechanical Actuator (EMA) and a proxy flight control computer (FCC) as a test case for proof of concept. The rigorous and systematic approach to the simulation system design and implementation with performance metrics for selected components will generate suitable requirements and specifications to be used in the verification task.

Assigned Session: C 2 Failure Prevention for Materials and Structures

Presenting Author: Bob Ware **Ser:** 9

Organization: US Air Force Research Laboratory

Country:

Paper Title: **Mitigating Technical Risk when Applying Novel Materials & Processes**

Co Authors:

Abstract:

Mitigating Technical Risk when Applying Novel Materials & Processes Emerging Materials & Process (M&P) solutions hold the promise of cost reductions and performance improvements. Many initial implementations are selected out of desperation. Advocates of the new M&P approaches are often biased and / or may not fully understand the nuances of the target application. Economic trades are difficult to assess, because cost savings during procurement are offset by unquantified risks during usage and sustainment. Desite these complications, we do the taxpayer a dissservice if we do not take advantage of genuine M&P improvements. The author presents two historical examples of M&P insertion gone awry, as well as a set of guidelines to minimize risk during application of novel M&P. 1) Identify Unique Limitations 2) Test Limitations Directly in Realistic Environments 3) Select Initial Applications Carefully 4) Establish Appropriate Process Control

Assigned Session: C 2 Failure Prevention for Materials and Structures

Presenting Author: Onome Scott-Emuakpor **Ser:** 10

Organization: Air Force Research Laboratory

Country:

Paper Title: **Bending Fatigue Life Comparison between DMLS and Cold-Rolled Nickel Alloy 718**

Co Authors: Onome Scott-Emuakpor, Jeremy Schwartz, Tommy George, Casey Holycross, and Joseph Slater

Abstract:

Bending fatigue life behaviors of direct metal laser sintering (DMLS) and cold-rolled Nickel (Ni) Alloy 718 have been compared in this study. The work was motivated by the possibility of using DMLS manufacturing to improve functionality of hot section components in gas turbine engines. In other words, by using DMLS, features like cooling passages with enhanced functionality can be created in turbine blades and heat exchangers, leading to larger flight envelopes and improved specific fuel consumption (SFC). The work in this document focuses on assessing high cycle fatigue (HCF) behavior of DMLS Ni Alloy 718. DMLS specimens from two different suppliers were fatigued via a vibration-based bending technique, and compared to published rotating bending behavior of cold-rolled Inconel 718 (Ni Alloy 718 composition). Tensile material properties of the DMLS specimens were observed as well. The comparisons conclude that fatigue and tensile properties may be sensitive to DMLS process parameters and post-sintering treatments, thus showing a need for process control optimization. Nonetheless, fatigue performance of DMLS Ni Alloy 718 compares well with rotating bending fatigue of cold-rolled Inconel 718.

Assigned Session: C 2 Failure Prevention for Materials and Structures

Presenting Author: Dan Kaplowitz **Ser:** 26

Organization: US Army Research Laboratory

Country:

Paper Title: **Cursory Development of an NDI Method for Internal Coatings on Army Gun Barrels**

Co Authors: Reinhold Ludwig, Gene Bogdanov, Victor Champagne, William de Rosset, and Marc Pepi

Abstract:

The Army has researched the concept of utilizing cold spray coating technology as an alternative to the conventional electroplated chromium coating within 20mm gun barrels. This project was undertaken as part of the Army's Toxic Metal Reduction program to remove hexavalent chromium from the manufacturing process, and involves the creation of tantalum-10% tungsten "donor tubes" for explosive bonding to the inner gun barrel. A major concern of any internal coating process (such as the interior of a gun barrel) is the integrity of the final product, since it is not a location that is easily inspected. As such, a nondestructive inspection method was developed, allowing successful evaluation of the interior gun barrel coating. The research involved a high-frequency ultrasonic inspection whereby the elastic waves were transmitted from the exterior. The equipment consisted of contact and immersion probes with center frequencies of ~10 MHz connected to a pulser/receiver system with variable duty cycles. The analog time-amplitude signals were acquired with a high-speed (2 GHz) digitizing oscilloscope and evaluated/stored in a PC. The test arrangement was used to measure the average liner thickness as a function of distance along the barrel. Results comparing well-bonded and delaminated samples were also achieved.

Assigned Session: A 3 Prognostics 2

Presenting Author: Steven Moore **Ser:** 61

Organization: Emerson Process Management

Country:

Paper Title: **Wireless HART: An Enabling Technology for Essential Asset Monitoring**

Co Authors:

Abstract:

Wireless HART (IEC 62591) is a wireless, open standard protocol for process instrumentation. This paper will discuss the multiple reliability applications where the sensor technology enables economical, reliable prediction and real time monitoring of essential assets. Pumps, blowers, heat exchangers and cooling towers are only a few of the applications that the wireless technology permits extensive monitoring for prediction of early failure or maintenance as well overall asset efficiency. Basics of the technology, available sensors (Vibration, temperature, pressure, acoustic, etc) and successful applications will also be covered.

Assigned Session: A 3 Prognostics 2

Presenting Author: Fred Discenzo **Ser:** 48

Organization: Rockwell Automation, Advanced Technology

Country:

Paper Title: **Integrated Prognostics and Control Provides Enhanced Asset Utilization**

Co Authors:

Abstract:

There remains a high level of interest in maximizing the value from deployed assets and insuring continued high production levels along with safe, reliable machinery operation. Machinery efficiency and high production rates are typically the concern of operations, scheduling and automation staff. Machinery reliability and machinery uptime is typically the responsibility of plant maintenance, service, and repair staff. New opportunities for enhanced asset utilization is possible by integrating diagnostic and prognostics with automation and machinery control. Diagnostic and prognostic techniques may be effectively coupled with novel control techniques in the context of an intelligent system. A framework for integrated prognostics-control is presented for general automation systems and a specific example is given for a pumping application. Such a system can effectively sense the operating condition and health of the components in a manner superior to a passive monitoring system. The assessment of the hydraulic system health can then be used to prescribe an automatic change the operation of the system to prolong the life of the machinery or to more efficiently realize business objectives. The operation of such an integrated system can achieve unprecedented and important capabilities for protecting critical processes, process equipment, operations personnel, and the environment while maximizing value to the organization. This system also provides a basis for dynamic optimization of critical operating and financial objectives such as longest MTBF, lowest life-cycle cost, or lowest cost per gallon pumped. Future intelligent systems will provide the basis for next generation CBM systems, distributed intelligent systems, and autonomous systems. This paper describes the fundamental principles and opportunities for integrated prognostics and control. A framework for describing an integrated system is presented. Examples of integrated prognostics-control systems are provided for industrial and aircraft systems. This concept is extended and applied to distributed intelligent systems that support dynamic control changes and dynamic reconfiguration in order to insure sustainable operation and enhance asset utilization. An example of prognostics-driven control modification and dynamic reconfiguration is then presented for a shipboard system.

Assigned Session: A 3 Prognostics 2

Presenting Author: Jean-Baptiste Léger **Ser:** 51

Organization: PREDICT & DIAG 21

Country: France

Paper Title: **Health Monitoring and Prognostic Assessment in a Fleet Context**

Co Authors: Alexandre Voisin, Gabriela Medina-Oliva, Maxime Monnin, Jean-Baptiste Léger, and Benoit Iung

Abstract:

Prognostics aims at estimating the remaining useful life in order to plan a maintenance action before unit performances are affected. However, such goal is hard to reach since many parameters affect system's behaviour. Many approaches have been proposed to performed prognostics each of them with strength and weakness. In the present paper we propose to follow historical based prognostics together with the notion of fleet. The originality of the paper lies in the use of "similar" system historical instead of identical system historical as usually done in such approaches. In the present paper a fleet is composed of heterogeneous units (mainly components but could be systems or sub-systems) that are grouped together considering some similarities. Hence, the fleet can provide capitalized data and information coming from other members of the fleet for the prognostics. In order to achieve such a goal within a fleet-wide dimension, it is thus necessary to manage relevant knowledge arising from the fleet taking into account heterogeneities and similarities amongst components, operational context, behaviours, etc. This paper will focus mainly in the formalization of a data-driven prognostic model considering a fleet-wide approach. The model is based on a prognostic approach of the system health using Relevant Vector Machine. The proposed model is based on historical data coming from similar units of a fleet. The heterogeneity of the monitored data is treated by assessing a global health index of the units. The proposed approach is shown on a case study in the marine domain.

Assigned Session: A 3 Prognostics 2

Presenting Author: Raj Bhatnagar **Ser:** 35

Organization: University of Cincinnati

Country:

Paper Title: **Investigations on Spindle Bearings Health Prognostics Using a Data Mining Approach**

Co Authors: Divya Sardana, Raj Bhatnagar, Radu Pavel, and Jonathan Iverson

Abstract:

In the metalworking industry, the machine tool is a key component of the manufacturing chain. Unmanaged downtime is directly related to the performance characteristics of the machine tool and may result not only in high repair costs, but also in production delays, customer dissatisfaction, and lower potential sales. Therefore, maintaining the machines in good working condition and avoiding unexpected break-downs is of utmost importance. One of the machine tool systems that fail most often is the spindle. Spindle breakdowns are commonly caused by bearing failures that could be generated by a number of causes such as corrosion, wear, and improper lubrication. Although many attempts to predict time to failure of spindle bearings have been reported in the literature, there are still challenges related to data availability and methodology. In addition, there is significant variation from case to case due to the complexity of system usage and failure modes. This paper presents the results of an investigation focused on developing a new data-driven methodology for predicting the time to failure of the bearings of a spindle. Data collected from over five run-to-failure tests of a spindle test-bed has been reviewed and processed using a number of pattern discovery tools. A Fourier Transform-based analysis showed that episodes of bursts of energy were observed with monotonically increasing frequency and intensity as the spindle bearings' health deteriorated. The predictions made based on the observed pattern of energy bursts have provided encouraging results. The methodology developed and the findings to date are presented in the paper along with the experimental setup and the degradation evolution recorded for each case.

Assigned Session: A 3 Prognostics 2

Presenting Author: Liang Xu **Ser:** 64

Organization: SpectraQuest, Inc.

Country:

Paper Title: **A Generic Bayesian Approach Using Laplace Approximation for Model-Based Failure Prognosis**

Co Authors:

Abstract:

This paper presents a generic Bayesian framework using Laplace approximation for model-based remaining useful life prognosis. The developed generic Bayesian prognosis approach models and updates remaining useful life distributions by incorporating timely evolving sensory data using a general Bayesian inference mechanism and employs an efficient Bayesian updating approach using Laplace approximation (LA) method. The developed Bayesian prognosis approach eliminates the dependency of evolutionary updating process on a selection of distribution types for the parameters for a given system degradation model. Furthermore, with the developed LA method, the Bayesian updating process can be carried out efficiently which makes the proposed approach possible for real-time prognosis applications. The proposed Bayesian prognosis methodology is generally applicable for different degradation models without prior distribution constraints as faced by conjugate or semi-conjugate Bayesian inference models.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: Paula Dempsey **Ser:** 50

Organization: NASA Glenn Research Center

Country:

Paper Title: **Data Fusion Tool for Spiral Bevel Gear Condition Indicator Data**

Co Authors: Paula Dempsey, Lance Antolick, Jeremy Branning, and Josiah Thomas

Abstract:

Tests were performed on two spiral bevel gear sets in the NASA Glenn Spiral Bevel Gear Fatigue Test Rig to simulate the fielded failures of spiral bevel gears installed in a helicopter. Gear sets were tested until damage initiated and progressed on two or more gear or pinion teeth. During testing, gear health monitoring data was collected with two different health monitoring systems. Operational parameters were measured with a third data acquisition system. Tooth damage progression was documented with photographs taken at inspection intervals throughout the test. A software tool was developed for fusing the operational data and the vibration based gear condition indicator (CI) data collected from the two health monitoring systems. Results of this study illustrate the benefits of combining the data from all three systems to indicate progression of damage for spiral bevel gears. The tool also enabled evaluation of the effectiveness of each CI with respect to operational conditions and fault mode.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: Jake Siegel **Ser:** 36

Organization: Luna Inc.

Country:

Paper Title: **Non-intrusive Load Monitoring of Electric Motor Driven Machine Equipment**

Co Authors:

Abstract:

Operation schedules require electric motor driven machine equipment is reliable and ready for usage, regardless of age or service history. Because of unremitting needs to increase machine service life and reliability, reduce maintenance costs, and eliminate equipment outages, cost effective sensing platforms that can autonomously perform data collection tasks without increasing personnel workload are necessary. Currently used hour meters or odometers do not provide indication of when machines ran, for how long, or at what load level, which greatly comprises machine usage life. There is a need for a non-intrusive means of recording electric motor start and stop times as well as measuring runtime load levels to provide a historical load profile, and therefore, an idea of how hard a machine was run and for how long. To meet this critical need, condition based maintenance of electric motor driven machine equipment using embedded instrumentation and sensor networks, capable of monitoring critical machine health parameters, has been shown to increase the reliability of machine equipment. Such monitoring capabilities, if broadly deployed, would result in operational improvements, including increased efficiency of asset resource and reduced time and resource barriers to the addition of instrumentation to existing infrastructure. The objective of this paper is to introduce a distributed plant monitoring embedded sensing system, utilizing a non-intrusive method for estimating mechanical load by analyzing emitted electric motor energy in the form of magnetic flux, vibration, and heat. A 2.4 inch diameter air core RF coil designed for 10 G/V sensitivity, embeddable accelerometer, and RTD are used to measure machine parameters on custom designed, 1 Hp and 5 Hp AC induction motor test stands and field survey motors at USAF Arnold Engineering Development Complex. Analysis shows the dependence of machine stray flux output on applied motor speeds and mechanical loads (generator output, torque, and current), and indicates that the air core RF coil transducer and the presented method for non-intrusive collection of motor speed and magnetic stray flux can statistically measure the difference between any two load points with 95% confidence, if their values differ by 6% full scale or greater (±2s). Root mean square analysis of magnetic flux data is used to estimate machine service longevity, and provides a cheap, low-power computational process for embedded sensing system processing. Additionally, areas of further research, including thermal energy harvesting for increased system longevity and generalization of the approach and scalability for different sized motor applications are identified.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: Pat Henning **Ser:** 37

Organization: Spectro Scientific, Inc

Country:

Paper Title: **Fluid-Based Portable Machinery Assessment Tools**

Co Authors:

Abstract:

Here we present an overview of the latest developments, issues, and future outlook re. miniaturized systems for machinery assessment based on fluid analysis. Included are discussions of hardware and software tools, as well as example implementation scenarios and related feedback. The overall motivation for portable systems for machinery condition is the ability to put instant answers into the hands of the practitioner. Over the years this has not been in general possible due to the unavailability of such tools and field analysis protocols which made their use feasible. With the advent of portable technology across a wide range of applications including machinery condition, the user now has more and more information in near real-time. For machinery condition especially, the pure analytical capability of instrumentation has always had to have been balanced with the recommendations surmised by the analyst. With portable systems the story is no different. Outside of the laboratory, this in itself provides an interesting array of challenges and opportunities. Here we discuss these considerations in detail in the context of two application examples.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: Ann Kao **Ser:** 13

Organization: Center for Intelligent Maintenance Systems, University of Cincinnati

Country:

Paper Title: **Dynamic Condition Based Feature Extraction Strategy for Machine Health Monitoring Applications**

Co Authors: Hung-An Kao, Chao Jin, Zongchang Liu, Shanhu Yang, and Zhe Shi

Abstract:

Machine health condition monitoring and fault diagnosis are two important tasks for the optimization of factory up time, diagnosis of component failure modes, and eventually support predictive maintenance decisions. That is why research to prognostics and health management (PHM) is being conducted world wide in different industrial applications. Within these applications, data acquisition is a key to collect machining data and understand machine conditions. The traditional data acquisition devices deal with controller data, sensors and other manufacturing systems at the same time. The feature extraction strategy is static once the PHM system being designed and established. However, which features to extract and when to extract them are highly related to real-time machine/component conditions. Therefore, this paper presents a framework for dynamic condition based feature extraction strategy for machine health monitoring applications. A knowledge base for the relationship of features and corresponding failure modes is developed first using quality function deployment (QFD) format. Then, a decision tree for prioritizing feature extraction order will be built based on the calculation of Bayesian probabilities. Because of the hierarchy and priority, the DAQ system can dynamically extract critical features based on the real-time condition of monitored machine systems.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: David Siegel **Ser:** 59

Organization: Predictronics Corp

Country:

Paper Title: **Investigation and Evaluation of Condition Indicators, Variable Selection, and Health Indication Methods and Algorithms for Rotorcraft Gear Components**

Co Authors: David Siegel, Jay Lee, and Paula Dempsey

Abstract:

Providing better fleet-wide availability, reliability, and maintainability, are some of the potential benefits of a rotorcraft health and usage monitoring system. Despite several advances in research and development on drivetrain condition monitoring and also many deployed rotorcraft health and usage monitoring systems, there is a still a significant need to further validate and improve upon the diagnostic and prognostic algorithms for drivetrain components. This study focuses on performing an investigation on gear condition indicators, methods for ranking and selecting the condition indicators, and also health indication algorithms that fuse multiple gear condition indicators into a single health index. For investigating the gear health monitoring algorithms, a spiral-bevel gear fatigue test-rig is used to conduct four run-to-failure experiments. Vibration measurements along with a tachometer pulse are collected throughout the life testing, and visual inspection and oil-debris measurements are used to compare the vibration symptom response with the actual gear health condition. Time domain statistics, time synchronous average spectrum indicators, amplitude modulation, residual signal, auto-regressive residual signal, and second order cyclostationary indicators are evaluated in this study. Three different variable ranking methods based on the Fisher criterion, the area under the receiver operating characteristic curve and the monotonic criteria were weighted together to rank and select the best performing condition indicators. The top performing condition indicators were from the residual and amplitude modulation signal, and consisted of the residual signal RMS, residual signal peak to peak value, the sideband level indicator, and the amplitude modulation peak to peak value. A principal component based health indicator provided the most consistent health trend when compared with the distribution overlap and auto-associative neural network methods. The future work will consider further validation of the algorithms with additional run-to-failure tests, and a more in depth study on the influence of load and speed on the condition indicators.

Assigned Session: B 3 Health Management Tools and Capabilities 1

Presenting Author: Mike Hurrell **Ser:** 63

Organization: Sierra Lobo, Inc.

Country:

Paper Title: **Rotordynamic Model Development of a Spiral Bevel Gear Test Rig Drive Train**

Co Authors:

Abstract:

A rotordynamic model of the NASA Glenn Spiral Bevel Gear Fatigue Test Rig was developed. The model considers the uncoupled lateral, axial and torsional vibration of the test rig pinion shaft assembly. The extent of coupling between the three classes of vibration was determined and the results were then compared to frequency response measurements performed on the rig. In addition, the frequency response measurements were used to tune model parameters such as bearing preload and fastener torque. The results indicated a good correlation between model and measurement. The model will be used in further studies of gear train health monitoring and gear mesh dynamic modelling of the rig drive train.

Assigned Session: C 3 Failure Analysis

Presenting Author: Tom Considine **Ser:** 28

Organization: US Army Research Laboratory

Country:

Paper Title: **Characterization of Tape Adhesion to Chemical Agent Resistant Coatings**

Co Authors: Thomas Considine, Thomas Braswell, and Joseph Labukas

Abstract:

Advanced military coating technologies have incorporated chemical agent resistance, desirable mechanical properties, and corrosion mitigating properties into CARC systems currently in use. The performance of these coatings is evaluated using MIL-DTL-53072 . During the coating application phase and in the field, a tape pull off test is required by MIL-DTL-53072 to gauge adhesive strength of a coating to a primer or substrate. We have investigated the chemical and physical interactions of a variety of tapes used for the verification of coating adhesion with ASTM D3359 on several substrates using tensile pull-testing, infrared-spectroscopy, and contact-angle measurements. A correlation between tape adhesion and surface wetting characteristics has been established. Tapes meeting the minimum performance parameters of 80 inch ounce-force over the selected CARC systems were indentified.

Assigned Session: C 3 Failure Analysis

Presenting Author: Aurélie Gouby **Ser:** 17

Organization: Snecma

Country: France

Paper Title: **A Measurement Validation Algorithm Used in Test Cell**

Co Authors: Aurélie Gouby

Abstract:

Aircraft engines are systematically tested throughout development phases to evaluate their performance. During a test, several measurements on engine and on the bench itself are acquired and then stored in a dedicated database during the test. Many factors can cause an abnormal measure is not detected on time; rerun a test can be very expensive. Prevent measurement errors is thus the priority during an engine test. In the following article, we present a measurement validation algorithm used in batch mode, during the test with a short delay or at the end of each test. The algorithm consists in modeling the measurement by building a mathematical model. An anomaly Z-score is then computed with model's residues and compared to an abnormality threshold learned on real data. The user will be alerted about the measurement value if the Z-score exceeds this abnormality threshold. Through this monitoring system, if a measurement problem occurs, the engine test owner can then be reactive and rerun the acquisition or change the sensor if faulty.

Assigned Session: C 3 Failure Analysis

Presenting Author: Chao Liu **Ser:** 7

Organization: Department of Thermal Engineering, Tsinghua University

Country: P R China

Paper Title: **Failure Analysis of Fan Mill in Thermal Power Plant**

Co Authors: Chao Liu, Dongxiang Jiang, and Fulei Chu

Abstract:

Fan mill is an important device in thermal plants, which supply coal power to boiler. Crack failures recently occurred in pulverizing wheels of fan mills in a power plant in China. The cracks happens in quite a few pulverizing wheels and they affect the normal operation. To find out the root cause of the cracks, Finite Element Analysis (FEA) of the pulverizing wheel is carried out in this work. The assembly with real dimensions is modelled to calculate the concentrated stress and strain with centrifugal load, driving load, and operational temperature taken into account. Contact effects are included in the finite element model as well as nonlinear material property. Based on the analysis, the crack causes are determined: (i) the initial stress exceeds the yield limit in normal operational condition, resulting low safety coefficient; (ii) the stress increases significantly in the worn pulverizing wheel, where the risk of failure is greatly increased.

Assigned Session: C 3 Failure Analysis

Presenting Author: Zhengping Chen **Ser:** 47

Organization: BeiHang University

Country: P R China

Paper Title: **Research on How to Identify and Avoid Counterfeit Electronic Components**

Co Authors:

Abstract:

As the poor development of domestic semiconductor industry in China, the manufacturing of electronic equipments highly depends on the import of electronic components, especially monolithic integrated chips. Unfortunately, numerous counterfeit parts have been found in the supply chain because of the embargo, obsolete and other complicated reasons. Once these counterfeit electronic components were used, they can have devastating effects on the security and reliability of the electronic equipments. This article analyses the reason of the emergence, source and types of counterfeit electronic components, and expound the method of identification and avoiding use of those counterfeit parts in the process of electronic equipments manufacturing, which is based on destructive physical analysis of electronic components and the database for basic features of imported electronic parts.

Assigned Session: A 4 Condition Based Maintenance

Presenting Author: Chris Sautter **Ser:** 6

Organization: University of Alabama in Huntsville

Country:

Paper Title: **Actionable Maintenance Information from HUMS**

Co Authors: Rodrigo Teixeira, Kari Morris and Christian Sautter

Abstract:

Condition Based Maintenance (CBM) of military helicopters is tracked by Condition Indicators (CI) calculated from Health Usage and Monitoring Systems (HUMS) vibration sensors. Even though many CIs have been proposed and implemented, they remain highly variable and difficult to interpret, leading maintainers to become desensitized. Here we show that a sequential Monte Carlo algorithm operating a stochastic non-linear model that includes a description of fault evolution can circumvent the fundamental shortcoming of the CI approach. We estimate fault probabilities from vibration spectra time-histories, showing excellent artifact rejection and accurate fault detections several months prior to all other existing warnings. We expect this approach may eventually allow scheduled maintenance to substitute unscheduled downtime, reducing maintenance cost.

Assigned Session: A 4 Condition Based Maintenance

Presenting Author: Marc Hilbert **Ser:** 20

Organization: RWTH Aachen

Country: Germany

Paper Title: **Comparison of state of the art SCADA and High Sampled Data Condition Monitoring for Wind Turbines**

Co Authors:

Abstract:

Maintenance can account for up to 75% of the total lifecycle cost of an asset. As such, proactive maintenance is essential to reduce costs, increase quality and increase availability. In order to enable a proactive maintenance strategy, condition monitoring of the asset is required. This paper details and compares the state of the art techniques of condition monitoring on both high frequency, and low frequency data, with a case study applied to wind turbines to demonstrate the practicalities of the approaches. Wind turbines are fundamental components of power conversion. The drive train, especially, is a crucial part to convert mechanical power into electrical power. With the increasing number of wind turbines worldwide, the exposure to harsh environmental conditions and the increased installment in remote areas like offshore, arctic or desert regions, it is important to predict abnormal machine behavior as early as possible. Therefore, automated condition monitoring is necessary, which will prevent extensive damage in case of failure and create time to react to failures; for example, to prepare inspections and/or to purchase spare parts. Reasons for down-time and their probabilities are presented in various papers. To prevent failures multiple measurements are continuously taking place at the wind turbine, including machine parts such as bearings, gears, and windings. For predicting abnormal machine behavior the machine parts are monitored by high sampled data (vibration and strain measurements) and by low sampled data (operation data). The vibration and strain measurements are mainly used to monitor the drive train condition including blades, bearings, gears and electrical components; the strain measurements to monitor the structure health of the tower and foundation. The operation data includes measurements to the overall condition of the turbine e.g. power output, temperatures, and wind speed. The operation data is delivered by the Supervisory Control and Data Acquisition (SCADA) system. In the last years an immense effort was carried out in developing sophisticated methods to analyze such wind turbine data using high sampled data and SCADA data. More important, SCADA data is available from every wind turbine, while high sampled data is only available if the operator installed such a system on the turbine. The decision to install a system that collects, stores and analyses high sampled data is influenced by the goal of the monitoring as well as investment constraints of the operator. The final paper will provide an overview of state of the art methods to monitor and predict the machine behavior. Benefits and drawbacks of various state of the art techniques from both SCADA and high sampled data will be presented, allowing for a comparison between techniques given a specific monitoring goal. This will provide the reader with a guideline to choose the correct technique and data acquisition process to receive the best results for their monitoring goals. Furthermore, it will provide a basis for decision making for an investment in condition monitoring systems.

Assigned Session: A 4 Condition Based Maintenance

Presenting Author: Junda Zhu **Ser:** 46

Organization: Renewable NRG Systems

Country:

Paper Title: **Wind Turbine Lubrication Oil Condition Monitoring, the Impact of Water Contamination and Oxidation**

Co Authors: Junda Zhu, Tom Nostrand, and Cody Spiegel

Abstract:

The safety and reliability of a functioning wind turbine depend largely on the protective properties of the lubrication oil for its drive train subassemblies such as the gearbox and thus highlights the important role of lubrication oil condition monitoring and degradation detection on a wind turbine. The purpose of lubrication oil condition monitoring and degradation detection is to determine whether the oil has deteriorated to such a degree that it no longer fulfills its function. Lubrication oil degradation is classified into three categories: particle contamination, water contamination and oxidation which are defined as three basic degradation features. In this paper, the impact of water contamination and oxidation on the health condition of turbine gearbox oil are investigated. Water contamination can cause oxidation to increase tenfold, which leads to premature aging of the lubricant. Therefore, these two basic degradation features play a significant role in turbine failure prevention. In this research, gear oil oxidation and water contamination were simulated in a controlled laboratory environment. Lubrication oil performance parameters including dynamic/kinematic viscosity, density, dielectric constant and water content were closely monitored and trended against increasing water contamination and oxidation level. The effectiveness and sensitivity of each performance parameter against water contamination and oxidation level will be discussed.

Assigned Session: A 4 Health Management Tools and Capabilities 2

Presenting Author: Jordan Jameson **Ser:** 69

Organization: Center for Advanced Life Cycle Engineering

Country:

Paper Title: **Failure Cause Determination for a Field-Deployed Solenoid Valve**

Co Authors:

Abstract:

This paper presents the results of a recent analysis of field failures observed in pilot-operated, 3-way solenoid valves. The failure modes and mechanisms of solenoid valves are reviewed. This information is applied in the development of a procedure to investigate valves, which failed while deployed in the field, with environmental conditions ranging from 0-60°C and 60-90%RH. This work will assist future researchers who are attempting to discover root causes of failures in solenoid valves. It will also be of value in identifying diagnostic methods for fault detection and identification in these valves.

Assigned Session: A 4 Health Management Tools and Capabilities 2

Presenting Author: John Lucero **Ser:** 62

Organization: NASA John H Glenn Research Center

Country:

Paper Title: **Using a Systems Engineering Method to Provide a Particle Imaging Velocimetry Capability for a Supersonic Wind Tunnel**

Co Authors:

Abstract:

Using the Systems Engineering (SE) method, a new capability has been developed for the 1 Foot by 1 Foot (1X1) Supersonic Wind Tunnel (SWT). Previously, the 1X1 SWT only used Schlieren flow visualization system, and pressure and temperature taps to characterize shock wave patterns, pressure and temperature gradients on aerospace components being tested. It was decided that a more quantitative method was needed to characterize these flows.

Therefore, a Particle Imaging Velocimetry (PIV) capability was developed for the 1X1 SWT. This presentation shows how an SE method was used to capture the operational concept, requirements development and technical design maturation of this novel capability. The system is now in use and provides excellent velocity gradient information that the researcher can use to verify computational simulation models.

Assigned Session: B 4 Diagnostics 2

Presenting Author: Yongzhi Qu **Ser:** 31

Organization: University of Illinois at Chicago

Country:

Paper Title: **A Study on Comparing Acoustic Emission and Vibration Sensors for Gearbox Fault Diagnostics**

Co Authors: Yongzhi Qu, Brandon Van Hecke, David He, Jae Yoon, Eric Bechhoefer, and Junda Zhu

Abstract:

In recent years, acoustic emission sensors (AE) and AE based techniques have been developed and tested for gearbox fault diagnosis. In general, AE based techniques require much higher sampling rate than vibration analysis based techniques for gearbox fault diagnosis. Therefore, it is questionable if an AE based technique would give a better or at least the same performance as the vibration analysis based techniques using the same sampling rate. To answer the question, this paper presents a comparative study for gearbox tooth damage level diagnostics using AE and vibration measurements, the first known attempt to quantify the diagnostic sensitivity in terms of tooth damage level. Partial tooth cut faults are seeded in a gearbox and experimentally tested. Results have shown that AE has the potential to differentiate damage level in comparison with vibration. While vibration signals are easily affected by mechanical resonance, the AE signals show more stable performance.

Assigned Session: B 4 Diagnostics 2

Presenting Author: Ayan Sadhu **Ser:** 40

Organization: University of Waterloo

Country: Canada

Paper Title: **Fault Detection of Rotating Machinery Using a Hybrid Hidden Markov Model**

Co Authors: Ayan Sadhu and Sriram Narasimhan

Abstract:

In this paper, a generalized hybrid hidden Markov model (HMM) is proposed to perform multi-state fault detection of rotating machinery. Time-frequency signatures extracted from wavelet packet transformation based Teager Kaiser energy operator are first used to construct de-noised damage features of the raw signal, and then GMM-based HMM is undertaken for fault detection. This approach improves the traditional HMM over a more accurate state estimation and simpler codebook preparation under multiple failures and oper¬ating conditions. The proposed method is finally validated using bearing data of Case Western Reserve University. This research provides an attractive solution to practising engineers to undertake timely intervention and maintenance scheduling of rotating machineries in several industrial applications.

Assigned Session: B 4 Diagnostics 2

Presenting Author: Blake Van Hoy **Ser:** 8

Organization: Oak Ridge National Laboratory

Country:

Paper Title: **Performing Diagnostics on the Spallation Neutron Source Vision Beam Line to Eliminate High Vibration Levels and Provide Sustainable Operation**

Co Authors: Blake Van Hoy

Abstract:

The Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory (ORNL) provides variable energy neutrons for a variety of experiments. The neutrons proceed down beam lines to the experiment hall, which houses a variety of experiments and test articles. Each beam line has one or more neutron choppers which filter the neutron beam based on the neutron energy by using a rotating neutron absorbing material passing through the neutron beam. Each beam line is named and excessive vibration of the "Vision" beam line, believed to be caused by the T0 chopper, prevented the Vision beam line from operating at full capacity. This problem had been addressed several times by re-balancing/reworking the T0 chopper but the problem stubbornly persisted. To determine the cause of the high vibration, dynamic testing was performed using VibPilot hardware and Smart Office software. Twenty-seven accelerometer and motor current channels of data were collected during drive up, drive down, coast down, and steady-state conditions; resonance testing and motor current signature analysis were also performed. The data was analyzed for traditional mechanical/machinery issues such as misalignment and imbalance using time series analysis, frequency domain analysis, and operating deflection shape analysis. The analysis showed that the chopper base plate was experiencing an amplified response to the excitation provided by the T0 beam chopper. The amplified response was diagnosed to be caused by higher than expected base plate flexibility, possibly due to improper grouting or loose floor anchors. Based on this diagnosis, a decision was made to dismantle the beam line chopper and remount the base plate. Neutron activation of the beam line components make modifications to the beam line especially expensive and time consuming due to the radiation handling requirements, so this decision had significant financial and schedule implications. It was found that the base plate was indeed loose because of improper! grouti

Assigned Session: B 4 Diagnostics 2

Presenting Author: Marc Hilbert **Ser:** 19

Organization: RWTH Aachen

Country: Germany

Paper Title: **Intrinsic Method for Monitoring Industrial Applications for Virtual Diagnostics**

Co Authors: Markus Schütz, Marc Hilbert, Domenic Boos, Christian Bernet, Ralph Baltes, Karl Nienhaus, and Claudia Sequeira

Abstract:

The Internet of Things (IoT) refers to a network and virtual representations of individual objects (e.g. machine part) in an internet-like structure. This representation enables the comparison of the behavior of the real world object to a virtual counterpart. On the virtual counterpart the reactions of loads or an estimation of remaining life time among other aspects can be simulated. To realize those industrial visions each object's needs to have cheap and reliable systems that monitor and record the object conditions during the full lifetime. Only with these data a mapping of the virtual object will be possible and, therefore, an estimation of the remaining life can be provided.
This paper will describe a method that covers these challenges on two sample applications. 1. Condition monitoring of a wind turbine epicyclic gear, especially the planet meshing and the planet bearing using a measurement system mounted on the planet carrier. 2. Condition monitoring of a single centered chain strand built in an armored face conveyor, by use of a special measurement chain link.

Assigned Session: B 4 Diagnostics 2

Presenting Author: Wenguang Yang **Ser:** 14

Organization: Tsinghua University

Country: China

Paper Title: **Experimental Investigation and Analysis of Some Common Faults for Wind Turbine**

Co Authors: Wenguang Yang, Shaohua Li, and Dongxiang Jiang

Abstract:

This paper focus on the fault characteristic by experimental research. A test rig is built for the direct driving stall fix-pitch horizontal axis wind turbine. 8 signals are collected by the experiment system, including wind speed, rotor rotational speed, shaft torque, the output electric power, vertical and horizontal vibration displacement of main shaft, vibration acceleration of the front bearing pedestal and the back bearing pedestal. 11 common wind turbine faults are researched by experiment. These faults are rotor mass imbalance, pneumatic asymmetry, airfoil changed, yaw fault, shaft horizontal misalignment, shaft vertical misalignment, front bearing pedestal looseness, rear bearing pedestal looseness, front bearing outer ring fault, front bearing inner ring fault, and front bearing roller fault. Several signal analysis methods, which are waveform analysis, orbit analysis, amplitude domain analysis, frequency domain analysis and envelope spectrum analysis, are adopted to extract characteristics from vibration signals. The influence on output power and vibration characteristics of these faults is presented by comparing with normal operation. The findings can be used to guide wind turbine fault diagnosis in engineering applications.

Assigned Session: B 4 Diagnostics 2

Presenting Author: Wangpeng He **Ser:** 12

Organization: State Key Laboratory for Manufacturing Systems Engineering

Country: P R China

Paper Title: **Adaptive Tunable Q-factor Wavelet Transform for Fault Feature Extraction of Gearbox Based on Vibration Signals**

Co Authors: Wangpeng He, Yanyang Zi, Zhiguo Wan, Shuilong He, and Zhengjia He

Abstract:

Fault diagnosis of gearbox is of great importance to avoid catastrophic accidents. Feature extraction has always been a key problem for fault diagnosis. In this paper, a novel fault feature extraction method called adaptive tunable Q-factor wavelet transform for gearbox fault diagnosis is proposed. The proposed adaptive method is implemented using the tunable Q-factor wavelet transform (TQWT). Kurtosis as an effective index of impulses is adopted to choose the optimal TQWT basis. The new method can obtain the optimal Q-factor according to the maximum of kurtosis. Thus, the Q-factor of the TQWT can match the oscillatory behavior of signals optimally without artificially specified. The interested fault feature is extracted by the single branch reconstruction of optimal subband. The proposed method is applied to vibration signals analysis of a bevel gear with a scratch defect from an antenna transmission chain and a gearbox from an electric locomotive. The processed results demonstrate that the proposed method can extract weak fault features of gearbox efficiently.

Assigned Session: C 4 Signal Analysis 2

Presenting Author: Suri Ganeriwala **Ser:** 66

Organization: SpectraQuest Inc

Country:

Paper Title: **A Comparison of Different Techniques for Rolling Element Bearing Fault Diagnosis**

Co Authors:

Abstract:

Rolling element bearing fault diagnosis using vibration signals relies profoundly on using the well-developed methodology of envelope analysis. Envelope analysis is traditionally performed by amplitude demodulating an excited frequency band using Hilbert transformation to determine the fault frequencies. The enveloping technique surfers due to a low signal-to-noise ratio and not knowing the frequency band where to apply it. In this paper we present, the results of seeded faults of bearing with inner race and outer race defects using traditional enveloping, discrete random separation (DRS), autoregressive filtering (AR), minimum entropy deconvolution (MED), spectral Kurtosis (SK), and cepstrum editing. Different types of signals with inner and outer race localized faults from a number of applications are presented and discussed. These include signals taken from wind turbines, gearboxes, and machinery fault simulators. Results show that the efficiency of the envelope analysis in providing a correct diagnosis is increased when it is augmented with bearing signal enhancing and frequency band determination techniques.

Assigned Session: C 4 Signal Analysis 2

Presenting Author: Mate Toth **Ser:** 65

Organization: SpectraQuest, Inc.

Country:

Paper Title: **A Comprehensive Study of Shaft/Coupling Misalignment Signature using Vibration Analysis**

Co Authors:

Abstract:

Shaft misalignment is the most common fault in rotating machinery besides unbalance. It causes rotational angle dependent preload forces in couplings which are transmitted to other machine components, reducing their lifetime. A poorly aligned machine can cost a factory up to 30% in machine down time, replacement parts, inventory, and energy consumption. Considering the importance of alignment, the vibration spectrum of misalignment is not well understood and lacks a consensus. This report is based on the research to determine the unique vibration signature for misalignment under a varying operating and design conditions such as speed, type and level of misalignment, coupling types and machinery dynamic stiffness. The tests were conducted on machinery fault simulator. Rotors were precisely balanced before each significant configuration change. Measurements were carried out at three different shaft speeds, using three types of couplings – rigid, spiral and rubber –, three shaft diameters and multiple misalignment configurations which include parallel and angular types with three different severity levels. Experiments were also performed to measure misalignment forces and determine the dynamic stiffness of the rotor system for model refinement. A rotor dynamics model of the machinery fault simulator is also being constructed with the ultimate goal of developing physics based model for correct fault diagnosis and malfunctions severity. The results indicate that the rotor speed, the coupling and shaft stiffness, have the most profound influence on the vibration signature. However, the data indicate confusing picture of misalignment signature. This research will be continued further to determine a unique vibration signature and/or develop an approach to diagnose misalignment of an operating machine.

Assigned Session: C 4 Signal Analysis 2

Presenting Author: Suri Ganeriwala **Ser:** 67

Organization: SpectraQuest Inc

Country:

Paper Title: **Differential gearbox diagnostics using Adaptive Wavelet Decomposition**

Co Authors:

Abstract:

A powerful signal processing tool named Adaptive Wavelet Decomposition (AWD) has recently emerged in the context of non-stationary signal processing. Based on the concept of wavelet decomposition, its basic objective is to provide a time frequency representation of a non-stationary signal more adaptively than discrete wavelet and wavelet packet transform which is constrained by a fixed decomposition ratio. Motivated by the idea of constructing wavelet basis functions in Fourier domain and combining it with automatic peak detection, it can also be used to extract the individual components of a non-stationary multi-component signal, akin to empirical mode decomposition (EMD). The rich mathematical structure based on the concept of filter-bank algorithms makes AWD one of the potential candidates for rotating machinery drive train diagnosis. Such signals are frequently constituted out of multiple amplitude-modulated / frequency-modulated signals (AM-FM) and periodic impulses due to bearing ring impacts embedded in noise. This work utilizes the decomposing power of AWD to extract the useful components from gearbox signals followed by the separation of bearing and the gear part of the signals. Once the gear and the bearing counterparts are separated, standard gear and bearing diagnostic tools can be applied to identify damage. The efficacy and the robustness of the algorithm are demonstrated with the aid of practical experimental data obtained from a seeded bearing fault test, called the helicopter integrated diagnostic system (HIDS) carried out using an iron bird test stand (SH − 60) at Naval Air Warfare Center (NAWC)- Trenton, and SH−60B/F flight vehicles at NAWC-patuxent river.