ARC Collaborative Research Seminar Series
Winter 2010

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January 29th, Friday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 3, Johnson Room B & C

Presented by **Thrust Area 1 - Dynamics and Controls of Vehicles**

The Seminar Theme is "Vehicle Electrification"
Host: Prof. Jeffrey L. Stein, Thrust Area 1 Leader

This seminar, through the combination of three presentation, research issues in the area of vehicle electrification. More particularly, this seminar will explore the design and control issues of managing the flux of electricity from the grid to storage and use in vehicle propulsion either alone or in concert with other energy sources.

Presentation 1: **Model-based Control for Battery Cells, Strings, and Packs**
Presenter: *Prof. Anna Stefanopoulou, ARC Director*

We will show how an electrochemical lithium-ion battery model is approximated with electrode-averaged solid diffusion dynamics and parameterized through a reasonable set of experimental data. The parameterized model renders the critical solid-electrolyte surface charge as observable and allows the application of an extended Kalman filter for state of charge (SOC) estimation from the measured voltage. Apart from control and protection, the SOC estimator is then used for cell balancing, diagnostics, and battery pack design. We finally discuss next steps in thermal management, packaging, and advanced diagnostics.

Presentation 2: **On Battery Health-Conscious Power Management in Hybrid Automotive Applications**
Presenter: *Dr. Hosam Fathy*

This talk is motivated by the need for hybrid powertrains that carefully balance performance and overall energy efficiency vis-a-vis the concurrent degradation in powertrain battery health. The talk surveys recent progress in hybrid power management, then examines a common electrochemistry-based model of Lithium-ion battery health degradation. Example battery health-conscious optimal power management problems are explored, and the talk ends with a brief discussion of potential applications of this research to military propulsion problems.

Presentation 3: **Design, simulation, and control of electric machines**
Presenter: *Prof. Heath Hofmann*

This talk will provide an overview of the presenter's background in the development of designs, simulation tools, and control algorithms for electric machinery. Advanced machine models and adaptive techniques are used in the development of high-performance control algorithms for induction and synchronous reluctance machines. Finite element analysis (FEA) techniques with improved computational efficiency have been developed to aid in the design of AC synchronous machines. It is further shown how FEA models of these machines can be reduced to lower-order models which are more presenter's work has been incorporated into products such as flywheel energy storage systems and electric vehicles will be discussed. The end of the presentation will touch on areas of future work in this area.

Dr. Hofmann received his Ph.D. in Electrical Engineering and Computer Science from the University of California at Berkeley in 1998, and is now an Associate Professor at the University of Michigan. Dr. Hofmann's research area is power electronics, specializing in the design and control of electromechanical systems. Specific interests are propulsion drives for electric and hybrid electric vehicles, energy harvesting, flywheel energy storage systems, and finite element analysis. Dr. Hofmann has published approximately twenty papers in refereed journals, and has been awarded four patents. Dr. Hofmann was awarded a Prize Paper Award (First Prize) by the Electric Machines Committee at the IEEE Industry Applications Society Annual Meeting in 1998.

February 19th, Friday (9:30-11:00am)
University of Michigan, Duderstadt Center, Room 1180

Presented by **Thrust Area 3 - High Performance Structures and Materials**

Novel Sensor Placement Technology for Complex Structures with Cracks and Structural Variability
Presenter: *Bogdan I. Epureanu, The University of Michigan*

Novel sensor placement technologies are proposed. They are designed to provide vibration characteristics for complex structures which have cracks and structural variability (such as thickness variations and Young's modulus variations). Cracks and structural variability affect the mode shapes of a structure and thus the optimal sensor locations. Two novel approaches are developed and used to compute the mode shapes of a structure with structural variability: (a) PROMs (parametric reduced order models), and (b) BMA (bilinear mode approximation). Based on PROMs and BMA, a novel sensor placement technology (which uses a derivative the EIDV - Effective Independent Distributed Vector - algorithm) is used to determine the optimal sensor locations for complex structures with cracks and structural variability. The novel technology can also be used to identify the crack length. The length is identified by using only a few mode shapes and only a few selected measurement locations. The information from the sensors can be used to determine variations in mode shapes of the structure (between healthy and cracked states) for different crack lengths. The variation in mode shapes can then be used to identify the crack length.

The ability to predict the response of a structure with structural variability means of PROMs as well as the use of PROMs for optimal sensor placement are essentially dependent on the parameterization applied at component level. In previous research, we used a formulation based on (third order) Taylor series for this parameterization. However, we found that such a parameterization is inadequate because of the highly nonlinear dependence of element level structural characteristics on parameters. Thus, a novel special parameterization has been developed and implemented in the next-generation of PROMs. Next, these novel PROMs have been used for is sensor placement.

Numerical results are presented for structures such as a HMMWV frame model. The sensor placement technology is applied: (1) to find optimal sensor locations for structures with parameter variability; (2) to find the optimal sensor locations for structures with both cracks and parameter variability; (3) to identify the length of a crack. Displacement mode shapes are customarily used. However, the novel technology incorporates also stress mode shapes. For that case, optimal sensor locations are shown to be different from the selected locations based on displacement mode shapes. In addition, a simple plate example is presented to demonstrate the limitations of the previous PROMs and highlight the enhanced abilities of the next-generation PROMs.

Fundamental Multidisciplinary Structure Technology with Application to an Innovative Gunner Restraint System for Improved Safety of Military Vehicles
Presenter: *Zheng-Dong Ma, The University of Michigan*
Quad members: *Guang Dong, Gregory Hulbert, Noboru Kikuchi (The University of Michigan), Sudhakar Arepally, Karrie Hope, Madan Vunnam, James Sheng (U.S. Army TARDEC), Ken-An Lou (ArmorWorks, LLC), Hui Wang (AM General, LLC)*

In 2008, we created and distributed a questionnaire to HMMWV gunners in the battlefield (Operation Iraqi Freedom) through the US Army Operations/Intelligence NCO. The purpose of the questionnaire was to obtain input from the soldiers regarding their experiences with existing gunner restraint systems (GRS) and their suggestions on GRS improvements. We obtained responses from 27 gunners, in which 11 of them experienced dangerous vehicle situations, including 6 explosions (IED and E.F.P.) and 5 dangerous scenarios due to bumps, brakes, and sharp turns. Important responses include: 1) 90% gunners complained that the current GRS is uncomfortable; 2) 74% gunners said that the GRS affects gunner's fire operation in a negative way; 3) 58% gunners complained that the GRS is too complicated. Thus, the opportunity to develop improved gunner restraint system (GRS) exists for improving solder safety, survivability, gunner's comfort, and ability to operate effectively in military vehicles.

The objective of this research is to develop a new and general multidisciplinary and function-oriented design methodology that can address broadly safety restraint systems for military and commercial vehicles and that can address particularly the critical need to improve gunner restraint systems (GRS) in military vehicles. The aim is to identify an innovative and optimally combined structural and material system from an open design space, which includes passive, active, and reactive devices in a multibody dynamics system, and which can satisfy various operating conditions and battlefield scenarios. A new topology optimization method has been developed for this purpose. A representative G-force element is also developed to represent a wide range of passive, active, and reactive members in the multibody dynamics model for the optimal design problem. A new optimization algorithm is further developed to deal with the multi-disciplinary and multi-objective design problem with needed efficiency.

A Fatigue Damage Formula and A New Definition of Roughness of Terrain Profiles
Presenter: *T.C. Sun, Wayne State University*

There have been complaints that the root mean square (rms) does not describe well the roughness of terrain profiles. In this talk we shall first derive a fatigue damage formula using the idea from the linear damage theory in fracture mechanics and the concept of rainflow counts of the oscillation cycles in a terrain profile. And then we shall use this formula to define a new measure of roughness of a terrain profile which seems to be more sensitive to the road roughness. We believe that this new definition can be used in parallel to the root mean square method as measures of roughness of terrain profiles.

March 26th, Friday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by **Thrust Area 5 - Vehicle System Integration, Optimization, and Robustness**

Validating Designs through Sequential Simulation-based Optimization
J. Li, Z. Mourelatos, M. Kokkolaras, P. Papalambros and D. Gorsich

Computational simulation models support rapid design processes. Given computational model approximations and operating conditions uncertainty, it is important that designers ascertain a measure of confidence that the designs obtained using simulations will perform as expected. Considering the cost and time limit reliance on physical testing, it is practically impossible to assess the validity of many designs in the design and parameter space. This talk presents a methodology for validating designs as they are generated during the simulation-based optimization process. Current practice focuses on validation of the analysis or simulation models throughout the entire design space. In contrast, the proposed methodology requires validation only at design points generated during optimization. The goal of validation is confidence in the resulting design rather than in the underlying computational simulation or analysis model. The proposed methodology aims to serve as an effective design validation process; it is demonstrated on a cantilever beam design subject to vibration.

Time-Dependent Reliability using a Random Process Approach in the Design for Lifecycle Cost and Preventive Maintenance of Vehicle Systems
Amandeep Singh, US Army RDECOM TARDEC, PhD Candidate, Oakland University
Zissimos P. Mourelatos, Jing Li, Oakland University

Reliability is an important engineering requirement for consistently delivering acceptable product performance through time. As time progresses, the product may fail due to time-dependent operating conditions and material properties, component degradation, etc. The reliability degradation with time may increase the lifecycle cost due to potential warranty costs, repairs and loss of market share, and also affect maintenance schedules. Reliability is the probability that the system will perform its intended function successfully for a specified time interval. We will present methodologies considering the cost during the life of the product to determine 1) the optimal design of time-dependent, multi-response systems, and 2) a preventive maintenance schedule. The lifecycle cost includes a production, an inspection, and an expected variable cost. All costs depend on quality and/or reliability. Examples will highlight the calculation of the cumulative distribution function (probability of first passage or upcrossing) and the design methodology for lifecycle cost. Existing methods to calculate the first-passage reliability provide an upper bound to the true reliability which may overestimate the true value considerably. A methodology will be also presented to calculate the first-passage probability of failure of a dynamic system, driven by an ergodic input random process. Time series modeling is used to characterize the input random process based on data from a "short" time period (e.g. seconds) from only one sample function of the random process. Sample functions of the output random process are calculated for the same "short" time, assuming that it is impractical to perform the calculation for a "long" duration (e.g. hours). The time-dependent reliability, at a "long" time is calculated using an accurate "extrapolation" procedure of the failure rate. A quarter car model on a stochastic road demonstrates the proposed methodology. Future research will concentrate on developing an importance sampling method to calculate time-dependent reliability, which will allow us to use MC simulation with only a small number of sample functions.

April 2nd, Friday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by **Thrust Area 4 - Advanced and Hybrid Powertrains**

Modeling and Simulation of Series Hybrid Electric Vehicle with In-Hub Motors
Youngki Kim, Tae-Kyung Lee and Zoran Filipi, University of Michigan

Power and energy efficiency of vehicle systems are of strategic importance for TARDEC and as such are receiving increased emphasis in the Automotive Research Center. Advanced models of energy conversion and storage, system integration methodologies, analysis and optimization of complex hybrid vehicle power systems (main and ancillary), and techniques for supervisory control will provide the corner stone of the new vision. In addition, novel hybrid propulsion systems contribute to the improved mobility of ground systems and enable application of active protection systems. This presentation provides highlights of recent research accomplishments and details of on-going work aimed at developing a new hybrid propulsion platform for studies of vehicle power and energy.
Recent work had a particular focus on methodologies for optimizing design and supervisory control of series hybrid systems. The series architecture has unique advantages in military applications, but it has not received much attention in the commercial vehicle world. The integration and system optimization problems become particularly interesting in case of high power-density and low-energy capacity configurations, such as the hydraulic hybrid truck or electric hybrid with a supercapacitor. While the conventional wisdom favors component-centric approach to power management, we have shown that application of stochastic dynamic programming uncovers significant additional benefits from considering efficiency on the system level. The on-going effort pursues development of the next-generation electrified tactical truck based on the M-ATV specifications. This vehicle is significantly larger and heavier than the HMMWV and it will be equipped with a number of electrified systems. High mobility, packaging and implementation of IED protection favor application of in-hub motors. Component sizing addresses performance requirements and representative driving schedules. The supervisory strategy considers propulsion requirements, charge sustaining and optimization of engine operation. This task supports long-term goals of the Hybrid Electric research group and CASSI.

Analysis of the Opposing Effects of Recycled Gases on the Cold Start of Diesel Engines
Naeim A. Henein, Ph.D., Professor of Mechanical Engineering, WSU
Quad members: Pete Schihl (TARDEC), Inderpal Singh (DDC) and Rafik Rofail (Ph.D candidate, WSU)
PIs of three projects: Drs. Dinu Taraza, Nabil Chalhoub and Naeim Henein

The presentation will start with an overview of ARCIII research at Wayne State University and will be followed by an investigation on the role of recycled gases during the cold start of diesel engines on enhancing and/or hindering the autoignition process in subsequent cycles. Three approaches are taken in this investigation to determine the effect of recycled aldehydes on the autoignition process. The first is the analysis of experimental data obtained on a 4-cylinder advanced diesel engine in the cold room.
The second is a CFD/Chemical Kinetics models. The third is comparative imaging of the pre-injection chemical reactions in an optically accessible engine. The effect of the increase in the concentration of recycled aldehydes will be explained.

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