

ESM Today

Graduate Research Symposium

11 February 2006

ESM Today is a showcase for the research done by the graduate students of the Engineering Science and Mechanics (ESM) department. The symposium was organized by students in the ESM Graduate Student Council.

Schedule

09:00 **Mike Pedrick** — *Welcome*

09:05 **Dr. Richard P. McNitt** — *Opening remarks*

CHAIRS NEEDED , chairs — *Session I: Talks*

09:20 **Fei Yan** — *Ultrasonic Guided Wave Tomographic Considerations for Structural Health Monitoring*

09:40 **K. Jaya Prakash** — *A distributed GMRES Algorithm for Finite Element Problems*

10:00 **Matthew Kelly** — *Quantitative Microstructural Analysis of Thermal Barrier Coatings produced by Electron Beam*

10:20 *Break*

10:30 **Ashutosh Tewari** — *A Novel Approach to Build and Train a Hybrid Neuro-Fuzzy Knowledge Based System*

10:50 **Charan Srinivasan** — *Molecular Resists Enabling Nanofabrication*

11:10 **Joby John** — *The Dynamics of Skilled Human Movement: Goal Equivalent Manifolds, Stability and Control*

11:30 *Session II: Posters*

12:30 *Lunch*

CHAIRS NEEDED, chairs — *Session III: Talks*

13:00 **Joseph B. Geddes III** — *Manipulation of Optical Pulses with Chiral Sculptured Thin Films*

13:20 **Matt Kropf** — *Remote High Temperature Thermometry Using Ultrasonic Guided Waves in Thin Wires*

13:40 **Michael Pedrick** — *Ultrasonic NDE in Thin Walled Concrete for Flaw Detection*

14:00 *Break*

14:10 **Sean Pursel** — *Effect of Annealing on the Optical Response of TiO₂ Sculptured Thin Films*

14:30 **Ying Shan** — *Flexible Matrix Composite Actuators and Structures*

14:50 **Huidong Gao** — *Sensor placement optimization in structural health monitoring using genetic and evolutionary algorithms*

15:10 *Break; judges confer*

15:30 *Distribution of awards*

Dr. Richard P. McNitt



With 21 years of service, Dr. Richard McNitt has been integral in the growth and development of the Engineering Science and Mechanics department over the last several decades. Dr. McNitt's relationship with Engineering Science and Mechanics at Penn State has involved all facets of education from student to professor to Department head. Before obtaining his PhD in Engineering Science from Purdue University in 1965, McNitt received his Masters in Engineering Mechanics and Bachelors in Engineering Science from Penn State in 1959 and 1957, respectively. After teaching appointments at Purdue University and Virginia Polytechnic Institute and State University, McNitt returned to Penn State in 1981 to Head the ESM department. He was responsible for expanding the department from 18 to 30 faculty members, increasing research expenditures, and instrumental in expanding two research laboratories into College-wide centers.

McNitt has created many new courses and won numerous teaching awards including the Lawrence J. Perez Memorial Student Advocate Award in 1994 and the American Society of Engineering Educations Archie Higdon Teaching Award in 2001. He has held numerous appointments including fellow and past president of Society of Engineering Science, past treasurer of American Academy of Mechanics, as well as past chair of ASEE's Mechanics Division and the National Science Foundations Minority Fellowship Selection Committee. Recently, a scholarship has been instituted to honor Dr. McNitt and is awarded to undergraduate and graduate students demonstrating great academic achievement and promise. It is only fitting that such an integral person in ESM's development be honored in this year's exhibition of graduate research.

Acknowledgments

The organizers thank Dr. Judith Todd and Dr. Akhlesh Lakhtakia for the support of the ESM department in creating this event. We thank Carol Ritter, Sue Croyle, Ardell Hosterman, and Kathleen Zimmerman for help with scheduling and logistics. Bill Ames was enormously helpful in poster printing.

Abstracts: Talks¹

Hudiong Gao[†], Joseph L. Rose — *Sensor placement optimization in structural health monitoring using genetic and evolutionary algorithms*

Structural Health Monitoring (SHM) is of major concern in civil, mechanical, and aerospace system in order to provide early warning of structural damage and to prevent catastrophic failure. An optimized sensor design and sensor placement strategy will be extremely beneficial for both safety ensuring and cost reduction of structural health monitoring systems. A new framework of structural health monitoring sensor placement optimization program was recently developed in Pennsylvania State University based on genetic and evolutionary computing. The problem of optimization is formulated to minimize the damage misdetection rate as well as minimize the number of sensors by searching the optimized pattern of sensor placement topology on the feasible region of the monitored structure. Case history damage statistics information is used in the training session of the sensor placement optimization. The SHM sensor types considered in the program includes single sensor cases such as acoustic emission, pulse echo ultrasonic testing, and electro/mechanical impedance method, and the actuator-damage-sensor scenario such as ultrasonic guided wave through transmission method. The results of optimization of an aging aircraft wing sample problem are also presented in this paper.

Joseph B. Geddes III — *Manipulation of Optical Pulses with Chiral Sculptured Thin Films*

Using finite-difference calculations in the time domain, I studied the scattering of normally incident pulsed optical plane waves and beams from linear and nonlinear dielectric chiral sculptured thin films (STFs).

Pulsed plane waves consist of a carrier plane wave whose amplitude was modulated by a pulse envelope. The carrier phase was found to have significant effects on the shape—as described by the instantaneous Poynting vector—of pulsed plane waves reflected from linear and nonlinear chiral STFs; the shaping depends crucially on the circular Bragg phenomenon (CBP) exhibited by chiral STFs.

Several measures of the durations and average speeds of ultrashort optical pulses transmitted through chiral sculptured thin films were calculated. Durations of transmitted pulses tend to increase with decreasing (free-space) wavelength of the carrier plane wave, while average speeds tend to increase with increasing wavelength. An increase in nonlinearity, as manifested by an intensity-dependent refractive index, tends to increase durations of transmitted pulses and decrease average speeds. These trends are explained via frequency-domain arguments. The CBP exhibited by chiral STFs distorts the shapes of transmitted pulses with respect to the incident pulses, and such shaping can cause sharp changes in some measures of average speed with respect to carrier wavelength.

Finally, I examined the spatiotemporal anatomy of the CBP exhibited by chiral STFs in two spatial dimensions, and I comment on its implications for pulsed beam shaping by STF-based devices. Since pulsed beams spread out due to diffraction, the position of an STF-based device with respect to the beam source will influence any spatiotemporal pulse shaping that takes place. The size of the beam waist could have a significant influence on the shapes of pulses reflected from and transmitted through chiral STFs, and the corner of a chiral STF could be used as a circular-polarization-sensitive beamsplitter.

The results point towards uses of the nanoengineered STFs in optical communication and sensing devices. The theoretical results presented could be corroborated or refuted with present-day experimental techniques. The finite-difference time-domain technique described in this thesis could be extended, for example, to study other models of material nonlinearity than the one used here.

¹A superscript [†] indicates the presenter in the case of multiple authors.

Joby John — *The Dynamics of Skilled Human Movement: Goal Equivalent Manifolds, Stability and Control*

Living beings including humans, exist in a dynamic world of forces, inertia and accelerations. As an infant learns to move and perform tasks with skill, its motor learning and motor control systems are shaped fundamentally by the mechanics of interaction of its morphology (body structure) and body forces with the physical environment that it is embedded in. However, this interaction with the environment is not a constraint on our range of motions. We humans possess many more degrees of freedom to do a task than is actually required. We exploit the redundancy in the degrees of freedom of motion and the mechanics of our environment and are able to perform skilled movements repeatedly and reliably even while exhibiting a great deal of variability at the level of movement details. This inherent redundancy in fact enables us to adapt, learn and skillfully perform a wide variety of tasks, unlike contemporary machines. In this work we introduce the concept of Goal Equivalent Manifolds (GEMs) to describe and analyze the inter trial dynamics of repetitive skilled behavior. It is assumed that with a reasonable level of generality, a skilled task can be described as a mathematical function of the task requirement, the environment and subject morphology. As dictated by the goal function, the set of all body state configurations that achieve the goal successfully form a manifold in the body state space. With this description we are able to analyze the inter trial dynamics in the repeated performance of a skilled task. Other recent work (Uncontrolled Manifold Concept and the Minimum Intervention Principle) also address similar issues but fail to address the passive and active components that lead to performance. We are able to mathematically decompose the variability in performance at target in to its constituent passive and active components. As an example we analyze a simple ball-throwing task and show that performance at the target is dependant on requirements of the given task, the subjects morphology, the interaction between the subject and the environment, the inherent noise in the system the stability of the controller driving the system. With this example we are able to show that time-accuracy trade-off similar to Fitts law is an emergent property of such a system.

Matthew Kelly — *Quantitative Microstructural Analysis of Thermal Barrier Coatings produced by Electron Beam Physical Vapor Deposition*

Thermal barrier coatings are additional thin film structures applied to existing products that reduce the thermal conductivity. Currently thermal barrier coatings are used primarily in hot sections of aerospace and power generation turbines to protect metal components from high operating temperatures and corrosive environments. Advancements in coating methods and materials for thermal barrier coatings have resulted in significant increases of coating life and operating temperature of power turbines, which have reduced operation cost and pollution. Thermal barrier coatings produced by Electron Beam Physical Vapor Deposition (EB-PVD) process have a complicated column like microscopic structure. The columnar structure determines the thermal and mechanical properties of the coating. Size, shape, density of individual columns, and voids between columns vary through the coating thickness and depend on the EB-PVD coating process parameters. Process parameters can be controlled to optimize coating performance for a specified application. Optimization of the coating process is often accomplished experimentally resulting in lengthy and costly development. Current methods of evaluating Thermal Barrier Coatings produced by Electron Beam Physical Vapor Deposition on the microscopic level provide little quantitative information on coating structure. Knowledge of internal coating structure can be used for developing dynamic coating methods improving coating performance in areas of engineering design interest. Modern computer aided image analysis and metallographic techniques have allowed for new methods of evaluating coating structure quantitatively. Performing image analysis multiple times through the coating thickness results in descriptive curves in column geometries and distributions of those geometries. Using quantitative microstructure results, the EB-PVD coating process could be optimized analytically, thereby reducing thermal barrier coating

development costs.

Matt Kropf[†], B. R. Tittmann — *Remote High Temperature Thermometry Using Ultrasonic Guided Waves in Thin Wires*

An ultrasonic technique to accurately and remotely measure high temperatures has been developed. Using long, thin (2 mm) refractory metal wires as ultrasonic wave guides, changes in time-of-flight between fixed reflectors are monitored while the temperature of the wire changes. Several physical phenomena contribute to the change in the time of flight as the temperature of the wire increases. The wire thermally expands causing both the physical distance between reflected signals to increase and the density of the wire to decrease. The velocity of sound decreases due to changes in Youngs Modulus and density. By relating these effects in terms of guided wave propagation to the precise time-of-flight measurement, temperature can be accurately measured from 20 to over 1000 degrees Celsius. Measurements have been made on wire waveguides of lengths greater than 20 meters. By using digitally automated signal processing to monitor the changes in time-of-flight, temperature measurements can be made continuously. This method of ultrasonic in-situ thermometry has proven viable in accurately and remotely monitoring high temperatures in harsh environments.

Michael Pedrick — *Ultrasonic NDE in Thin Walled Concrete for Flaw Detection*

Accurate inspection techniques for todays infrastructure have become an area of great interest. Several ultrasonic techniques for testing and evaluating concrete have been established and show great promise. However, much of the work is concerned with concrete piles or thick-walled specimen (¿500mm). Vast amounts of concrete piping in sewer systems require testing techniques applicable to thinner walled systems (¿100mm). This work aims to extend Ultrasonic inspection techniques to thin-walled systems. Impact-echo and Resonant Ultrasonic Spectroscopy (RUS) techniques are explored. Finite Element models are being developed to describe the propagation characteristics in different specimen. Several specimens have been tested experimentally to determine the effects of steel reinforcements, pipe curvature, and simulated defects. The investigation of Guided Ultrasonic Waves in the specimen has been modeled and confirmed. Results show promise in the aforementioned applications. The potential for Wavelet analysis is explored for isolation of wave propagation modes and defect characterization.

K. Jaya Prakash — *A distributed GMRES Algorithm for Finite Element Problems*

A parallel formulation of the Generalized Minimal Residual Algorithm (GMRES) is developed to solve the system of linear equations arising from the finite element discretizations. One advantage of iterative algorithms such as GMRES is that the stiffness matrix need not be explicitly formed and stored, instead a procedure for computing the matrix-vector, vector-vector products at the element level and then assembled at the global level can be obtained. Hence this algorithm provides an inherent parallelism. The storage requirements of the krylov subspace vectors can also be addressed by a domain decomposed model.

The computing cost issue is addressed by partitioning the mesh using the graph partitioning primitives from the Metis library, which uses the spectral graph partitioning algorithm to distribute the elements and the load equally among the processors. Algorithms were designed to obtain the data locality in each node at the same time retaining the global information of each partition. This leads to a reduced amount of data to be communicated among the processors making the implementation faster.

The algorithm has three main parts, establishing communications between each processors, carrying out the local computations and then assembling the final solution. Communication can represent a substantial part of the total run-time, thus affecting the overall efficiency of the program. The various libraries provided by Message Passing Interface (MPI) standard are used efficiently to optimize the routing of the data between

the processors.

A Beowulf cluster was developed and benchmarked for carrying out the computations. This cluster consists of four nodes running the Linux operating system, on which all the tests were carried out. All the routines were written in Fortran 77 and tested for a fluid transport problem using finite element methods. The results obtained for a grid with 82590 elements indicated a speedup of 3.8 for the four nodes used.

Sean Pursel[†], Mark Horn, Akhlesh Lakhtakia — *Effect of Annealing on the Optical Response of TiO₂ Sculptured Thin Films*

Sculptured Thin Films, or STFs, contain highly oriented 2D and 3D engineered nanoscale structures. These structures can be described as freestanding nanowires or microcolumns. The film morphology is controlled through the deposition process and is often engineered into slanted, S-shaped, C-shaped, and chiral columns. Chiral STFs exhibit the Circular Bragg Phenomenon (CBP). This property can be observed when circularly polarized light is incident onto STFs. Left/right handed circularly polarized light, in a certain frequency band, will be nearly completely reflected from a STF which is deposited to have a periodic left/right handed chiral morphology; All circularly polarized light of the opposite handedness is transmitted. The center of the reflected bandwidth is called the Bragg wavelength. This wavelength and the shape of the reflection peak is dependant on the periodicity of the film morphology, the type of film morphology, and the indices of refraction of the void space and film. Any process or substance that changes any of these variables can be detected by measuring shifts in the Bragg wavelength. The CBP allows STFs to be used in sensor applications. STFs that are difficult to deposit in the correct crystal phase or stoichiometry must be annealed after deposition. Amorphous films may become partially crystalline through low temperature crystallization. This change in refractive properties changes the Bragg response and makes sensors less consistent. A volume change also occurs during most annealing processes intended to change stoichiometry. The periodicity of the films would change, thus changing the Bragg response. Recent research with tin oxide films suggests these trends. In this study chiral titanium dioxide films were deposited using the serial bideposition technique. This technique produces films with a high local linear birefringence that is necessary for detecting shifts in the CBP. Measurements were made of the film's crystallinity, circular and regular transmission spectrums, and composition before and after annealing. SEM analysis of the films was used to view the films morphology. As-deposited films were amorphous. Films were annealed in an oxygen environment and formed crystalline anatase. Results show that Bragg wavelengths were blueshifted as much as 30nm and that linear birefringence increased slightly. These results were compared with values predicted from changes in refractive properties and periodicity.

Ying Shan[†], Charles E. Bakis — *Flexible Matrix Composite Actuators and Structures*

Flexible matrix composites (FMCs) consist of highly extensible, flexible elastomers reinforced by relatively inextensible, stiff fibers. FMCs are particularly promising materials for large structural deformation applications. One possible application is to use FMCs to construct cylindrical, pressure driven actuators. These FMC actuators demonstrate various actuation behaviors (extending, contracting, and twisting) when pressurized, depending on the lamination configuration of the membrane. Special interest is given to the contracting type actuator because of the mechanical advantage it provides, and its analogy to muscle function. Using a continuum mechanics approach, a finite axisymmetric deformation model is developed to model the behavior of contracting type FMC actuators during pressurization. This model combines large deformation membrane theory and large deformation theory for laminated composites and is capable of including material nonlinearity and geometric nonlinearity that arise from large deformation and fiber reorientation. The behavior of FMC actuators under various loading conditions are discussed based on the proposed model.

Model predictions are compared with experiments and show good agreement. By integrating multiple FMC actuators together, it is possible to construct very interesting active structures. In the current study, a 4-tube active beam and a 20-tube active plate structure is presented. By actuating different combination of embedded tube actuators, these structures can demonstrate different actuation behavior as predicted by the finite element analysis. To demonstrate the concept and to validate the models, both active structures were built at the Composites Manufacturing and Technology Center at Penn State University. The experimentally observed actuation behaviors of these active structures follow the model predictions quite well.

Charan Srinivasan[†], Mark W. Horn — *Molecular Resists Enabling Nanofabrication*

Lithography is the technology used to transfer a pattern on to a silicon substrate to fabricate computer chips, for example. Aggressive scaling in the critical dimension of solid-state devices fabricated using lithography has enabled a new generation of computer chips every 2 years, with twice the processing speed (Moore's Law). Traditional lithography faces fundamental limits imposed by the laws of physics; in addition the cost of scaling increases exponentially with every new node of fabrication. The combination of conventional lithographic techniques with chemical self-assembly allows for the cost-effective creation of nanostructures whose spacing and line-edge resolution reach nanometer-scale precision. The controlled placement and thickness of self-assembled multilayers composed of alternating layers of α -mercaptoalkanoic acids and coordinated metal ions form precise molecular ruler resists to produce tailored, lithographically defined patterns. Initial structures created by conventional techniques are referred to as parents and subsequent structures generated by the molecular ruler process are identified as daughters, or subsequent generation structures. Other advantages of the molecular ruler procedure include increased throughput and reproducibility by automating the iterative nature of the procedure and by utilizing appropriate chemical liftoff solutions. These structures have sub-50 nm dimensions, and can be applied in a variety of critical applications such as nanoscale device fabrication and advanced pattern transfer.

Ashutosh Tewari[†], Mirna Urquidi-Macdonald — *A Novel Approach to Build and Train a Hybrid Neuro-Fuzzy Knowledge Based System*

The hybrid neuro-fuzzy inference systems have found variety of applications in different fields primarily because of 3 reasons. Firstly, such systems have the capability of inferring a database like a human expert. In other word, these systems deal with linguistic variables owing to the fuzzy logic which is used to infer the rule base. Secondly, the complexity of a system can easily be handled by constructing a set of rules, which would govern the system behavior. And last but not the least, the incorporation of artificial neural networks makes it possible to fine tune the parameters (mainly the shape of membership functions) of the resultant inference system via supervised learning algorithms. One of the most popular hybrid neuro-fuzzy inference systems, ANFIS (Adaptive Neuro-Fuzzy Inference System), [Jang, J.-S.R., IEEE Transactions on Systems, Man and Cybernetics, v 23, n 3, 1993, p 665-685] uses backpropagation algorithm to train the system parameters.

In this work we propose a new methodology to build hybrid Neuro-Fuzzy knowledge based systems, which can be used to model complex systems. In addition, a novel approach is being developed to train the parameters associated with the proposed hybrid neuro-fuzzy knowledge based system. This new training method developed for supervised learning is computationally less intensive as compared to the commonly known back propagation algorithm. Moreover, as compared to the ANFIS model the proposed neuro-fuzzy inference system is more robust i.e. it is less prone to errors if the training data set used for supervised learning is erroneous.

Fei Yan[†], Eric Hauck, Huidong Gao, R. Ramsharan, Joseph Rose, Elizabeth Blickley, and Bernhard Tittmann — *Ultrasonic Guided Wave Tomographic Considerations for Structural Health Monitoring*

Ultrasonic guided wave tomography has great potential for structural health monitoring. In this study, circular arrays of 16 piezoelectric wafer sensors were used to monitor damage added to an aluminum plate and an orthotropic carbon-fiber composite plate via Lamb waves. Baseline data was taken for both plates before any defects were introduced. Three simulated corrosion defects were introduced to the aluminum plate. The composite plate was impacted three times to create internal delaminations. Damage state data was collected after each defect was created. Signal difference coefficients (SDCs) were calculated for the ultrasonic guided wave signals taken by each sensor pair in different states. The SDCs were used as the input for guided wave tomography algorithms. Two image reconstruction algorithms were used in this study: the reconstruction algorithm for probabilistic inspection of damage (RAPID) and the algebraic reconstruction technique (ART). The abilities of both algorithms to accurately locate the defects and image multiple defects were studied by modifying the controllable parameters of the algorithms and comparing the reconstructed images with ultrasonic C-scans. Sparse array (8 sensors) measurements were also studied. The experimental results showed the following: Both reconstruction methods, RAPID and ART, can locate single defects reasonably well and are comparable to C-scan delamination images. However, both methods require parameter tuning for accurate detection of defects. The anisotropy of the composite plate limited multiple defect imaging. With fewer sensors, the orientation of a sparse array may affect the location of the defect on the reconstructed image in a composite plate. At this time, ART has better potential to locate and size multiple defects in both isotropic and anisotropic materials.

Abstracts: Posters

Huidong Gao[†], Joseph L. Rose, and Manton Guers — *Flexible Ultrasonic Guided Wave Sensor Development for Structural Health Monitoring*

Sensor development and signal processing are two key issues in structural health monitoring (SHM). In the works presented in this paper, PVDF sensors are designed to monitor the occurrence and progression of simulated circular shaped corrosion damages in an aluminum plate. Guided wave propagation analysis was used to select effect wave modes for the damage detection and assessment. Three dimensional finite element method (FEM) analysis were performed to study the wave field excited from PVDF annular arrays and sectioned annular arrays in the aluminum plate. A sectioned annular array design with enhanced mode selection capabilities was utilized in the experiment. A distributed sensor network consisting eight sensors were permanently attached to the plate. The simulated corrosion damages were successfully detected, localized in the structure using wave mode based signal analysis and feature extraction. The relation between the damage severity and the features from the signal were also studied and presented in this paper.

R. Lance Haney — *Microwave Characterization of Thin Film Titanium Dioxide*

Utilizing parallel plate capacitor structures with short standards designed for microwave frequency operation; titanium dioxide (TiO₂) thin film dielectric characteristics were obtained. The TiO₂ thin film was deposited on a Pt electrode layer utilizing a pulsed DC sputtering system. Lithography techniques were used to pattern the top Pt structure. The TiO₂ thin film in a mixed anatase [101]/rutile [110] crystalline structure was found to have an average permittivity of 67.2 and the Q of the device was determined to range from 27 to 4 in the frequency range of 1–3 GHz.

Eric T. Hauck[†], Yun Zhu, and Joseph L. Rose — *Novel Methods for Crack Detection in Green and Sintered Parts*

Crack detection in unsintered, or green, powder metal parts has been of interest for decades with no commercial solution available. Traditional ultrasonic techniques using liquid couplant cannot be used with green parts since residue left behind from the couplant will degrade the final quality of the sintered part. Two couplant free techniques are presented for the inspection of green and sintered parts. The surface wave mediator technique uses point contact with a part to induce and receive Rayleigh surface waves which are sensitive to surface breaking cracks and density variations. The mediator tip can be shaped to effectively inspect both flat and curved geometries such as boreholes. Feasibility studies performed using ultrasonic Electromagnetic Acoustic Transducers (EMATs) on both green and sintered parts have been successful in impinging ultrasonic energy into the parts for defect detection. Due to the low aspect ratio of many powder metal parts, ultrasonic guided waves can provide full part characterization. Shear horizontal waves were used to inspect the flange of a transmission part and torsional waves have been used to inspect the welded region of a sintered porous filter.

Jing Mu[†], Li Zhang, Joseph L. Rose and Jack Spanner — *Defect Sizing in Pipe Using an Ultrasonic Guided Wave Focusing Technique*

Circumferential defect sizing is studied with an ultrasonic guided wave focusing inspection technique. Differently shaped defects, such as a planar saw cut, a volumetric through-wall hole, and volumetric spherical shape corrosion are studied. A Phased array is used to spin the focal point of the ultrasonic energy around the pipe. The maximum amplitude of the defect echo is recorded with respect to each circumferential focal position. Circumferential lengths of the planar saw cut and volumetric through-wall hole are then measured

by comparing the experimental results with numerical calculations obtained through use of the Normal Mode Expansion Method (NME). It is shown that this measurement technique works well with the planar saw cut and volumetric through-wall hole defects. In addition, it is shown that reflections from defects with the same cross sectional area (CSA), but different shapes, might be very different. A 1% CSA through-wall hole can give a substantial reflection, whereas the reflection from a 1 % CSA spherical corrosion could be very small. This implies that defect surface shape plays an important role in wave reflection and scattering and must be considered in defect sizing studies.

Ying Shan[†], Charles E. Bakis — *Flexible Matrix Composite Actuators and Structures*

Flexible matrix composites (FMCs) consist of highly extensible, flexible elastomers reinforced by relatively inextensible, stiff fibers. FMCs are particularly promising materials for large structural deformation applications. One possible application is to use FMCs to construct cylindrical, pressure driven actuators. These FMC actuators demonstrate various actuation behaviors (extending, contracting, and twisting) when pressurized, depending on the lamination configuration of the membrane. Special interest is given to the contracting type actuator because of the mechanical advantage it provides, and its analogy to muscle function. Using a continuum mechanics approach, a finite axisymmetric deformation model is developed to model the behavior of contracting type FMC actuators during pressurization. This model combines large deformation membrane theory and large deformation theory for laminated composites and is capable of including material nonlinearity and geometric nonlinearity that arise from large deformation and fiber reorientation. The behavior of FMC actuators under various loading conditions are discussed based on the proposed model. Model predictions are compared with experiments and show good agreement. By integrating multiple FMC actuators together, it is possible to construct very interesting active structures. In the current study, a 4-tube active beam and a 20-tube active plate structure is presented. By actuating different combination of embedded tube actuators, these structures can demonstrate different actuation behavior as predicted by the finite element analysis. To demonstrate the concept and to validate the models, both active structures were built at the Composites Manufacturing and Technology Center at Penn State University. The experimentally observed actuation behaviors of these active structures follow the model predictions quite well.

Jason Van Velsor — *Health Monitoring of Rock Bolts Using Ultrasonic Guided Waves*

Approximately 200,000 high-strength rock bolts were used in the construction of the five-step ship lock that allows ships to circumnavigate Three Gorges Dam in the Hubei Province of China. There is an imperative need for the length and bonding evaluation of these embedded rock bolts, both for determining the quality of construction and for health monitoring of the structure in service. Deviations from the pre-embedded length indicate a fractured bolt and delaminations between the rod and concrete imply a weak bonding condition. In this study, the propagation of ultrasonic guided waves in a two-layered structure, composed of a solid steel rod and a semi-infinite layer of concrete, is investigated theoretically and experimentally. The longitudinal mode dispersion equation is analyzed with assumptions of continuous stress and displacement along the rod-concrete interface. Numerical simulations of the longitudinal mode dispersion curves and particle displacement distributions are generated. Utilizing these theoretical and numerical simulations, a series of experiments, involving longitudinal mode propagation in a simulated rock bolt, was completed. Five specimens were constructed using 3 foot long, ? inch diameter steel rods embedded in concrete. Each of the specimens had a different amount of simulated delamination measured as a percentage of the entire rod length. In addition, a sixth, un-embedded rod was used to simulate a 100 percent delamination. These specimens were then used to investigate the possibility of performing guided wave health monitoring using a pulse-echo arrangement. It is demonstrated that with the optimum mode, frequency, and transducer, it

is possible to perform rod length measurement and delamination detection using ultrasonic guided waves. Experimental results are in good agreement with theoretical analysis.

Cliff Zearfoss — *High Frequency Piezoelectric Transformers*

Piezoelectric transformers have been in use for a little over 50 years. They are devices that operate electro-mechanically via the piezoelectric and the converse piezoelectric effects. They often are advantageous because of their low magnetic flux, high efficiency and small size. Their operation at a specific resonant frequency gives them a narrow bandwidth, which in turn creates and restricts some of their practical applications. In an effort to explore a range of applications, this study designed and tested three types of transformers. The goal was to push for an operational frequency that is as high as possible. First a Rosen-type transformer was constructed. This transformer achieved a gain of 4.64 at frequencies of about 63.4 kHz. A stack transformer was fabricated next. This transformer achieved a gain of 0.296 at a frequency of 680 kHz. Finally transformers were fabricating utilizing thin film technology with designs similar to surface acoustic wave devices. Preliminary results show that these transformers can provide output voltages around 65 MHz and may provide voltage gains greater than 1. Each of these transformers achieved their goals of obtaining higher resonant frequencies but not always achieving a gain greater than 1. An equivalent circuit analysis following the groundwork originally made by Mason was developed for the Rosen-type and stack transformers. From this equivalent circuit an equation for gain as a function of angular frequency was derived and successfully matched data taken experimentally. An alternative form of analysis has also been derived which also matches the experimental data with similar success for both the Rosen-type and stack transformers.