EURODINAME III
Preliminary programme

This proceedings volume presents the tentative programme, including all abstracts to be presented during EURODINAME conference. Updated on May 22, 2026.

Opening Ceremony

Morvan OUISSE, Rafael TELOLI, Domingos ALVES RADE, Paulo Roberto Gardel KURKA

Mon 08/06 - 14:30

Opening Ceremony

Opening Keynote

Chair: Didier Remond

Mon 08/06 - 14:40

From classical rotordynamics to smart rotors

V. STEFFEN JR[1]
[1] *Federal University of Uberlândia - UFU*

Opening Keynote - Paper 14132

Since the first paper on rotordynamics by W. J. M. Rankine in 1869, titled "On the centrifugal force on rotating shafts", this research topic has gained increasing attention from scientists and engineers over the world. It is possible to say that most of the tools used in the study of rotating systems have been developed throughout the last century, particularly after 1950. In general terms, most of the work developed so far can be classified as classical rotordynamics, encompassing numerical methods dedicated to the determination of Campbell diagram, unbalance responses, orbits, and modal analysis, and experimental testing both in university laboratories and industry facilities. It is worth mentioning that the impressive development of digital computers together with enhanced numerical methods (such as those for direct and inverse problems and uncertainty analysis), control techniques, signal analysis, new sensors and actuators, and material science have made possible new achievements on rotordynamics, permitting an evolution from the so-called Classical Rotordynamics to Smart Rotors whose definition is still under construction. As a suggestion, a smart rotor is the rotating system that besides allowing classical rotordynamics analysis and optimization, can offer automatic diagnosis of faults together with the ability to apply control forces to optimize the dynamics of machine behavior aiming at quiet, ecological, robust and efficient machines. At the same time industry has increased the demand for high efficiency, thus requiring even higher rotation speeds requiring more flexible rotors and new types of bearings and couplings. The present contribution is dedicated to exploring some examples of successful research on the dynamic behavior of smart rotors.

Rotor dynamics

Chair: Aldemir Ap Cavallini Jr

Mon 08/06 - 15:20

Angular harmonic balance method for the bifurcation analysis of rotating machines in non-stationary conditions

D. REMOND[1], V. CLERC[1], M. AHANI[1], R. ALCORTA[1]
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Rotor dynamics - Paper 15010

Numerical continuation methods, a powerful tool for studying the dynamics of nonlinear systems, is typically limited to steady-state regimes such as static of periodic solutions. Moreover, they cannot be directly applied to rotating mechanisms due to the presence of rigid-body modes. In this contribution, we propose a method to extend such methods to the aforementioned applications, such that they may provide meaningful information about the bifurcations to be encountered under non-stationary conditions. The key idea is to use an angular transformation of the equations of motion, followed by changes of variables and the use of the harmonic balance method. Furthermore, we detail a practical implementation of the method which reduces the number of back-and-forth transformations between angle and angle-frequency domains to a minimum, and consequently the numerical effort for solving these sophisticated dynamical behaviours. Our method is tested on an example system, showing excellent agreement and opening the door to a wide range of further studies in analysis of bifurcations.

Mon 08/06 - 15:38

Rotating machinery balancing without test weights using cokriging metamodeling

T. C. EMRICH[1], A. CAVALLINI JUNIOR[1], D. P . LANNES[2], V. STEFFEN JUNIOR[1]
[1] *Universidade Federal de Uberlandia - UFU,* [2] *Universidade Federal Fluminense*

Rotor dynamics - Paper 12402

Unbalance is one of the main causes of mechanical problems in rotating machinery, leading to excessive vi- bration levels, premature component wear, and catastrophic failures. The influence coefficient method, widely used in industry, requires test runs with trial masses, which prolongs maintenance time and increases costs. This work proposes a balancing methodology without test weights using cokriging metamodeling. The approach combines two data sources: experimental vibration signals collected directly from the machine (high-fidelity data) and numerical vibration signals generated from a finite element model (low-fidelity data). The methodology was validated both numerically and exper- imentally using a Bently Nevada RK 4 Rotor Kit test rig. Numerical validation considered Monte Carlo uncertainty in bearing parameters and rotor elastic modulus. Experimental validation used 7 high-fidelity samples and 110 low-fidelity samples, achieving an average vibration reduction of 84.20% with a standard deviation of 9.64 for the reference sensor, excluding outliers (49.41%). Cross-validation with 15 different training sets showed an average reduction of 74.02% with a standard deviation of 6.27%, demonstrating the robustness of the methodology. The results indicate the viability of the proposed approach for rotating machinery balancing without the need for trial mass runs.

Mon 08/06 - 15:56

Integrated multiphysics framework for gust-induced dynamic response of wind turbine rotors

R. MARTINS DE CASTRO NETO[1], L. CAMPANINE SICCHIERI[1], F. JOSÉ DE SOUZA[2], A. APARECIDO CAVALLINI JR.[1], V. STEFFEN JR.[1]
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Rotor dynamics - Paper 13482

This paper presents an integrated multiphysics computational framework for analyzing the dynamic response of wind turbine rotors subjected to gust excitation. Aerodynamic loads are computed using a nonlinear Vortex Lattice Method (NL-VLM) with a decambering correction and validated against the reference power and thrust curves of the NREL 5-MW turbine, yielding discrepancies of approximately 9% for power and 18% for thrust. Structural and drivetrain dynamics are modeled using a finite-element shaft formulation that includes rigid disks, rolling-element bearings, and equivalent gear-mesh elements representing the multi-stage gearbox. Owing to the limited availability of public drivetrain data, complementary literature sources were used to define consistent inertial and geometric properties. Time-domain simulations are performed using the Newmark method, considering residual mass unbalance levels defined according to ISO 21940 and IEC-prescribed gust events, including wind-speed and combined wind–yaw disturbances. Frequency-domain analyses based on the Discrete Fourier Transform (DFT) show that residual unbalance predominantly excites the fundamental rotational harmonic (1X), whereas aerodynamic gust effects introduce dominant components at 3X and higher harmonics. The results demonstrate the proposed framework's ability to capture coupled aerodynamic–structural interactions and their influence on drivetrain vibration behavior.

Coffee Break

Mon 08/06 - 16:14

Coffee Break

Smart and Advanced Structures for Vibration and Acoustic Control

Chair: Manuel Collet

Mon 08/06 - 16:35

Optical visualization and motion control of acoustically levitated particles

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 12838

This paper studies the controlled movement of acoustically levitated particles along a designated path by combining phase-based boundary control of actuators with mechanical tilting. The ultrasonic field is visualized using optical (Schlieren) imaging with stroboscopic modulation. The latter enables the separation of energy flux (traveling waves) from standing acoustic waves. Extensive simulations and experiments underscore the importance of incorporating impedance boundary conditions to model the pressure distribution accurately. The study challenges common modeling assumptions—especially the use of scalar Gor'kov potential formulations in standing wave analysis—and proposes an alternative approach that involves the acoustic intensity vector field. The local balance of standing and traveling waves is quantitatively evaluated through RMS calculations of this vector field and the real and imaginary parts of the acoustic pressure field. Boundary Element Method (BEM) simulations are extensively performed, validated, and refined using experimental data and Schlieren visualization. A modified Schlieren imaging technique, integrating an ABEL transformation designed to eliminate optically accumulated pressure artifacts, successfully reconstructs the true cross-section of the acoustic field.

Mon 08/06 - 16:53

Reinforcement learning technics for reaching stable control of electroacoustic absorbers

A.D. FLOR TORQUATO FERNANDES[1], L. FERREIRA[2], E. DE BONO[3], R. TELOLI[2], M. OUISSE[2], S. DE ROSA[3], G. PETRONE[3]

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13458

In recent years, active noise control approaches have gained growing interest in the market, being used in devices such as earbuds and headphones. One promising direction involves Electroacoustic Absorbers (EAs), systems that combine a loudspeaker diaphragm with collocated microphones. By monitoring the pressure inside a cavity and applying a control algorithm, the absorber adjusts the velocity at the resonator's surface to enforce a target acoustic impedance. This enables custom absorptions at specific frequency targets.This type of control differs from conventional active noise control by not employing the concept of anti-noise. Instead of creating a quiet zone, these devices modify the boundary conditions of a chamber, much like passive solutions such as porous materials or Helmholtz resonators.Although specific impedances can currently be targeted, these systems remain incapable of self-adapting their control algorithms to different conditions and are prone to instability depending on the target impedance. To overcome these limitations, this work explores the use of reinforcement learning (RL) to improve adaptability and robustness under changing environments.Reinforcement learning is a subset of machine learning algorithms in which an agent learns to identify an environment while taking actions to optimize its performance. It does so by receiving from the environment a reward function, which must be optimized to achieve its highest value over time. These techniques differ from traditional machine learning in that they do not require a pre-existing dataset to be trained. Thus, the agent can be deployed in an environment and learn its particularities from the data it collects, without relying on previously known information. By constantly updating the world model it constructs, the algorithm can track changes in the environment and adapt its policy accordingly.In this study, off-the-shelf reinforcement learning algorithms will be deployed to enhance the functioning of the current control strategy in order to reduce its instabilities while still making it capable of achieving the target absorption.

Mon 08/06 - 17:11

Spatial modulation of electroacoustic absorbers for programmable wavefront control

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13478

Acoustic metasurfaces composed of subwavelength resonant elements can be classified as passive or active depending on their ability to adapt their properties in real time. Among active solutions, electroacoustic resonators offer a versatile platform, as their target acoustic impedance can be individually programmed

through a pressure-based, current-driven control law. This reconfigurability makes them natural candidates for implementing spatially varying boundary conditions without mechanical modification. This work investigates the effect of spatially modulating the control law parameters of an electroacoustic resonator array on the reflected acoustic field. A periodic cosine modulation is applied to the target stiffness along the metasurface, and the resulting scattered field is analyzed using a Bloch-Floquet expansion that predicts the wavenumbers of the generated spatial harmonics. Finite element simulations confirm that the modulation generates harmonics whose propagation angles are governed by the modulation wavenumber, enabling controlled beam splitting away from the specular direction. A trade-off is identified between the angular separation of the harmonics and the range of admissible incidence angles. The results demonstrate programmable wavefront control through spatial modulation of the surface impedance, providing a foundation for the analysis and design of reconfigurable acoustic metasurfaces.

Mon 08/06 - 17:29

Dispersion tailoring by nonlocal acoustic liners

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[1] *University Federico II of Naples, Department of Industrial Engineering*

Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13502

Nonlocality is being exploited by so-called metamaterials or metasurfaces to achieve larger wave manipulation capabilities, for example by dispersion tailoring or reflection and transmission steering, both in solid mechanics and acoustics. The study of nonlocal interactions in acoustic metamaterials has larger impacts also in other fields of research, such as quantum mechanics and medicine, where the dimensions involved are excessively small. Indeed, nonlocality is often introduced in acoustic macroscopic analogues of condensed-matter systems, which are able to reproduce salient phenomena of quantum mechanics. In addition, nonlocality also characterizes the recent modelling of the cochlea of our ears, as an array of micromechanical resonators, in the attempt to explain the tinnitus. In this contribution, we investigate the potential of nonlocal interactions in acoustic liners to tailor the dispersion function, by extending the previous achievements from solid mechanics to acoustics. Acoustic liners are used to treat noise propagation in waveguides, and are applied to ducts' parietal walls. It is the so-called grazing-incidence problem. The industrial application of acoustic liners ranges from noise treatment of Heating and Ventilation Air Conditioning systems (HVAC) to reduction of noise radiation from turbofan engines. The general framework employed in this contribution might be exploited by either passive or active means.

Mon 08/06 - 17:47

Design methodology of synclastic sandwich composites at resonance for piezoelectric energy harvesting

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13483

This work proposes a methodology for the dimensioning and design of synclastic sandwich composites. For conventional materials, Poisson's ratio typically ranges between 0 and 0.5. In certain cases, however, cellular solids can be structured to exhibit a negative Poisson's ratio. Such structured materials referred to as auxetic involve two main types of geometrical configurations: inverted honeycomb cells and chiral structures (e.g., tetrachiral, hexachiral). The use of an engineered auxetic structure as the core layer of a

sandwich composite can allow the overall structure to exhibit auxetic behavior. Such behavior can be useful in several applications such as piezoelectric energy harvesting [1]. The behavior of auxetic structures embedded in sandwich composites is well understood under axial loading, but less under bending. When dealing with structures with global negative Poisson ratio, the corresponding flexure is referred to as synclastic. Here, we propose a new dimensioning methodology for sandwich composites employing an auxetic structure as the core layer. The dimensioning approach combines finite element analysis with homogenization techniques. The auxetic core layer is modelled as a homogenized orthotropic material characterized by directional elastic moduli and Poisson's ratios. It appears that, to maximize the ability of the auxetic core layer to achieve overall synclastic behavior, its lateral stiffness should be maximized. Indeed, if the lateral Young modulus, E2, is weak compared to the stiffness of the outer skin layers, Achieving proper synclastic behavior may be challenging. However, using re-entrant honeycomb, parametric studies also show that the higher the lateral stiffness is, the higher the Poisson's ratio is (getting closer to 0, even turning positive), reducing therefore, the synclastic behavior. The analysis of these initial results, obtained using FEM Comsol simulations under static loading conditions and subsequently validated at resonance, will be presented at the conference. Preliminary experimental results with a prototype with re-entrant honeycombs, based on 3D vibrometry and curve fitting, confirm the trends. Experimental measurements are under progress on machining an aluminum core layer and bonding it with outer layers to validate the experimental Poisson's ratio behavior under resonance conditions of sandwich. [1] Ferguson, William JG, et al. Auxetic structure for increased power output of strain vibration energy harvester. Sensors and Actuators A: Physical 282 (2018): 90-96.

Mon 08/06 - 18:05

A thermally driven smart sandwich structure with a shape memory polymer core for semi-passive vibration control

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13706

Constrained layer damping (CLD) treatment is a passive technique used to reduce vibration levels by incorporating viscoelastic materials into multilayered structures to increase structural damping. As a passive vibration control technique, it does not require external energy input to operate. In particular, the damping layer contributes to vibration reduction when the structure is subjected to high-frequency excitations. However, the efficient design of such a solution often requires an appropriate strategy for allocating the viscoelastic layer, since the strain energy distribution varies with load frequency and boundary conditions. Moreover, improving the robustness of traditional CLD solutions leads to an increase in structural mass, and the resulting multilayered structures still lack adaptability once fabricated. The development of advanced materials such as shape memory polymers (SMPs) enables the design of structures with enhanced adaptability. By controlling the temperature-dependent mechanical properties – storage modulus and loss factor – of these viscoelastic materials, a multilayered structure can exhibit various dynamic behaviors. In this work, a thermally driven sandwich structure is developed by integrating embedded thermocouples and in-core heaters to achieve active thermal control. The structure is divided into independently controllable patches, allowing it to be programmed with distinct thermal configurations. This capability enables local adjustments of stiffness and damping through temperature control at each patch, thereby enhancing the overall adaptability of the structure. An equivalent modeling approach for the sandwich structure is adopted to construct a Pareto front that evaluates the damping and static stiffness levels of various thermal configurations. Based on different damping–stiffness trade-offs, the dynamic responses of selected configurations are experimentally characterized. The results demonstrate that the proposed structure exhibits improved adaptability and achieves significant vibration reduction under different imposed thermal configurations.

Mon 08/06 - 18:23

Robust design of shunted and active piezo metamaterial for cloaking against flexural waves

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 13682

The metamaterial we are interested in is a plate with a circular hole for which we want to suppress the scattering effect by using a cloaking domain around the hole. The cloaking strategy consists of dividing this domain into two: an absorbing region in front of the incident waves, and a second one at the back of the hole, which will synthesize the missing wave front. The absorbing region is realized using negative capacitance shunted piezo patches, and the emitting one with voltage-controlled piezo patches.Negative capacitance shunting of piezo patches is an effective solution for achieving broadband vibration control of flexural waves. The tuning process of the metamaterial to achieve absorption leads to close to unstable modal zone and thus sometimes to trade-off between stability and performance. To better known the interaction between the operating and manufacturing environment, for example industrial ones, and the targetted configuration, we need to evaluate its robustness. However, to date, no articles have tackle this issue. Therefore we propose to study the influence of the uncertainty of shunted and voltage-controlled patches parameters and excitation frequency on stability and on the cloaking of incident flexural waves with respect to our two-region strategy. The studied structure is an aluminum plate with a circular hole surrounded by arrays of bonded piezoelectric ceramic patches connected to their electrical circuit. Starting from the optimal configuration, we first proceed to a sensitivity analysis on the targeted frequency interval using Morris method on our 3D FEM model. After screening the most significant parameters, we construct the probability distribution functions according to the principle of maximum entropy and finally propagate the uncertainties to the cloaking performance using Monte-Carlo method. Finally we aim to develop a robust design methodology allowing us to treat performance reduction as a specification of the metamaterial thus being able to treat quantitatively the trade-off between performance, uncertainty and stability.

Mon 08/06 - 18:41

Comparing spatially periodic feedback and space-time modulation for unidirectional wave propagation in a 1d mass-spring-damper system

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Smart and Advanced Structures for Vibration and Acoustic Control - Paper 14415

Unidirectional wave propagation has emerged as a key concept in the dynamics of non-reciprocal mechanical and acoustic metamaterials. This work investigates two fundamentally distinct strategies for achieving directional wave propagation in a periodic one-dimensional mass-spring-damper lumped system: space–time modulation and spatially periodic feedback. In the first approach, the springs' stiffness is modulated periodically in both space and time. The resulting space–time periodic system is analyzed using a Plane Wave Expansion (PWE) formulation based on the Bloch-Floquet theory to obtain the dispersion relation. The traveling modulation produces asymmetric dispersion diagrams and directional band gaps,

within which elastic waves propagate preferentially in a single direction due to broken time-reversal symmetry. In the second approach, non-reciprocity is introduced through a spatially periodic feedback action. The force input can depend on the displacement response and/or its derivatives, such as velocity or acceleration, and is applied to the masses along the system. The lumped system with a finite number of unit cells is modeled using classical mechanics principles, yielding a state-space model of the system. The active mechanism can generate directional amplification or attenuation via the non-Hermitian skin effect (NHSE), characterized by boundary-localized modes identified by a topological invariant, the winding number. Dispersion relations for both configurations are obtained using a PWE approach. The stability of the space-time periodic system is assessed through the Lyapunov–Floquet theory by computing the monodromy matrix over one modulation period. In the periodic feedback case, stability is investigated using the eigenvalues of the state matrix, which includes the feedback action. Finally, the results elucidates the fundamental differences between modulation-induced and feedback-induced non-reciprocity in mechanical systems, including achievable unidirectional bandwidth and stability limitations inherent to active systems. These results provide design guidelines for directional wave propagation in elastic waveguides.

Diner

Mon 08/06 - 19:00

Diner

Keynote Forum I - Vibration Control

Chair: Morvan Ouisse

Mon 08/06 - 20:30

Exploring ultra-low frequency isolation using the best from passive and active strategies

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Keynote Forum I - Vibration Control - Paper 15002

Passive vibration isolators are used at many places in daily life, e.g. car suspensions, silent blocs in washing machines, bushers, for drone cameras to cite a few examples. For some more specific applications, even small vibrations are not acceptable, for example: microscopy, medical imaging, lithography machines, tomography, or physics experiments. It often means that dedicated developments are necessary, mainly for two reasons: either due to the specific operating conditions (temperature, radiation, pressure,..), or due to the isolation requirements which are too stringent.Emblematic examples of dedicated developments are large physics instruments like gravitational wave detectors, light sources, or particle accelerators.Most efficient vibration isolation systems on Earth are found in gravitational wave detectors. After about half a century of research and development, their seismic isolators allow to reach a stability at the attometer scale (10^{-18}m), which allowed to make de the first detections of gravitational waves, and give birth to experimental gravitational wave astronomy. To pursue the exploration of the universe through gravitational waves, even better isolators will be required in future instruments, especially at low frequency.The paper will first review fundamental limitations of passive and active isolation systems. Then, in order to bypass these fundamental limitations, and further improve the isolation at low frequency, an original architecture will be presented using an active isolation platform, on which is installed a large, inverted pendulum. It is found that such unique hybrid configuration allows to improve drastically the isolation performance at low frequency. Experimental results will be shown to comply with the specifications of future gravitational wave detectors, and open new avenues for other applications with stringent specifications.

Mon 08/06 - 20:50
Piezoelectric metamaterials for sound and vibration control

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Keynote Forum I - Vibration Control - Paper 15004

Dynamic metamaterials are engineered structures capable of controlling wave propagation through band gaps, i.e., frequency ranges in which waves are suppressed. Tunable or programmable functionality is typically achieved via mechanical reconfiguration or multifield coupling. Among the available coupling mechanisms, piezoelectric materials are a particularly attractive choice, as wave behavior can be adjusted by modifying external passive shunt circuits or employing active control strategies. This talk explores tunable piezoelectric metamaterials for sound and vibration control. The presented cases focus on a reconfigurable piezoelectric metamaterial plate designed for both acoustic and vibration attenuation, as well as sound directivity control. In the first configuration, numerical and experimental results demonstrate that, by selectively adjusting the spatial distribution of tuned unit cells, vibrations can be confined to specific regions of the plate, producing distinct far-field radiation patterns at a target frequency. In a second case, an experimentally validated mode-shaping technique is introduced, enabling the induction of a specific mode at different target frequencies via an electromechanical coupling mechanism. The results highlight the metamaterial's ability for on-demand wave manipulation and adaptive sound field shaping, exhibiting similar directivity patterns across different operating frequencies. Overall, these findings underscore the potential of reconfigurable piezoelectric metamaterials as a versatile platform for adaptive noise and vibration control in engineering applications.

Mon 08/06 - 21:10
Shunted piezoelectric systems for passive structural vibration damping: recent developments and applications

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Keynote Forum I - Vibration Control - Paper 15005

Piezoelectric materials are widely used in structural dynamics due to their electromechanical coupling capabilities, which enable vibration sensing and control. Current research involving these materials spans several areas, including energy harvesting, as well as passive and active vibration control, and structural health monitoring.This presentation will focus specifically on passive reduction of structural vibrations using shunted piezoelectric patches, i.e., patches connected to resonant electrical circuits designed to dissipate mechanical energy. It will begin with a discussion of electromechanical modeling and numerical solution approaches, relying on the finite element method and the development of reduced-order models.Key parameters influencing the design and optimization of these passive damping systems will be highlighted. Their performance will then be evaluated through comparisons between numerical simulations and experimental results across various applications, ranging from vibration control of complex composite structures to problems involving nonlinear dynamics and fluid–structure interactions.Finally, recent advances

in multimodal damping will be presented, particularly through the use of multi-branch shunt circuits and interconnected electrical networks. Applications related to flow-induced vibrations in naval lifting surfaces will also be addressed.

Mon 08/06 - 21:30
Keynote forum i - vibration control - discussion

Keynote Forum I - Vibration Control

Breakfast

Tue 09/06 - 07:00

Breakfast

Multibody Dynamics and Control of Dynamical systems

Chair: Juan Camino

Tue 09/06 - 08:00
Analysis and correlation of railway measurement data using global navigation satellite system based curvature estimations

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[1] *Instituto Federal de São Paulo,* [2] *Faculdade de Engenharia Mecânica - UNICAMP*

Multibody Dynamics and Control of Dynamical systems - Paper 12085

This paper addresses the problem of accurately allocating measured railway operational data, obtained from different trips of an instrumented railcar. Precise geographic allocation of dynamical measurements obtained in different train trips is important to build a reliable database of the track's operational condition. The methodology involves transforming two or more Global Navigation Satellite System (GNSS) data into a consistent linear distance versus curvature information format. Both datasets are filtered and then re-sampled at regular, equal intervals to facilitate direct comparison. A correlation map image from curvature data is subsequently generated to identify the linear distance correspondence between the datasets, as well as to quantify and correct any linear scale discrepancies that may exist between them. The proposed correlation technique is applied to a couple of GNSS data collected from an actual railway instrumented vehicle, passing the same track position on different dates. A shorter distance length data record is compared to a longer track distance recording. This shows the ability of the technique to exactly position of the shorter distance measurements in the context of the longer distance track record. The quality of data correlation (possible linear scale discrepancies) is also accessed in the analysis.

Tue 09/06 - 08:18

Analysis of rollers' influence on the cargo velocity during a gravity airdrop operation

G. CARVALHO[1], Y. PEIXOTO[2], T. SALES[3]
[1] *ITA / EMBRAER,* [2] *EMBRAER,* [3] *ITA*

Multibody Dynamics and Control of Dynamical systems - Paper 13463

The floor of cargo aircraft is equipped with rollers that facilitate the loading and airdrop of palletized cargo during resupply missions. Since different aircraft use rollers of varying diameters and geometries, understanding if and how these parameters can influence the cargo drop time and its exit velocity from an aircraft is essential for improving drop accuracy and operational efficiency. To study this, in this work, the cargo airdrop is modeled as a rigid-body dynamic system, accounting for normal and tangential contact forces between the cargo and rollers. The tangential component of the contact forces is modeled such that static, dynamic, and transitional friction regimes are taken into account. The rollers are represented as cylindrical bodies of finite length, including their inertia and resistive damping moments that simulate bearing friction. Simulations were performed using a MATLAB code validated against MATLAB's Simscape platform. The results show that the damping coefficient associated with the rollers' resistance to rotation is the parameter with the greatest influence on the cargo dynamics, while variations in roller diameter and contact friction coefficients have lesser effects. The developed simulation framework provides a useful basis for enhancing the modeling and design of cargo airdrop systems and can support future studies aimed at improving drop accuracy and overall system performance.

Tue 09/06 - 08:36

Learning-based control of a single-dof aero system

G. DA SILVA LIMA[1], W. MOREIRA BESSA[1]
[1] *University of Turku*

Multibody Dynamics and Control of Dynamical systems - Paper 12929

This paper presents a learning-based control that integrates feedback linearization and reinforcement learning (RL) for adaptive control of nonlinear mechatronic systems. The control law is derived through Lyapunov stability analysis, ensuring closed-loop stability and convergence.Feedback linearization is employed as the main control framework, while a reinforcement learning component estimates and adapts to modeling uncertainties, unmodeled dynamics, and external disturbances. The RL module is based on the REINFORCE-with-baseline algorithm, which improves learning efficiency by reducing the variance of policy gradient estimates. This enables faster and more stable policy updates during online adaptation.The reward function is designed to balance trajectory tracking accuracy and control effort, promoting precise reference following while avoiding excessive actuation. Through this formulation, the controller autonomously refines its policy to minimize both the tracking error and the energy consumed in control actions.The proposed controller is experimentally validated on a one-degree-of-freedom (1-DOF) Quanser Aero system representing the pitch dynamics of an aerial platform. Results demonstrate accurate tracking performance, rapid convergence, and strong robustness against parameter uncertainties and disturbances.Overall, the proposed framework combines the analytical guarantees of Lyapunov-based control with the adaptability of reinforcement learning, providing an effective approach for intelligent and energy-efficient control of nonlinear mechatronic systems.

Tue 09/06 - 08:54

Machine learning-based feedback linearization control of quadrotor subject to unmodeled dynamics

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Multibody Dynamics and Control of Dynamical systems - Paper 13273

The control of agile quadrotors in dynamic and uncertain environments remains an open area of investigation to this day, particularly when the complete system dynamics are partially known or highly nonlinear. This work introduces a novel machine learning-based feedback-linearization control framework that employs a Gaussian Radial Basis Function (RBF) neural network (NN) to model and compensate for unmodeled dynamics in real time. The proposed controller leverages the universal approximation capability of RBF networks to model nonlinearities and uncertainties. An online adaptation of the RBF NN updates the network's weights without prior training. The control law is derived using the Lyapunov stability theory, herein guaranteeing closed-loop stability and providing theoretical guarantee of asymptotic convergence of a trajectory tracking task. Gazebo simulation and real flight experiments are conducted using the Bitcraze's Crazyflie 2.1 quadrotor subject to unmodeled air drag, actuator dynamics, and external disturbance. Despite incomplete knowledge of prior dynamics and presence of external disturbance such as air drag and drift in state estimation, the proposed controller improves trajectory tracking with rapid convergence and reduction of position-norm and yaw orientation RMSE by more than 7.13% and 49.27% respectively compared to baseline feedback linearization controller.

Tue 09/06 - 09:12

Influence of radial basis activation functions on intelligent controller for robotic manipulators

K. PALDANIUS[1], G. DA SILVA LIMA[1], W. MOREIRA BESSA[1]
[1] *University of Turku*

Multibody Dynamics and Control of Dynamical systems - Paper 13496

This paper presents an intelligent control framework for trajectory tracking of robotic manipulators using radial basis function (RBF) neural networks for online disturbance estimation. The proposed control structure combines modelbased nonlinear control with an adaptive neural approximator that compensates for parametric uncertainties, friction, and unmodeled dynamics. A Lyapunov-based adaptation law with projection guarantees boundedness of the closed-loop signals and convergence of the tracking error to a compact region. The primary objective of this work is to investigate how the choice of activation function within the RBF network influences transient behavior, steady-state accuracy, and control smoothness. The controller is implemented on a robotic manipulator. Experimental results demonstrate that although stability is preserved for all kernels, activation function selection significantly affects adaptation dynamics and practical tracking performance. These findings demonstrate that activation function selection acts as a structural design parameter in intelligent control, directly shaping adaptation dynamics and practical closed-loop performance.

Tue 09/06 - 09:30

Reducing vibrations enhances the aerodynamic performance of a flapping wing vehicle

R. CAVENAGHI SILVA[1], D. GARCÍA-VALLEJO[2], D. D. BUENO[1]
[1] *São Paulo State University (UNESP), School of Engineering, Ilha Solteira,* [2] *University of SevilleUniversity of Seville*

Nature evolved the ability to fly using a reciprocating motion of the wings to generate the lift and thrust forces required to sustain flight.On the other hand, conventional rotary or fixed-wing aircraft configurations generate these forces using rotating propellers.The flapping wing vehicle is a configuration inspired on natural fliers attracting attention from the research community that replicates the motion from flying animals to obtain better stealth, safety and maneuver characteristics in comparison with conventional designs. However, the flapping motion generate vibrations that propagates to the vehicle body and affecting the velocity on the aerodynamic surfaces.The objective of this work is to investigate how these vibrations affect the aerodynamic loads and analyzing the effect of including a vibration neutralizer to the vehicle design. Since the flapping wing vehicle operate in a narrow frequency band, a vibration neutralizer is included to passively reduce these vibrations by generating a force opposing the excitation source. The expected results is that the inclusion of the extra mass from the vibration neutralizer is justified by an increase of the generated lift.The equation of motion of the flapping wing body is derived from first principles using Lagrangian mechanics. The vehicle body is modeled by a series of mass and springs and the inertial loads of the wing during the flapping motion act as the excitation force. A vibration neutralizer is designed to suppress the vibrations originating at the flapping wing frequency and the frequency response functions of the systems are compared. The dynamic response of the system undergoing the flapping wing motion is obtained by integrating the equation of motion in time using a numerical approach. The Unsteady Vortex Lattice Method is used to model the aerodynamic loads, which assumes an incompressible, irrotational and inviscid fluid flow outside the regions of confined vorticity to find the superposition of elementary solutions of the Laplace equation that satisfies the non-penetration condition at the collocation points on the surface of the wing. The aerodynamic loads are computed using the Joukowsky method and the lift from the different models are compared to verify the efficacy of the vibrations neutralizer to the design of flapping wing vehicle.

Tue 09/06 - 09:48

On the use of a co-rotational finite element method to investigate flapping wing uavs

B. CARNIELO[1], F. TOFFOL[2], D. BUENO[1]
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Multibody Dynamics and Control of Dynamical systems - Paper 12933

Flapping wing air vehicles have attracted the interest of many researchers due to their flight efficiency, maneuverability and reduced noise generation. The silent and inconspicuous flying animal-like appearance reveals an interesting potential which can be used for military applications, ecological research and others. In nature, birds or insects use flexible wings and muscles to generate aerodynamic forces. Therefore, understanding the influence of flexibility on flapping wings can be useful to design unmanned aerial vehicles (UAVs). Despite the most recent research, it is still a challenge to develop this kind of aircraft, in part due to the nonlinear dynamics and unsteady flow, combined with the quantity of parameters that characterize the problem, for example, wing kinematics, geometry and structural properties. This work uses the co-rotational finite element model for three dimensional problems to evaluate the dynamic responses of a wing with spanwise flexibility. The co-rotational finite element analysis is a method applied to flexible multi-body systems with large displacements and rotations. An inertial system is used to define nodal coordinates, velocities, accelerations, displacements, and rotations. The equations of motion are defined with respect to the inertial system, while stresses are measured in the co-rotational coordinate system of the element. This element coordinates system rotates and translates along with each element but does not deform with it. This formulation is one of the approaches applicable to geometrically nonlinear problems, and its main advantage is that it leads to an artificial separation between material and geometrical nonlinearity. Moreover, Lagrange multipliers are used to impose the flapping motion, the structure's first node is constrained to follow a pre-determined sinusoidal motion. The structural flexibility is evaluated by considering different levels of stiffness, mainly focused on determining the influence of the nonlinear stiffness on the system responses. The wing behavior is also analyzed considering different flapping frequencies and amplitudes. The results demonstrate that it is an interesting approach to investigate flapping wing systems focused on designing bio-inspired aerial vehicles.

Coffee Break

Tue 09/06 - 10:06

Coffee Break

Metamaterials for vibration and acoustic control

Chair: Thiago de Paula Sales

Tue 09/06 - 10:30

A novel metastructure for vibration-related applications with tunable nonlinear properties

L.J.D. ALCÂNTARA[1], A. BARBOSA[2], L.P.R. DE OLIVEIRA[1], N. KACEM[2], N. BOUHADDI[2]
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Metamaterials for vibration and acoustic control I - Paper 13462

This work proposes a nonlinear metastructure architecture for vibration energy harvesting and sensing applications, enabling operation across both low- and high-frequency ranges. The system is modeled as an array of lumped-parameter piezoelectric Duffing oscillators, where the nonlinearity arises from geometric effects and the coupling between oscillators magnetically induced. Such configuration allows the exploitation of nonlinear resonance, multi-frequency synchronization, and inter-oscillator interactions to enhance power output and extend the operational bandwidth beyond that achievable by linear counterparts or by the simple superposition of individual units. Each unit cell consists of nonlinear beams whose geometry and axial stress are parametrically controlled, allowing tunability through straightforward adjustments in a 3D-printed design. In addition to frequency tuning, the coupling between neighboring cells enables spatial management of mechanical energy within the array, promoting localization phenomena such as stationary solitons and enabling both passive and active modulation of vibrational energy transfer. The main contribution of this study is the demonstration of a metastructure for vibration-related domains, that bridges nonlinear dynamics theory with practical engineering applications. To illustrate the approach, two configurations of particular interest are analyzed: a coupled multiresonant array, in which inter-oscillator energy exchange is investigated with emphasis on energy harvesting and vibration control, and a long periodic chain, whose continuous envelope formulation leads to a nonlinear Schrödinger equation describing stationary energy localization within the array.

Tue 09/06 - 10:48

Analytical modeling of dynamic buckling and nonlinear mode coupling in rotatable 2d mechanical metamaterials

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Metamaterials for vibration and acoustic control I - Paper 11739

Programmable mechanical metamaterials hold great promise for applications in vibration control and adaptive structures. However, their design is often constrained by the complexity of nonlinear dynamic behaviors. In this work, we investigate the dynamic buckling phenomena observed in coupled two-dimensional networks composed of rotatable nonlinear oscillators. Based on experimental prototypes, a finite element model is first developed using COMSOL to examine the static buckling behavior and identify mechanical parameters such as stiffness and mass. Subsequently, an analytical model of the 2D network is established to analyze the linearized pre-stressed modes. The comparison with finite element simulations confirms the validity of the analytical formulation. Finally, the analytical model is employed to reproduce the experimentally observed nonlinear dynamic responses and to analyze the nonlinear coupled modes. This study provides theoretical insights into the coupled nonlinear dynamics of programmable mechanical metamaterials, offering a foundation for the design of adaptive and reconfigurable metastructures.

Tue 09/06 - 11:06

Modal interactions of an essentially nonlinear chain metamaterials

L. MESNY[1], R. ALCORTA[2]
[1] *ISAE-SUPAERO,* [2] *INSA Lyon*

Metamaterials for vibration and acoustic control I - Paper 13694

In line with the economical and ecological realities of the current day, industries -such as aerospace- turn towards increasingly lighter structures, whose integrity and overall performance must nevertheless be at least equivalent to that of previous designs. In this context, metamaterials offer a promising alternative, since they can be taylored in such a way as to achieve mechanical, acoustic and/or dynamical properties out of reach for conventional materials.In the field of vibrations, a current trend sees nonlinearity exploited to produce notable vibration reduction mechanisms, including in particular the mass-in-mass concept. Furthermore, recent advances in the field of hybrid control (i.e., combining passive and active components) has lead to the development of hybrid nonlinear absorbers. This motivates the idea of incorporating such mechanisms at the material level.The present work deals with the design of intelligent or adaptive structures, where nonlinear effects are understood as performance enhancers for advanced metamaterials rather than limitations. In particular, we conduct the study of a chain of lumped masses coupled to their neighbors through essentially nonlinear (cubic) springs, in order to understand its modal interaction mechanisms and their potential use within a functional chain-like metamaterial. To this end, a three-degree-of-freedom is generalized by leveraging periodicity boundary conditions. This modelling approach makes it possible to cast a light on atypical phenomena such as mode localization, forbidden bandwidths and bifurcations of different types.Our analysis incorporates both analytical and numerical methods. Nonlinear normal modes and frequency responses are computed to highlight the role of modal interaction as the driving mechanism behind efficient vibration absorption by a nonlinear chain. In this way, we pave the way for experimental validation of this metamaterial concept in the near future, and consider extensions such as the coupling with more traditional active or passive control strategies.

Tue 09/06 - 11:24

Computing nonlinear dispersion relations via harmonic balancing

R. BOUKADIA[1], E. DECKERS[2]
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Metamaterials for vibration and acoustic control I - Paper 13479

We introduce a general framework for computing nonlinear dispersion relations in homogeneous and periodic media exhibiting smooth nonlinearities. The method relies on a multi-harmonic expansion of nonlinear Floquet-Bloch waves, resulting in a nonlinear system of equations that can be efficiently approximated using the Harmonic Balance Method. As an illustrative example, the approach is first applied to a geometrically nonlinear Euler-Bernoulli beam, from which we derive amplitude-dependent dispersion relations and corresponding waveforms. We then extend the methodology to arbitrary finite element (FE) models, thereby generalizing the Wave Finite Element Method to nonlinear regimes, before applying it to a geometrically nonlinear locally resonant metamaterial. Although computationally intensive for full FE models, the proposed framework provides a powerful tool for designing complex nonlinear metamaterials.

Tue 09/06 - 11:42

Piezoelectric ceramics nonlinearities: experimental evidence of non-smooth nonlinearities and model identification using phase-locked-loop

O. THOMAS[1], H. FAYOLLE[1], C. BERTRAND[1], C. GIRAUD-AUDINE[2]
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Metamaterials for vibration and acoustic control I - Paper 15009

Among piezoelectric materials, PZT (lead zirconate titanate) ceramics are widely used because they offer the best performance in terms of electromechanical transduction and temperature stability. However, various literature results show that their dynamic response can be nonlinear. This talk will focus on the characterisation and identification of the nonlinear characteristics of simple piezoelectric resonators used for proof of concept for piezoelectric shunt damping or energy harvesting. The main originality of this work lies in the systematic use of experimental continuation techniques based on phase-locked-loop (PLL). It enables measuring and following nonlinear frequency response curves, including their possible unstable parts, but also to automatically measure backbone curves by locking the phase lag between excitation and response. Thanks to the phase resonance concept, it is possible to identify separately the conservative (with the backbone curve, which coincides with the conservative nonlinear mode) and dissipative (because the forcing exactly cancels the damping at phase resonance) parts of the nonlinear forces. For a piezoelectric resonator, three kinds of measurements are obtained with increased accuracy thanks to the PLL: (1) the backbone curves in open and short circuit (by locking the phase and changing the forcing amplitude); (2) some frequency response curves at several forcing amplitude (by changing the phase at constant input force) and (3) a third (and original one), useful for energy harvesting applications. In this case, the resonator is shunted by a resistor and the PLL enables measuring the evolution of the harvested power resonance as a function the resistor value, obtaining a continuous variation from short to open circuit, enabling efficient characterisation of the resonator, including its electrical part. This methodology was tested on two devices: a simple unimorph bender (an inox thin beam with a PZT patch) and a commercial MIDE bender. In both cases, we observed: (1) softening backbone curves with a non vertical slope at low amplitude; (2) an increase of the damping with respect to the motion amplitude and (3) open circuit resonances less damped than short-circuit ones. To explained those features, a refined analysis of nonlinear piezoelectric constitutive laws, including ferroelastic non-linearities (with a characteristic non-smooth part) and elastic, piezoelectric and dielectric losses, will be presented in order to explain and identify a model on the experimental results. Moreover, a refined study of the effect of the boundary conditions (clamped or free) on the

nonlinearities will be presented, in order to precisely quantify piezoelectric nonlinearities separately from other possible nonlinearities.

Tue 09/06 - 12:00

Characterizing the complex dynamics of a resonant linear oscillator coupled to a bnes and a piezoelectric element through fast–slow analysis

A. COUINEAUX[1], G. POULIN VITTRANT[1], S. BERGER[1], M.L. GOBERT[1], V. DENIS[1], M. BAVENCOFFE[1], B. BERGEOT[1]
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Metamaterials for vibration and acoustic control I - Paper 12990

In the context of the ecological transition, renewable energy sources such as wind turbines have become essential. However, these structures can experience harmful structural vibrations. A scientific, economic, and industrial challenge thus lies in designing devices capable of mitigating these vibrations. Among passive solutions, nonlinear energy sinks (NES) can be implemented. NES devices absorb vibrational energy over a wide range of frequencies through a phenomenon known as targeted energy transfer. Specifically, compared to classical NES, bistable NES (BNES) demonstrate enhanced ability to attenuate low-amplitude vibrations. Furthermore, the vibrational energy harvested by the NES can be converted into useful electrical energy using a piezoelectric element. This electrical energy could be used to power sensors, enabling wireless monitoring of wind turbines. The dynamic behavior of a mechanical oscillating system coupled with a BNES and a piezoelectric element is highly rich and complex, exhibiting multiple time scales. Therefore, to deploy such absorbers in complex systems like wind turbine blades, it is crucial to understand and identify the underlying dynamic mechanisms in simpler systems. To this end, this study examines an academic model: a damped harmonic oscillator forced by sinusoidal excitation, coupled with a BNES and a piezoelectric element connected to an electrical circuit with a simple resistor. Numerical simulations first reveal the wide diversity of observed vibrational regimes - periodic, quasi-periodic, or chaotic - and show the voltage obtained across the resistor. In a novel approach, the Multiple Scale/Harmonic Balance Method (MSHBM) is then adapted to account for the specific characteristics of the BNES compared to classical NES. This results in a reduced model, known as the modulation flow, which can capture the main diverse responses of the original system. Finally, a slow-fast analysis of the modulation flow is conducted, providing insight into (i) the emergence of these regimes and (ii) the effect of the piezoelectric element. This understanding paves the way for identifying optimal configurations of the NES and piezoelectric element to maximize both energy harvesting and vibration attenuation.

Lunch

Tue 09/06 - 12:18

Lunch

Keynote Forum II - SHM and Waves

Chair: Rafael Teloli

Tue 09/06 - 13:20

Fusing physics, data, knowledge and uncertainty for structural health monitoring

A. CICIRELLO[1]
[1] *University of Cambridge*

Keynote Forum II - SHM and Waves - Paper 15001

This talk will describe the fusion of physics, data, knowledge and uncertainty for addressing challenges in in real-world engineering applications of Structural Health Monitoring (SHM), especially when hybrid physics-data (i.e., Physics-Enhanced Machine Learning) models are developed. The engineering applications would span from laboratory setups to bridges, ferry quays and offshore wind turbines. Initially it will be assumed that the physics is well-known, and that there is uncertainty in the "data", in terms of obtaining measurements at critical locations of wind turbines and ferry quays. This challenge is addressed by developing PEML strategies that enable to combine Operational Modal Analysis with probabilistic machine learning strategies, to yield virtual measurements at critical locations. These virtual measurements have been validated with real-world measurements obtained in operating conditions, showcasing the flexibility of the method. It will be then considered that in typical engineering applications a partially correct physics-based model (uncertainty in the physics) of the underlying structure (e.g., without damage) is typically available, and confounding factors (including environmental and operational inputs, damage conditions, and other factors) are normally hidden in the structural response measurements (observable data). Blindly applying Bayesian Model Updating in such cases, would lead to a wrong assessment of the posterior distribution of the latent parameters of interest. In turn, this will affect downstream tasks such as damage detection and reliability assessment, therefore hindering the value of SHM. An adversarial Disentanglement strategy based on Backpropagation with Physics-Informed Variational Autoencoder is going to be presented. This approach enables learning disentangled representations of the contributing factors in the measurements that are used to build an explainable, controllable and robust digital twin with enhanced generalisation performance. A bridge-like case study is going to be detailed. Finally, an approach for dealing with the uncertainty in the knowledge of the force function model to be used to described non-smooth nonlinearities is going to be presented, with particular focus to the identification of the friction and vibro-impacts functional form of a laboratory setup.

Tue 09/06 - 13:40

Efficient modelling of interacting systems with physics-informed architectures

E. CROSS[1]
[1] *University of Sheffield*

Keynote Forum II - SHM and Waves - Paper 15003

Physics-informed machine learning is a rapidly expanding area of interest and one that holds great potential in harnessing the power of what we know and what we have yet to learn from data. In the context of our growing reliance on AI, pursuing technology that builds in physical insight brings opportunity to ensure or improve interpretability and trust, while also reducing computational burden. This talk will consider a range of interacting physical and data-driven (ML) models for complex environments, questioning their utility against deep data-driven only approaches, and also their efficiency in a computationally constrained environment.

Tue 09/06 - 14:00

Periodic structures for wave and vibration control: progress and perspective on bragg scattering, local resonance, and coupling mechanisms

E. MANCONI[1]
[1] *University of Parma*

Keynote Forum II - SHM and Waves - Paper 15006

Over the past few decades, periodic structures and metamaterials have revolutionised the way elastic and acoustic waves can be controlled, enabling vibration attenuation, noise reduction, and energy localisation from microstructured materials to large-scale engineering systems. Their fundamental mechanism, known as Bragg scattering, relies on periodic impedance changes that cause destructive interference and create frequency band gaps where vibrations and waves are attenuated even without material damping. This mechanism, first recognised in early studies of periodic strings and later formalised by Brillouin through wave dispersion theory in periodic media, provides the understanding of elastic and acoustic wave blocking in periodic waveguides. Although Bragg-type stop bands provide broadband attenuation, they depend on the lattice spacing (period), which limits their effectiveness at low frequencies. The introduction of locally resonant metamaterials, by embedding periodic subwavelength resonators within a host medium, has overcome this limitation. The hybridisation between resonator and host modes produces negative effective parameters and subwavelength stop bands, enabling significant low-frequency isolation. Analytical models and experiments - from the classical mass-in-mass chain to continuous resonant beams and plates - have shown how band gaps can be tuned by adjusting resonance frequency, mass ratio, and coupling stiffness. However, local resonance results in narrow attenuation zones, prompting strategies that widen or merge band gaps through hierarchical resonances, inertial amplification, or aperiodic arrangements. Beyond periodicity and resonance, a third, increasingly acknowledged pathway for controlling elastic and acoustic waves emerges from interactions induced by wave coupling. When waves from different families, such as axial, flexural, or torsional modes, interact, their dispersion branches may exhibit codirectional veering or contradirectional locking. These phenomena, initially classified within dispersion theory, are now employed to create complete band gaps without the need for external resonators. Geometry-induced coupling in folded, wavy, or corrugated structures exemplifies this mechanism: the locking of counter-propagating wave modes results in complex-conjugate wavenumber pairs and the formation of absolute band gaps. By combining periodicity, local resonance, and contradirectional coupling within a unified design framework, exceptionally broad and tunable band gaps can be achieved. This presentation aims to trace this development - from Bragg scattering to local resonance and coupling-driven mechanisms - and to explore how these mechanisms can be synergistically combined through optimisation and inverse-design strategies for broadband, adaptive wave and vibration control.

Tue 09/06 - 14:20
Keynote forum ii - shm and waves - discussion

Keynote Forum II - SHM and Waves

Damage detection and SHM

Chair: Elizabeth Cross

Tue 09/06 - 14:35

Unsupervised detection of leak onset in multiphase flows using hidden markov models

M.M. DONATONI[1], C.M. RUIZ-DIAZ[1], J.M.A.M. FRÓES[1], O.M. RODRIGUES[1], L.P. DE OLIVEIRA[1]
[1] *Universidade de São Paulo - Escola de Engenharia de São Carlos*

Damage detection and SHM - Paper 12065

Leak detection in multiphase flow pipelines is a critical challenge in industrial safety. Conventional alternatives, such as fixed-threshold methods, often fail as the leak's dynamic characteristics vary with the flow pattern. Moreover, time series segmentation methods, while effective, can be computationally prohibitive for high-frequency signals. This work proposes an unsupervised, computationally efficient method to identify the transition instant between normal operation and the onset of a leak using vibration signals. The experimental apparatus consists of a pipeline with a two-phase flow of mineral oil and sulphur hexafluoride, where a set of pilot-operated valves simulates leaks in upward, downward, and lateral directions. Monitoring is performed by four accelerometers positioned along the line, and their signals are segmented into 15ms windows, from which features in both the time and frequency domains are extracted. To classify the sequence of features into two states (no-leak and leak) a Hidden Markov Model (HMM) is employed with a customized transition matrix that prohibits the transition back from the leak state to the no-leak state, reflecting the irreversible physical nature of the event. Unlike clustering algorithms such as K-Means or Gaussian Mixture Models, which disregard the chronological order of data, the HMM models temporal dependency, resulting in a much more precise demarcation of the transition boundary. Furthermore, compared to segmentation methods which become extremely slow on high-frequency raw data, the proposed methodology is significantly faster. This efficiency is achieved by extracting computationally low-cost features, which effectively reduce the problem's dimensionality and accelerate HMM execution. Finally, the fully unsupervised nature of the approach eliminates the need for labelled data and allows for adaptation to varying flow conditions.

Tue 09/06 - 14:53

Integrated approach for failure investigation and prevention in large-scale hydromechanical systems

R.L. SCHAEFER[1], G.C. BRITO JUNIOR[1]
[1] *Universidade Estadual do Oeste do Paraná*

Damage detection and SHM - Paper 13476

This paper describes a failure in a 350 MW generating unit driven by a Francis turbine resulted in significant damage to the turbine headcover. The design features a baffle plate, which partially detached and caused damage to the rotor. The monitoring system did not issue any alerts. The event required the complete disassembly of the unit and the shipment of components for repair, leading to a prolonged loss of generating capacity. Given the severity of the incident and the potential for similar occurrences in other units of the power plant, the utility company adopted a structured and multidisciplinary approach to manage the crisis and prevent recurrence.Immediately after the event, a partnership was established with a university to support the root cause investigation. The work included reviewing technical documentation, reprocessing monitoring system signals, mathematical modeling, and numerical simulations of the unit's components, as well as inspections and dynamic testing on the remaining machines. Preliminary results indicated that pressure pulsations and self-excited vibrations, associated with operational conditions, were major contributing factors to the failure. Based on these findings, urgent corrective actions were implemented. Metallographic and structural tests performed by a specialized institution identified deficiencies in the quality of welds at critical joints, which were insufficient to withstand dynamic stresses under certain operating conditions. Borescope inspections in the remaining units revealed similar defects at early stages. Consequently, mechanical reinforcements were emergently implemented in the baffle plate

attachment by installing tie rods in a complex process, carried out with the units still assembled. Operation was resumed with intensive monitoring and continuous supervision of the identified critical areas. In addition to emergency actions, the utility initiated the development of long-term solutions focused on preventive maintenance and intelligent monitoring. Data acquisition and real-time diagnostic systems are being evaluated using vibration analysis and structural integrity techniques, aiming at the early detection of anomalies. Maintenance protocols were revised to include new inspection routines and non-destructive testing procedures. The manufacturing process of the new turbine headcover was also modified, replacing welded joints with more reliable fabrication methods. Continuous collaboration with universities and research institutes has been essential for developing innovative solutions and improving operational efficiency. The integrated response of the utility demonstrated that synergy between academic and industrial sectors is crucial to enhancing the reliability and safety of large-scale hydromechanical systems.

Tue 09/06 - 15:11

Robotic in-situ detection of magnetic wedge looseness in hydropower generators using ai

I.J. CÁRDENAS NUÑEZ[1], L.L. CONCEIÇÃO ARAÚJO[2], A.A. CAVALLINI JUNIOR[2], L.C. BRITO[2], M.A.V. DUARTE[2]

[1] *Universidade Federal do Triângulo Mineiro,* [2] *Universidade Federal de Uberlândia*

Damage detection and SHM - Paper 13485

Magnetic wedges are widely employed in hydropower generators to secure armature windings within stator slots, ensuring electromagnetic efficiency and mechanical stability during operation. However, prolonged cyclic loading, thermal stresses, and electromagnetic vibrations can progressively loosen the wedges, a critical failure precursor linked to insulation degradation, abnormal vibration, catastrophic machine failures, and reduced generator efficiency. Conventional inspection methods, such as manual percussion tests or partial disassembly, require extended outages and pose safety risks to inspectors; they also introduce strong operator dependence and subjective interpretation. To overcome these limitations, this work presents the development of an autonomous robotic system capable of in-situ detection of wedge looseness without stator disassembly. The proposed solution is a compact magnetic climbing robot (10 mm height, 250 mm width, 350 mm length) designed to navigate the narrow air gap of large generators. A solenoid-actuated impact module with an instrumented hammer locally excites the wedges, while a microphone captures the acoustic response for subsequent analysis via artificial intelligence. All motion-control and data-acquisition subsystems are fully embedded in the robot architecture, enabling remote operation and automated inspection. Experimental bench tests achieved 99% correct classification of wedge fastening conditions, demonstrating the system's feasibility for reliable, minimally invasive condition assessment.

Tue 09/06 - 15:29

One-dimensional convolutional autoencoder-based monitoring for fault detection in wind turbines

A.A.S.R.d. SOUSA[1], R.d.O. TELOLI[2], M.R. MACHADO[3], E. RAMASSO[2]

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Damage detection and SHM - Paper 13517

As global wind energy capacity grows, ensuring the operational reliability and economic viability of wind turbines remains a critical challenge due to their susceptibility to unexpected faults that can compromise structural integrity and safety. Unsupervised deep learning has shown great promise in structural health monitoring, enabling automated fault detection through data-driven approaches. This work introduces an

unsupervised approach to anomaly detection in wind turbines using accelerometer-based vibration signals throughout the turbine. The methodology uses a one-dimensional convolutional autoencoder trained solely on healthy-state vibration data. By learning a compact latent representation of normal dynamic behavior, the autoencoder captures complex temporal patterns in vibration responses. Consequently, it exhibits a low reconstruction error (RE) on seen, healthy data but a significantly higher RE on unseen, anomalous data. This reconstruction error is used as a health index, with higher RE values indicating potential degradation. It is applied to an onshore wind turbine and evaluated under diverse operational scenarios, including normal conditions and fault states. By combining unsupervised deep learning with vibration analysis, the proposed methodology offers an efficient and flexible solution for early fault detection in wind turbines.

Tue 09/06 - 15:47

Experimental and numerical analysis of an innovative indicator for the detection and localization of damage in flax/epoxy composites taking damping into account

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[1] *Université Bourgogne Europe, DRIVE UR 1859*

Damage detection and SHM - Paper 15012

This study presents a new damage detection indicator, which takes into account the effect of damping. Its effectiveness has been evaluated through experimental and numerical studies conducted on beam- and plate structures made of natural fiber-reinforced composite materials. The results confirmed its robustness in incorporating the effects of damping: although damping reduces the amplitude of responses, the overall behavior remains comparable to that observed without damping, thus reflecting its dissipative effect without significantly altering the trends. The indicator highlights distinct behaviors depending on the nature of the fibers. In the case of flax/epoxy, it generates a single, well-localized peak, revealing a limited damage zone. Conversely, for carbon/epoxy, several peaks distributed in space appear, indicating more extensive damage propagation. This difference can be explained by the mechanical properties of the fibers: the high stiffness and brittleness of carbon fibers favor a wider diffusion of damage, whereas the ductility and damping capacity of flax fibers tend to confine the damage. Furthermore, in the presence of delamination, the indicator is more sensitive to defects located near the surface than to those situated in the material's core. This can be explained by the distribution of bending stresses through the thickness: the outer layers, subjected to higher stresses, generate more pronounced disturbances in strain or curvature fields, unlike internal delaminations whose effects may remain difficult to detect. Thus, the position of the defect in the thickness plays a determining role in the performance of the indicator. Ultimately, the pronounced peaks provided by this indicator constitute an effective means to detect and locate damage in laminated structures made of natural fiber composites. This method appears to be a reliable and promising solution for monitoring the structural integrity of composite materials.

Coffee Break

Tue 09/06 - 16:05

Coffee Break

Advanced Structural Dynamics

Chair: Tiago Silva

Tue 09/06 - 16:25
Inverse identification of a localized complex modulus in a cantilever beam using vpinns and localized test functions

M. AUGER[1], M. OUISSE[1], R. TITTARELLI[1]
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Advanced Structural Dynamics I - Paper 13607

We address the inverse localization of a hidden dissipative treatment from sparse frequency-domain measurements available on a restricted observation window. A variational physics-informed neural network (VPINN) is trained on complex displacement data generated by Finite Element simulations for a 1 m clamped–free Euler–Bernoulli beam with a short viscoelastic patch bonded to one face of the beam, while the network is not informed of the material discontinuity. The governing equation is enforced on the observation window through a Petrov–Galerkin weak residual, reducing the derivative order compared with strong-form PINNs and improving stability under partial observations. To promote identifiability on the window, the unknown complex modulus is represented by a compact trainable piecewise-plateau ("bubble") parameterization with learned transition locations and amplitudes. The contribution is a focused comparison of VPINN test-function families for inverse identification under hidden heterogeneity. On a representative case at 3490 Hz, localized RBF-type tests yield stronger identification proxies for the loss modulus than global Fourier/Legendre tests, despite similarly accurate displacement fits on the observation points.

Tue 09/06 - 16:43
Topology optimization of viscoelastic damping layers for structural vibration control

M. COUET[1], L. ROULEAU[2], J. DEÜ[2]
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Advanced Structural Dynamics I - Paper 13217

Efficient vibration control is essential for ensuring the performance and durability of lightweight structures subject to dynamic loading. Constrained Layer Damping (CLD) has proven to be an effective passive vibration reduction technique for dynamic structures. However, its effectiveness strongly depends on the distribution of viscoelastic material with respect to the vibration mode shapes. At the same time, the design of CLD treatments is often limited by strict mass constraints, making it crucial to identify optimal material placement for maximum damping efficiency. This work proposes a topology optimization framework to determine the optimal distribution of viscoelastic damping layers under a weight constraint. The approach is based on the Solid Isotropic Material with Penalization (SIMP) method, with objective functions formulated to maximize the modal loss factors of one or several targeted modes. The viscoelastic behavior is modeled using the Modal Strain Energy method, and analytical sensitivities with respect to the design variables are derived. The proposed methodology is demonstrated on plate structures to evaluate the influence of different optimization objectives on the resulting damping layer topologies and vibration performance. The results highlight the potential of topology optimization to efficiently design viscoelastic damping layouts for improved vibration control in complex structures.

Tue 09/06 - 17:01

Simultaneous identification of elastic and damping properties in bio-based composites

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Advanced Structural Dynamics I - Paper 13464

Conventional carbon- and glass-fibre reinforced composites exhibit excellent specific stiffness and strength but suffer from inherently low vibration damping, which can compromise structural durability in dynamically loaded applications. Bio-based composites reinforced with hemp fibres and combined with recyclable thermoplastic resins such as Elium® represent a promising alternative due to their enhanced intrinsic damping and improved sustainability. This study focuses on the reliable identification of both elastic and damping properties of bio-based composite plates. Beyond material characterization, the main contribution of this work lies in the development of a robust methodological framework for vibration-based parameter identification using Finite Element Model Updating (FEMU). The proposed approach integrates experimental modal analysis and numerical finite element simulations within a structured identification procedure. Material parameters are identified by minimizing the discrepancy between experimental and numerical modal characteristics, including natural frequencies and modal damping ratios. Particular attention is devoted to ensuring the stability and robustness of the identification process. Since FEMU relies on modal data, a dedicated sensitivity study is conducted to evaluate the influence of the material parameters on the modal response. This analysis enables the selection of an appropriate and sufficient set of vibration modes, ensuring a well-conditioned identification while avoiding instability related to frequency-dependent effects. The proposed framework therefore provides clear methodological guidelines regarding mode selection, stability assessment, and parameter identifiability. In addition, the FEMU strategy is extended to explicitly incorporate damping parameter identification, allowing the simultaneous estimation of stiffness and damping properties within a unified framework. This methodological enhancement makes the approach independent of simplified analytical plate models, which may become unsuitable when experimental excitation systems alter the structural dynamics. After validation on plate structures, the methodology is applied to pure resin plates made of Elium® and GreenPoxy®, and subsequently extended to unidirectional hemp fibre composites. Finally, the influence of temperature on the identified elastic and damping properties is investigated. The proposed FEMU-based framework provides a stable, transferable, and model-independent strategy for the comprehensive characterization of bio-based composites over a wide frequency range.

Tue 09/06 - 17:19

Development of a sandwich beam experimental setup for high-frequency characterization of viscoelasticity

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Advanced Structural Dynamics I - Paper 13474

Innovation in the tire industry is a key concern to increase the performance of products, by reducing energy consumption, extending lifespan, and improving road safety. Crucial tire properties such as grip, wear, and noise depend on contact phenomena between the tread surface and the road. Contact mechanics is a complex field studied worldwide, as it involves the material's response to the multi-scale roughness of the road,

which ranges from millimeters to micrometers. Each scale excites the material at different time scales, meaning that the macroscopic behavior depends on the response over a wide frequency range. However, in laboratory conditions, these high frequencies are difficult to reach in a controlled manner, making direct measurement of the relevant viscoelastic properties challenging.Tread compounds are elastomeric materials reinforced with nanometric fillers, exhibiting both viscoelasticity and pronounced nonlinearity under realistic operating conditions. Accurate identification of their mechanical properties across an extended frequency range is therefore essential for reliable tire modeling and design. Standard Dynamic Mechanical Analyzers (DMAs) are typically limited to frequencies below 100 Hz, which is insufficient to reproduce real-world contact dynamics.In this context, the present work introduces a sandwich beam configuration composed of metallic and viscoelastic layers. The setup is designed to enable dynamic excitation over a broad frequency range, up to the order of 10 kHz, and for different strain amplitudes, allowing for the investigation of both frequency-dependent and nonlinear effects. A finite element model of the beam is developed alongside the experimental setting. The viscoelastic parameters are identified through an optimization process that minimizes the discrepancy between experimental measurements and numerical simulations.The proposed approach provides an experimental and computational framework for characterizing the nonlinear viscoelastic response of filled elastomers beyond the frequency range accessible by standard DMA instruments. The paper presents the concept and preliminary performance of the developed setup, contributing to a deeper understanding of material dynamics and supplying high-frequency data for predictive modeling, supporting the development of more energy-efficient and durable tires.

Tue 09/06 - 17:37

Characterization of frequency-dependent mechanical properties of highly damped thermoplastic polyurethane (tpu) for vibration isolation using periodic structures

T. BECKER[1], J. BRANDÃO[1], B. SPIRANDELI[2], M. BATALHA[2], J.R. ARRUDA[3]

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Advanced Structural Dynamics I - Paper 13488

Characterizing frequency-dependent mechanical properties of highly damped polymers 3D-printed with various infill patterns and densities using conventional dynamic testing methods based on measured natural frequencies presents significant challenges due to overdamped responses. This work explores the dynamic characterization of such materials by curve-fitting frequency response functions (FRFs) of periodic arrangements of the material intercalated with metal elements. This introduces features in the measured FRFs due to frequency band-gaps that increase the information for parameter identification via curve fitting. This study considers frequency-dependent functions for the Young's modulus, the shear modulus, and the loss factors. These functions are systematically identified by applying a non-linear least-squares curve-fitting algorithm to experimentally obtained FRFs. This enhanced approach allows for a more accurate and comprehensive characterization of additively manufactured polymers, which are essential for predictive modeling and engineering design. Furthermore, this paper proposes a novel periodic vibration mount optimized for low-frequency vibration attenuation. The design, composed of alternating 3D-printed TPU and metal elements, is engineered to generate wide band gaps in the low frequency range. Its performance is rigorously evaluated through numerical simulations conducted in COMSOL Multiphysics, where force and acceleration transmissibility analyses are performed to predict its vibration isolation capabilities. The experimental validation of a physical prototype is currently being performed. This research aims to provide a comprehensive framework for both characterizing overdamped polymers and investigating their application as passive vibration isolators by associating wave band gaps and damping.

Tue 09/06 - 17:55

Equivalent vibro-acoustic modeling and experimental characterization of nonlinear interfaces in multilayered structures

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Advanced Structural Dynamics I - Paper 13193

In this work, we propose an equivalent vibro-acoustic method to experimentally observe and characterize the nonlinear behavior of imperfect interfaces in multilayers structures. This structure is modeled using a Zig-Zag approach, which, through coupling conditions between the different layers specifically, stress continuity and displacement discontinuity at the interfaces links the kinematic variables of successive layers starting from a reference layer. This method not only reduces the number of kinematic unknowns in the model but also maintains an independent description for each layer. Using an equivalent thin plate model based on Kirchhoff-Love theory, it is possible to obtain a frequency-dependent equivalent bending stiffness. Finally, transverse displacement field measurements using laser vibrometry, combined with the CFAT (Corrected Force Analysis Technique), show that the dynamic behavior of a three-layer beam with imperfect interfaces varies according to the applied stress level. This is observed through changes in the structure's equivalent mechanical properties, in particular, a variation in the equivalent bending stiffness parameter, which reflects its nonlinear behavior. This methodology enabled the experimental characterization of the nonlinear behavior of glass-epoxy-glass three-layer beams under varying excitation levels.

Roundtable discussion: Industrial Challenges

Chair: Emeline Sadoulet-Reboul, Scott Cogan

Tue 09/06 - 18:13

Roundtable discussion: Industrial Challenges

Join this roundtable discussion to explore the challenges highlighted by leading industrial companies. Representatives from Stellantis, Safran, ArianeGroup, and EDF -Olivier Sauvage, Mohamed El Badaoui, Stéphane Muller, Mathieu Corus- will share their perspectives on the key emerging topics and strategic challenges that will shape the next decade. Don't miss this opportunity!

Diner

Tue 09/06 - 19:13

Diner

EURODINAME Night

Tue 09/07 - 20:15

EURODINAME Night

Breakfast

Wed 10/06 - 07:00

Breakfast

Nonlinear Dynamics

Chair: Olivier Thomas

Wed 10/06 - 08:00

Rate-induced tipping in a dry-friction oscillator under parameter drift

B. BERGEOT[1], S. TERRIEN[2], C. VERGEZ[3]

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Nonlinear Dynamics - Paper 13032

Self-excited oscillations due to dry friction often occur in mechanical systems where the friction force depends nonlinearly on the relative velocity between contacting bodies. Such systems can also display multistable behavior, with several coexisting stable solutions (attractors) for a given set of control parameters.Classical bifurcation analysis, which assumes constant parameters, captures the multistable behavior discussed above by analyzing the solutions and their stability. For some minimal models, the basins of attraction of the stable solutions can be computed to determine which stable solution is actually reached, again for a given set of constant parameters. During transient regimes, however, parameters may vary in time, giving rise to phenomena that lie beyond the predictive scope of classical bifurcation analysis and the conventional definition of basins of attraction. In particular, a multistable system with time-varying parameters can undergo rate-induced tipping, that is, an abrupt regime shift induced by the rate of change of a parameter rather than by its value. This phenomenon, mainly studied in climate science, is rarely documented in mechanical engineering, even though it is crucial for understanding regime selection in systems exhibiting multistability under realistic operating conditions.This study theoretically and numerically investigates tipping phenomena in a well-known dry-friction oscillator, modeled as a mass–spring–damper resting on a conveyor belt whose velocity acts as the control parameter. This minimal model exhibits bistability between stick-slip (oscillatory) and steady-sliding (non-oscillatory) motions. The proposed methodology allows us to determine, as a function of both the initial conditions and the rate of change of the belt velocity, whether oscillations are produced following a transient that ends in the bistable region.

Wed 10/06 - 08:18

Nonlinear dynamics of a post-buckled elastica

H. KIBACH[1], A. TURE SAVADKOOHI[1]
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Nonlinear Dynamics - Paper 13385

In contrast to rigid bodies linked by connectors, flexible elements can undergo large strains when subjected to external time-dependent forces, which result in nonlinear stress-strain relationships. Such compliant mechanisms, in architectured materials, permit to engineer and to program build-in properties at the microscale in order to control the macroscale behaviours. This has led to the fabrication of structures/materials showing extraordinary responses such as energy trapping and shock absorption. This study focuses on the nonlinear postbuckling responses of an elastica under external harmonic excitation. Such system can be supposed as a single element of an overall architectured material. We consider the model of a forced and prestressed elastica, with clamped-guided boundary conditions. It is supposed that the external loading is applied gradually until reaching a desired buckling configuration. Then, a harmonic excitation is added to the buckling load. The system is treated analytically around one of its arbitrary equilibria and around its vibration modes. This study provides necessary insight for tuning physical and mechanical properties of the element for having engineered responses. It is spotted that, around different postbuckled configurations and vibritary modeshapes, the variation of corresponding nonlinear frequency can present different types of behaviours, namely softening and hardening ones. These analytical and numerical predictions will be compared with results obtained from the prototype experimental system.

Wed 10/06 - 08:36

Numerical and experimental nonlinear dynamics of the muse tribometer

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Nonlinear Dynamics - Paper 13393

In the industrial context of pressurized water reactors (PWR) within the French nuclear power plant fleet, some of the vessel internals are subject to wear, which requires the implementation of costly maintenance strategies. Faced with these challenges, EDF and CEA aim to enhance the understanding and prediction of wear phenomena. This work focuses on deepening the nonlinear dynamics modeling of wear testing machines, such as the MUSE tribometer, to better understand and predict vibratory regimes associated with

impact and friction during testing. These advancements significantly contribute to optimizing experimental setups and ensuring the accuracy and repeatability of wear studies.The MUSE tribometer, which serves as the experimental support for this study, features newly patented electromagnetic actuators that drive a projectile along two perpendicular directions, enabling it to impact or slide on a fixed target with micrometer precision. Actuator motion is achieved by generating a Laplace force through electric currents in coils, powered by permanent magnets. A dedicated control software manages signal type, voltage, frequency, and phase shift to precisely adjust actuator displacement. In order to best control the contact conditions in the tribometer, particular attention is paid to understanding the conditions and parameters that need to be set up to obtain periodic vibration regimes.In this context, to reproduce and analyze these complex behaviors numerically, a continuation algorithm based on the Harmonic Balance Method (HBM) is used to compute the system's nonlinear frequency response. Stability analyses based on Floquet theory are then conducted on the obtained periodic solutions. Furthermore, the recently developed Koopman–Hill method is implemented on the MUSE 1D system to assess its suitability for highly stiff nonlinear dynamics. All developments are carried out within the DYN2 numerical library, which focuses on reduced-order nonlinear vibration modeling. Written mainly in Python with integrated compiled C routines, DYN2 is designed to evolve into an open-source platform for the scientific and industrial community.This combined numerical–experimental approach allows for a comprehensive understanding of the system's vibratory regimes, including the identification of bifurcations and transitions induced by the vibro-impacting nature of the system. Extended experimental tests have been conducted on the MUSE tribometer to validate the models. Initial results involving 1D normal contact without friction modeling show very good agreement with the experimental measurements. Future work will focus on extending the modeling to 2D configurations including friction.

Wed 10/06 - 08:54

An open-source data acquisition and control system for nonlinear dynamic experiments

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Nonlinear Dynamics - Paper 15011

We introduce an open-source, user-friendly data acquisition system that enables the implementation of experi- ental continuation methods requiring real-time, sample-by-sample control. Following a brief overview of experimental continuation methods, their implementation on the data acquisition and control system is demonstrated using a non- linear beam experimental setup. The data acquisition system is controlled via MATLAB and enables the experimental determination of the bifurcation diagram around the beam's first bending mode.

Wed 10/06 - 09:12

Learning model discrepancy using sparse bayesian polynomial narx: case study for bouc-wen hysteresis model

E. ATNAFE[1], R. TELOLI[1], E. SADOULET-REBOUL[1], S. COGAN[1]
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Nonlinear Dynamics - Paper 14495

Physics-based models remain essential tools for understanding structural dynamics, yet they often diverge from experimental observations due to unmodeled nonlinearities or incomplete physical knowledge.

Rather than discarding these imperfect models, their discrepancies with experimental data can be leveraged to reveal the missing physics. In this presentation, I introduce an interpretable framework for discrepancy modeling that combines sparse system identification and nonlinear autoregressive modeling, referred to as the B-SINARX approach. Starting from a known physical model, an interpretable library of candidate nonlinear terms is constructed and refined through Bayesian regression, enabling both model sparsification and uncertainty quantification. The framework is applied to two cases: a numerical Bouc–Wen system, where the hysteretic nonlinearity is unknown, and an experimental bolted-joint structure exhibiting nonlinear contact effects. The results show that the B-SINARX framework effectively captures the missing nonlinear dynamics and highlights the potential of hybrid modeling strategies that integrate physical insight with data-driven learning.

Wed 10/06 - 09:30

On the role of translation-to-rotation coupling in omnidirectional vibro-impact nonlinear energy sink for vibrations mitigation of structures

S. LAMI[1], G. ROSA FRANZINI[1], S. LO FEUDO[2], S. JOB[2]

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Nonlinear Dynamics - Paper 14672

Our numerical study addresses a nonlinear device for the passive vibration control based on the mechanical energy dissipation achieved from impacts between solids in arbitrary directions.The device under consideration is an omnidirectional vibro-impact nonlinear energy sink (OVINES), consisting of a small rigid disk moving and bouncing inside a larger disk-shaped container. Such apparatus is attached to a primary structure with two degrees of freedom (one radial translation and one axial rotation), both systems lying in the same plane.The theoretical formulation describes the trajectories and rebound velocities of the disks after collisions. The normal and tangential components of the post-impact velocities are evaluated from the change in both linear and angular momentum due to the impacts. The formulation takes into account for normal and tangential coefficients of restitution; the later depends on the coefficient of friction between the colliding surfaces and the angle of incidence. Our study evaluates the influence of some of the OVINES parameters and of the main structure on the overall nonlinear dynamics of the system. In particular, we take into account — or not — the angular degree of freedom to reveal the effect of rotation on the mechanical response of the OVINES. For this, time responses and bifurcation diagrams will be presented and analyzed. The device's ability to mitigate structural vibrations in free and forced regimes, as well as energy dissipation and rejections mechanisms, will be discussed.In particular, we alternatively take into account or discard the angular degree of freedom to reveal the effect of rotation on the mechanical response of the OVINES. The latter is determined by computing time responses and bifurcation diagrams, which are correlated to the device's ability to mitigate structural vibrations in free and forced regimes thanks to energy dissipation and rejections.

Wed 10/06 - 09:48

Recent advances in experimental continuation: a ready-to-go phase-locked loop design

C. BERTRAND[1], H. FAYOLLE[1], C. GIRAUD-AUDINE[2], O. THOMAS[1]

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Nonlinear Dynamics - Paper 15008

Among the available experimental strategies for characterizing nonlinear structural dynamics and identifying model parameters, experimental continuation based on Phase-Locked Loop (PLL) offers a simple and efficient approach. Using a real-time control loop, PLL techniques enable the measurement and tracking of complete nonlinear frequency response curves, including segments that are open-loop unstable due to fold bifurcations. Furthermore, by exploiting phase-resonance conditions, PLL experiments directly provide backbone curves and nonlinear modes, allowing separate identification of the conservative and dissipative components of the nonlinear restoring forces. Despite recent methodological advances, several practical aspects remain open for ready-to-go settings applicable to a wide range of systems. This work presents a complete framework for PLL-based measurement of a targeted nonlinear resonance. An original broadband phase detector is introduced, with specific capability for low-frequency operation. The design of the phase controller, based on an Integral–Proportional (IP) architecture, is then detailed. A single parameter is shown to dictate closed-loop stability in terms of lock-in to periodic steady states and stabilization of open-loop unstable branches of the bifurcation diagram. A refined analysis of the open-loop and closed-loop dynamics is provided, supported by numerical simulations and experiments on representative nonlinear systems exhibiting hardening, softening, and various nonlinearity types (geometric, piezoelectric, dry friction). Finally, the method is demonstrated on tracking the isolated responses of two nonlinear modes in 1:1 internal resonance with localisation.

Coffee Break

Wed 10/06 - 10:06

Coffee Break

Metamaterials for vibration and acoustic control

Chair: Leopoldo de Oliveira

Wed 10/06 - 10:30

Acoustic wave propagation patterns in hyperbolic lattices

A.W. NUNES[1], D. BELI[2], R. PICÓ[3], J.R.F. ARRUDA[1]

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Metamaterials for vibration and acoustic control II - Paper 12939

Sonic crystals based on hyperbolic geometry are a recent and promising branch of acoustic metamaterial studies. The literature on the subject explores wave localization phenomena, super-resolution imaging, and robustness to defects, in addition to wave phenomena that are well known from traditional acoustic metamaterials. In brief, these hyperbolic metamaterials are constructed according to rules of hyperbolic geometry, enabling negative-curvature spaces that offer infinite possibilities for regular tessellations of periodic lattices. These tessellations enable the positioning of any polygonal arrangement without spatial gaps, thereby opening up new possibilities of periodic cell-placing configurations that cannot be assessed in conventional periodic lattices defined in Euclidean space. This work explores this topic by investigating how acoustic waves propagate in sonic crystals based upon hyperbolic lattices. To achieve this, we assess hyperbolic lattices for sonic crystals via numerical simulations. These results allow insights into the potential applications for noise control.

Wed 10/06 - 10:48

Uncertainty quantification of a beam-like phononic crystal with attached composite patches

Y. MARTINS[1], V. SANTOS[1], G. DIAS[1], T. SALES[1], D. RADE[1]
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Metamaterials for vibration and acoustic control II - Paper 13481

Periodic structures have recently gained growing attention in both academia and industry due to their unique vibration and wave propagation characteristics, including the formation of bandgaps, waveguiding phenomena, cloaking, etc. These properties open new strategies for developing innovative approaches to structural dynamics and vibroacoustics. Although the capabilities of periodic structures have been reported in numerous studies, the effects of manufacturing uncertainties on their performance, which are commonly present in practical applications, remain underexplored. Accordingly, this paper performs uncertainty quantification of a host beam with attached composite patches. Periodicity is obtained without the need for machining or printing highly complex unit cells, which can significantly deviate from the initial design and make modeling cumbersome. Hence, these composite patches are used instead, glued to the host beam through structural adhesives, so that the periodic beam behaves like a phononic crystal (PC) and, therefore, works to passively attenuate vibration transmission. The introduced inclusions lead to impedance mismatches that cause the scattering and partial reflection of elastic waves, enabling the formation of Bragg-type bandgaps in specific frequency bands. Since the effects of uncertainties remain unexplored in such systems, one proposes to investigate the influence of randomness associated with the gluing position and width, as well as the geometry of the patches, for each unit cell. Assuming prescribed probability distributions, the uncertain inputs are modeled as random variables, which allows for quantifying their effects on the position and width of the first bending bandgap of the composite PC-like structure, as well as constructing transmissibility envelopes for given confidence levels. For this purpose, the modeling strategy for the laminate patches is based on the equivalent single-layer (ESL) theory. Moreover, the interaction between the equivalent patches and the host beam is based on a multi-layer beam model, which considers Zig-Zag kinematics. With the governing equations developed, the Spectral Element Method (SEM) is employed, yielding an exact dynamic stiffness matrix for each unit cell of the periodic beam using SEM. By leveraging the Monte Carlo method, samples of random unit cells are generated, which are then combined to form a given, imperfect, periodic structure that can be suitably analyzed in terms of its dynamic behavior. By following such methodology, one expects to determine whether the considered uncertainties are relevant to the design of the PC-like beam.

Wed 10/06 - 11:06

Wave and vibration attenuation from railway traffic in tracks with winkler foundation and local resonators

M. SALES[1], B. ARAÚJO[1], J. DOS SANTOS[2], E. MIRANDA JR.[1], A. SINATORA[3]
[1] *Federal Institute of Maranhão,* [2] *Faculdade de Engenharia Mecânica - UNICAMP,* [3] *Vale Institute of Technology*

Metamaterials for vibration and acoustic control II - Paper 12957

Vibrations induced by railway traffic are transmitted to the ground and can affect nearby residential and industrial areas, potentially causing damage to infrastructure and rail vehicles. The conventional methods for mitigating this phenomenon include the use of dampers on tracks and sleepers, improved train suspensions, and ground barriers. However, the scientific community has been exploring metastructures (i.e., artificially engineered structures that exhibit mechanical properties not found in conventional materials) as an innovative solution for vibration control. Despite notable advances, a significant gap remains in the literature regarding the application of metastructures in the railway sector. This study aimed to design a railway track based on the concept of metastructures, incorporating local resonators to attenuate low-frequency vibrations using the Euler-Bernoulli beam model on a Winkler foundation. The finite element method (FEM) was employed to compute the band structure and the frequency response function (FRF). The proposed metastructure was able to attenuate vibrations in the 1–500 Hz range, according to the resonator properties. The band structure revealed the formation of a band gap associated with the damping of the rail on the Winkler foundation. The introduction of local resonators generated localized modes that split this band gap into two distinct gaps. The FRF of the finite structures corroborated these findings, showing an attenuation zone coinciding with the band gap region. Results also showed that, in the presence of the Winkler foundation, local resonators operating within the band gap frequency range concentrate energy within a significantly narrower interval. Conversely, in the model without the foundation, the resonators exhibit the opposite behavior, producing a broader attenuation effect over a wider frequency range. This design proved effective in preventing wave propagation and mitigating ground vibrations within specific frequency bands, demonstrating its feasibility for practical application and its potential for optimization to extend the attenuation range.

Wed 10/06 - 11:24

Numerical proof of concept of a self-adaptive mechanical system using a multi-agent approach

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Metamaterials for vibration and acoustic control II - Paper 13457

Natural systems such as bird flocks, fish schools, and insect swarms exhibit self-organization emerging from simple local interactions, giving origin to complex collective behavior. Inspired by these mechanisms, this work proposes a self-adaptive structure composed of interconnected cells capable of locally tuning their viscoelastic properties according to temperature and excitation frequency. The structure is formulated as a distributed multi-agent system, where each cell operates as an autonomous agent governed by local sensing and interaction rules. Agents interact only with their nearest neighbors by exchanging local frequency response information that describes their dynamic behavior, no centralized controller is employed. Each agent has internal states and update laws that govern the adjustment of its viscoelastic parameters. Through these decentralized interactions, the agents aim to reach consensus, meaning that neighboring converge to compatible dynamic responses. In contrast to approaches based on centralized control combined with global thermal mapping, the mapping in the proposed framework is used exclusively to initialize local parameters. Adaptation and consensus remain fully distributed, providing a scalable and robust strategy for intelligent structures operating in complex environments.

Wed 10/06 - 11:42

On the wave propagation in hydroelastic periodic structures: theory and experiments

V. MAURO DE SOUZA SANTOS[1], T. DE PAULA SALES[2], M. OUISSE[3], R. VIALA[3]

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Periodic structures (PSs) have enabled vibration and noise reduction thanks to the so-called bandgaps (frequency ranges within which wave propagation is forbidden or strongly attenuated). The dynamic behavior of hydroelastic PSs (HPSs), i.e., lattices that combine elastic (solid) and fluid media, appears, however, to has received limited attention. In this work, PSs with 1D periodicity and box-like unit cells featuring 3D geometry are investigated. The hollow unit cells allow different fluid fillings within the cell cavities, enabling the assessment of the dynamic behavior of empty, partially filled, and fully filled PSs. Comprehensive numerical simulations and experiments show that fluid filling plays a crucial role in the wave propagation characteristics of the considered PSs, shifting bandgaps and creating additional frequency bands of wave suppression. The results of this research open new avenues for the design of advanced strategies and structures for wave manipulation, spanning applications from tunable bandgaps to smart and self-/adaptive devices.

Wed 10/06 - 12:00

Wave cancellation mechanisms in periodic herschel–quincke-inspired frame structures

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Metamaterials for vibration and acoustic control II - Paper 13475

Mechanical metamaterials have emerged as a promising research field focused on controlling and manipulating the propagation of elastic and acoustic waves, providing innovative alternatives to conventional noise and vibration mitigation techniques. Among the various configurations explored, structures inspired by the Herschel–Quincke (HQ) acoustic tube have attracted attention due to their capability to induce wave interference and cancellation through phase manipulation. In this study, a periodic HQ-inspired frame structure is proposed and analyzed to investigate the mechanisms of wave cancellation in such structural systems. Spectral formulations based on the Timoshenko–Ehrenfest beam theory are employed to model the wave propagation, while a finite element (FE) model is developed for validation through forced response analyses. The dispersion diagram of the periodic unit cell reveals the presence of wide wave band gaps in which wave propagation is effectively suppressed. These results identify the frequencies of maximum attenuation. Furthermore, the analysis of transmission and reflection coefficients demonstrates that flexural waves propagating through the multiple branches of the HQ-inspired frame experience phase shifts that result in destructive interference and strong vibration attenuation within the identified band gaps. The findings provide new insights into the dynamic behavior of periodic HQ-inspired beam structures and highlight their potential as efficient and robust passive solutions for vibration isolation.

Wed 10/06 - 12:18

Engineering analysis of spin excitation and wave directivity in topological metamaterials

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Metamaterials for vibration and acoustic control II - Paper 13484

In recent years, some concepts originating from quantum mechanics, such as edge and bulk states and spin phenomena, have been investigated in the context of structural dynamics. Although considerable advances have been made in the study of wave attenuation, localization, and directivity, most of these works still

lack an engineering-oriented approach. For example, it has been shown that chiral excitation can induce polarization of the spin angular momentum (SAM) in elastic media, enabling controllable energy steering with potential engineering applications. While this topic is well known in quantum and condensed-matter physics, an engineering perspective remains limited. In this work, the wave steering produced by chiral excitation is interpreted from an engineering viewpoint, based on the combined action of internal forces and continuity of displacements. Furthermore, a closed-form expression for the external loads that optimize wave directivity in beamsis derived and validated through spectral analysis, time-domain simulations, and experiments. Finally, simulations and experiments show that the propagation direction remains unchanged in a topological phononic crystal, showing evidence that the topological effect prevails over the spin effect.

Wed 10/06 - 12:36

Evaluating a periodic vibration mount for electrified vehicle battery packs

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Metamaterials for vibration and acoustic control II - Paper 13487

The increasing operational demands of battery packs in hybrid and electric vehicles present significant challenges for their structural integrity and long-term durability. A critical issue is the susceptibility of battery packs to road-induced vibrations. Dynamic excitations within specific frequency ranges can lead to internal component damage, such as electrolyte degradation, potentially causing micro-short circuits and significantly reducing battery longevity. This paper presents the design and numerical validation of an innovative support structure engineered to isolate the battery from the detrimental vibrations of the vehicle chassis. The proposed solution consists of a periodic vibration mount concept, made of highly damped 3D-printed Thermoplastic Polyurethane (TPU), designed to create targeted frequency band-gaps. These mounts combine band gaps and high damping to isolate vibrations in a large frequency band. A mock-up model, representing the vehicle chassis, the periodic vibration mounts, and the battery pack, was developed and analyzed using the COMSOL Multiphysics® software. The performance of the proposed periodic mounts is compared with conventional solutions, including a rigid connection and a traditional rubber mount, under realistic operational scenarios. Frequency Response Functions (FRFs) were generated to assess acceleration transmissibility from the chassis to the batteries under various dynamic load cases, including vertical, pitch, yaw, and roll excitations to simulate operating vehicle conditions. The results consistently demonstrate the superior performance of the periodic mounts, which provide broadband vibration attenuation across all tested conditions. The findings confirm that the 3D-printed periodic mounts offer a highly effective passive solution to enhance the safety and lifespan of electric vehicle batteries.

Lunch

Wed 10/06 - 12:54

Lunch

Porquerolles trip

Wed 10/06 - 14:00

Porquerolles trip

Diner

Wed 10/06 - 20:00

Diner

Breakfast

Thu 11/06 - 07:00

Breakfast

Advanced methods for vibration control and monitoring

Chair: Lucie Rouleau

Thu 11/06 - 08:00

Exploring the dynamics of magnetically attached resonators for vibration controlling metamaterials

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Advanced methods for vibration control and monitoring - Paper 13491

Metamaterials offer lightweight and tunable solutions for noise and vibration attenuation, yet most existing concepts rely on rigidly attached resonators. Magnetically attached resonators are a promising alternative, providing a reversible, easy-to-attach solution in which the resonator is connected to the host structure through magnetic forces rather than mechanical fastening. While this connection simplifies installation, it also introduces the risk of (dynamic) decoupling, which may compromise attenuation performance.

Through a combined numerical–experimental approach, this work investigates the frequency regimes in which decoupling occurs and its resulting effect on vibration attenuation performance. A finite element model is developed to characterize the magnetically attached resonators and dynamic response at both unit-cell and plate level. Experimental tests validate those predictions and assess the behavior of the magnetic connection at system level under different excitations, with specific attention to varying connection stiffness and partial detachment on attenuation mechanisms. The results demonstrate that magnetically attached resonators can generate repeatable localized bandgaps and achieve substantial vibration reduction around their tuned frequencies. Practical limitations remain, such as sensitivity to non-linear behavior, nevertheless, the study confirms that interface dynamics, rather than resonator tuning alone, govern the robustness of the achievable attenuation.

Thu 11/06 - 08:18

Phononic crystal beam with embedded acoustic black holes as local resonators

W.V. DE OLIVEIRA MONTEIRO[1], J.M. CAMPOS DOS SANTOS[1], J.P. CARVALHO DOS SANTOS[2], J.P. CARVALHO DOS SANTOS[2]

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Advanced methods for vibration control and monitoring - Paper 13493

Phononic crystals have gained considerable ground in the field of mechanics. These structures are commonly composed of a unitary cell periodically spaced, creating a unique characteristic of band gaps, for passive wave propagation control. Recently, some studies have addressed the idea of embedded local resonators for wave attenuation in these crystals. In this work, we apply a phononic crystal beam with embedded acoustic black holes to work as local resonators. This effect is achieved by incorporating a local modification in the thickness of the beam, producing a significant reduction in the wave propagation speed and an increase in attenuation properties. A numerical approach is established using the Spectral Element Method (SEM) and verified by the Finite Element Method (FEM). Examples are performed, and the results are compared between the methods and with those found in the literature.

Thu 11/06 - 08:36

Analysis of the trade-off between absolute filtering properties and mechanical strength of elongated sandwich structures with lattice material core

A. PELAT[1], T. BONNEVAL[2], R. TANAYS[3], M. LANOY[1], G. MICHON[4]

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Advanced methods for vibration control and monitoring - Paper 14539

Lattice structures offer very interesting properties for vibration control due to their lightness and the possibility of adjusting their stiffness by choosing the geometry of the lattice. This presentation explores how these lattice materials can be used to create slender structures that act as absolute vibration filters capable of preventing any elastic wave from propagating, regardless of its polarization, within a selected frequency band. This work involves an analysis of wave dispersion similar to the classification of Lamb waves. It is possible to obtain an absolute filter, but this leads to structures that can be particularly flexible. To overcome this practical difficulty for mechanical engineering application, the introduction of skins is proposed, defining sandwich beams with a lattice core, which are stiffer but reduce filtering bandwidth. An analysis of the trade-off between these two properties is then developed. This work is based on numerical modeling using the spectral element method and experiments on demonstrators produced using 3D additive manufacturing.

Thu 11/06 - 08:54

An svd-based method for controlling a mimo system with a siso controller in flexible structure with two close modes

I. BUCHER[1] , Y. ACKERMAN[1]
[1] *Technion*

Advanced methods for vibration control and monitoring - Paper 12887

This paper presents an actuation and control scheme for a scanner that traces a desired trajectory in space by combining two resonant structural modes. Resonating electromechanical scanners offer an efficient and compact alternative to rigid motor-driven systems. By phasing and adjusting the amplitudes of two modes, a travelling-wave generator is effectively created. An operational scheme that combines iterative, orthogonal excitation with a phase- locked loop generates robust excitation that is insensitive to model changes and imperfections. A data-driven Singular Value Decomposition (SVD) identifies optimal excitation and sensing transformations, determines the optimal operating frequency, and is more resilient than standard modal decoupling. The method was shown to be robust both analytically and through simulation across several cases. Additionally, the theoretical framework is experimentally validated using an electromechanical system with both real and complex poles. Because vibration modes are not purely real, the SVD decomposition of the frequency response matrix is preferred over the traditional normal-mode-based approach.

Thu 11/06 - 09:12

Precision control of a synchrotron x-ray phase retarder

J. SANTOS[1], J.R. ARRUDA[1], J. CAMINO[1]
[1] *University of Campinas*

Advanced methods for vibration control and monitoring - Paper 13489

The analysis of the magnetic properties of materials is a critical field of study in material science, directly impacting several areas of science and engineering. These properties are characterized through precise experiments that utilize high-energy X-rays produced by a synchrotron particle accelerator. The success of these experiments depends on achieving high precision in the positioning of the X-ray phase retarder system, a challenging task due to environmental factors and system flexibility. The X-ray beam generated by the synchrotron crosses a frame with a set of crystals that spins around its center of rotation. The frame alternates between two fixed angles, holding each position for a specified period of time. To achieve the required positioning precision, an accurate angular position control system for the rotating frame is essential. A reduced-order computational model is developed to represent the mechanical system dynamics. The basic system consists of two frames, each equipped with a mounted set of diamond crystals. Attached to each frame is a plate-like structure with a vertical hinge that allows it to rotate. In the neutral position, these two plates are aligned, with their free ends adjacent. A single actuator is positioned at the center point where these two free plate ends meet. When activated, the actuator pushes the plate ends outward, causing each plate to rotate around its hinge and, consequently, the frames to rotate. In the model, the input is a reference signal of the square-wave type, and the output is the position of the frame corners. The difference between the output signals provides the angular rotation of the frame containing the crystal. It is shown that the reduced-order computational model adequately reproduces experimental results. This reduced-order model is used for control design and performance analysis. A control system is designed to ensure that the rotation of the crystal frames robustly follows the desired reference signal with adequate settling time and minimal overshoot, while rejecting measurement noise and external vibration disturbances, despite uncertainties arising from nonlinearities and unmodeled dynamics. The controller design is based on robust H2 optimal control, which is a well-known technique for achieving optimal performance while rejecting noise and disturbances. The optimal controller is obtained from the solution of two Riccati

equations. The angular position control system is expected to provide the required accuracy under parameter variations, noise and disturbances. Numerical simulations validate the design.

Thu 11/06 - 09:30
Passive vibration control of a monopile-supported dtu 10 mw offshore wind turbine using a pendulum-tuned mass damper and a high-fidelity finite element model

M.V. GIRÃO DE MORAIS[1], P. ALKHOURY[2], M. AÏT-AHMED[2], J. FAJOUI[2], A. SOUBRA[2]
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Advanced methods for vibration control and monitoring - Paper 14417

Offshore wind turbines have been shown to harness a greater amount of wind energy compared to their onshore counterparts, thus rendering them a valuable resource for the production of renewable energy. In order to optimize the utilization of wind resources, a considerable number of monopile-supported offshore wind turbines are strategically situated at water depths ranging from 30 to 50 meters. In 2021, offshore wind power installations set a record with 21,106 MW of new capacity, bringing the total cumulative capacity to 55,5549 MW (Global Wind Energy Council, 2023). These turbines generally comprise a wind rotor affixed to a nacelle, which is supported by a tall, slender, flexible tower. It is noteworthy that taller turbines exhibit an augmented energy harvesting capacity. However, an increase in tower height can result in elevated levels of vibrations caused by rotor operating frequencies and environmental loads. These vibrations are further exacerbated by the dimensions of the tower. Consequently, the implementation of structural control systems is imperative to avert failure and curtail maintenance expenditures and excessive vibrations. The Pendulum Tuned Mass Damper (TMD) is a passive structural control device that has gained significant popularity. The mechanism by which it functions is through the transfer of kinetic energy from the primary structure to a pendulum. In recent years, there has been a significant increase in research focusing on this passive device in conjunction with offshore wind turbines (OWTs). For instance, Sun and Jahangiri (2018) developed an analytical multi-degree of freedom model (MDOF) model for the National Renewable Energy Lab 5-MW monopile-supported OWT equipped with a 3D-Pendulum Tuned Mass Damper (3D-PTMD) to mitigate the effects of misaligned wind, wave, and seismic loads. However, there is few studies that have considered high-fidelity mechanical models when evaluating the vibration mitigation of monopile-supported offshore wind turbines under combined wind and wave loads. This study investigates the vibration mitigation performance of a 3D pendulum tuned mass damper (3D-PTMD) installed atop a monopile-supported DTU 10 MW offshore wind turbine (OWT) making use of a three-dimensional high-fidelity finite element mechanical model making use of Abaqus software. The optimal 3D-PTMD was determined in such a way to avoid resonance. The resulting configuration effectively mitigates the structural vibrations of the monopile-supported OWT under operational conditions, including stochastic excitations induced by turbulent wind and irregular waves. The efficiency of the proposed optimum design was evaluated in terms of tower-top displacement reduction.

Thu 11/06 - 09:48
Tbd

Advanced methods for vibration control and monitoring - Paper 15013

Tbd

Coffee Break

Thu 11/06 - 10:06

Coffee Break

Advanced Structural Dynamics

Chair: Paulo Roberto Gardel Kurka

Thu 11/06 - 10:27

A novel strategy for interface model reduction exploring component-level global modes for substructuring applications

V. MAURO DE SOUZA SANTOS[1], T. DE PAULA SALES[2], M. OUISSE[3]

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Advanced Structural Dynamics II - Paper 13698

Substructuring techniques play a crucial role in industry and academia in the analysis of complex assemblies involving multiple components. In this context, the dynamic behavior of assembled structures is determined based on the coupling of reduced-order models of individual substructures, which encompass the reduction of interior and, potentially, boundary/interface degrees of freedom (DoFs) to small sets of generalized/modal coordinates. The reduction of interior DoFs is commonly performed using the fixed-interface Hurty/Craig-Bampton (H/CB) model-order reduction (MOR) method — which considers fixed-interface normal modes and static/constraint modes. In traditional methods, those interface DoFs that are related to connections between substructures, on the other hand, are not reduced. However, as finite element models can contain many interface DoFs when fine meshes are used, or when an assembly is composed of many substructures, benefits can arise from their reduction. This can be performed mainly using local-level or system-level characteristic-constraint methods, as well as their variants. The former strategy operates locally, considering the uncoupled substructures, while the latter considers the assembly at the system-level. Although the reduction of interior DoFs was proposed long ago and has been improved over the years, the reduction of interface DoFs has been introduced more recently, such that it still might be enhanced. Hence, in this research, a novel local-level MOR approach is proposed and investigated for such a task. The adopted technique is inspired in a method developed for the reduction of boundary DoFs in periodic-like structures. Within the present framework, interface modes computed for reducing the boundary DoFs are obtained in a global setting at the substructure component level, i.e., considering the coupling that its interfaces' DoFs have with those at its interior. Such modes are augmented with local modes obtained for the interfaces, accounting for fixed interior DoFs. To guarantee compatibility conditions between adjacent substructures, the modes obtained for an interface, related to different substructures, are combined to form a single projection matrix, that is shared among them. Afterward, to alleviate numerical issues, a modal-assurance criterion-based strategy is employed to eliminate almost-collinear eigenvectors from the interface coordinate transformation matrix. Results from numerical simulations regarding a W-bracket model demonstrate that the proposed interface reduction strategy competes with current state-of-the-art alternatives in terms of accuracy, model size and computation time.

Thu 11/06 - 10:45

On the calculation of impulse response functions for mechanical systems

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Advanced Structural Dynamics II - Paper 12794

Having accurate estimates of a mechanical system's impulse response functions (IRFs) is fundamental for successfully applying Impulse-Based Substructuring (IBS), the time domain counterpart of the established Frequency-Based Substructuring (FBS). Especially in an experimental context, acquiring accurate IRFs is challenging. To estimate IRFs, a procedure called Time Domain Deconvolution is utilized, which is the inverse of the Duhamel (convolution) integral. This allows for the calculation of IRFs from measured responses and the corresponding excitation using a pseudo-inverse, as well as averaging.However, the way the deconvolution procedure was written in previous works is suboptimal. Based on the construction of the force convolution matrix, certain assumptions are already placed on the IRFs. While the previously proposed approach made the deconvolution problem overdetermined, it was also assumed that the IRF of the analyzed system is not longer than the length of the calculated IRF. This means, it was assumed that the measured system's response is fully decayed after the IRF calculation length, e.g., 10 ms. While this assumption is obviously bad, the advantages gained from the overdetermination are also minuscule. Further, the problem can be easily overdetermined by averaging multiple measurements.This contribution details the assumptions used for the previous approach of Time Domain Deconvolution and shows the negative effect on calculated IRFs. Then, a new method for the deconvolution procedure is proposed. Both methods are compared using numerical, simulated, and experimental IRFs. Lastly, the effect of the new deconvolution procedure on responses calculated through Impulse-Based Substructuring is investigated.

Thu 11/06 - 11:03

Prediction of high-frequency vibration localization in membranes with concentrated masses: an iterative landscape approach

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Advanced Structural Dynamics II - Paper 12855

Vibration localization, a phenomenon resulting from multiple interferences that inhibit wave propagation in infinite disordered media, manifests in finite domains through the emergence of spatially localized modes. At low frequencies, when localization is induced by heterogeneities such as blocked regions, the localization landscape provides a deterministic way to analyze the phenomenon: it predicts both the frequencies and the spatial locations of the modes through a simple static computation. In contrast, when localization occurs at high frequencies, particularly in the presence of local resonators, the classical landscape no longer provides predictive information.The objective of this work is to propose a new approach, based on the landscape theory, to predict high-frequency localization in vibrating systems. As a starting point, we investigate vibration localization in membranes with concentrated masses, acting as local resonators.Introducing a mass into the membrane gives rise to a veering of the eigenfrequencies with respect to the mass parameter. For sufficiently strong contrast, the coupling between the mass and the membrane becomes weak, and beyond its local resonance frequency the mass behaves as quasi-immobile in the vicinity of the first eigenmode of the homogeneous membrane. This quasi-immobility constitutes the mechanism that induces localization: the mass can then be replaced by a blocked region, allowing the application of the classical landscape to the modified membrane.Our approach consists in iteratively identifying quasi-immobile masses by verifying, through static computations, that their local resonance frequency lies below that of the first membrane mode obtained with the blocked mass. This process converges towards a static

prediction of the frequencies and localization zones of high-frequency modes. Because the method is iterative, the quasi-immobility of each mass is treated independently from the others, which means that the approach is only valid when the masses are sufficiently decoupled dynamically. In practice, such dynamical decoupling requires that the local resonances of the masses do not occur simultaneously. This condition is fulfilled when the masses are sufficiently far apart from each other and exhibit significantly different mass values.Beyond membranes with concentrated masses, the approach is designed to be general and transposable to other types of concentrated resonators and other vibrating structures. To our knowledge, this study provides the first pathway towards a predictive experimental framework for high-frequency localization induced by local resonators, based on limited prior knowledge of the studied system.

Thu 11/06 - 11:21

Mode scaling errors due to modal tests uncertainties: a numerical study

M. CIANCI[1], E. FOLTÊTE[2], S. COGAN[3]
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Advanced Structural Dynamics II - Paper 13454

Experimental modal analyses are usually performed to evaluate the capacity of Finite Element models to represent the dynamic behaviour of mechanical structures in the low frequency domain. The model-test comparison and, if necessary, the model calibration, are commonly based on a normalised distance between the simulated and experimental eigenfrequencies and eigenvectors. The Modal Assurance Criterion (MAC) is generally used to pair the eigenvectors and quantify the distance between them, comparing their shapes without taking into account their norms.However, for some applications, the norm of the experimental eigenvectors has to be well identified as it has a direct influence on the results of interest. The modal identification process being the resolution of an inverse problem, it is well known that the presence of uncertainties in the input data, i.e. the measured Frequency Response Functions, can have a great impact on the output data, i.e. the identified eigenfrequencies and eigenvectors.This numerical study focuses on the effect of measurement uncertainties on the norm of the identified eigenvectors. Considering the Finite Element model of a simple plate, pseudo-experimental Frequency Response Functions are simulated with different levels of added noise. Numerous data are generated and post-processed by an automatic modal identification technique based on the PolyMAX algorithm. The effects on the norm of the eigenvectors of parameters such as noise level, frequency resolution and identified damping are investigated in detail.Additionally, a technique is proposed to reduce the norm errors by using a theoretically constructed mass matrix.

Closing Keynote

Chair: Domingos Alves Rade

Thu 11/06 - 11:39

Exploring chaos and its control in mechanical systems

A. S. DE PAULA[1]
[1] *University of Brasilia*

Closing Keynote - Paper 15007

The term chaos refers to a type of response exhibited by deterministic dynamical systems, characterized by a marked sensitivity to initial conditions and, consequently, to small perturbations. This sensitivity implies that there is always some uncertainty in determining the future state of the system, regardless of how accurately its initial state is known. Within chaotic behavior lies a hidden order composed of infinitely many unstable periodic orbits (UPOs). This underlying structure makes the dynamics more comprehensible and provides great flexibility to the system. Chaos control relies on this wealth of periodic patterns and can be understood as the use of small perturbations to stabilize trajectories corresponding to these periodic behaviors. The ability to stabilize, in principle, any orbit among the infinite UPOs embedded in chaos gives such systems remarkable versatility that can be exploited in many applications. In engineering, this capability is particularly valuable, allowing the development of highly adaptable systems—since, for each situation, the most suitable periodic orbit can be stabilized with minimal energy expenditure. In this talk, nonlinear tools commonly used to analyze chaotic behavior will be employed to uncover the hidden order within chaos. Then, two classical chaos control methods—the OGY method and the Extended Time-Delayed Feedback Control—will be discussed and applied to mechanical systems.

Lunch

Thu 11/06 - 12:25

Lunch

Bus departure - 13:15

Thu 11/06 - 13:15

Bus departure - 13:15
