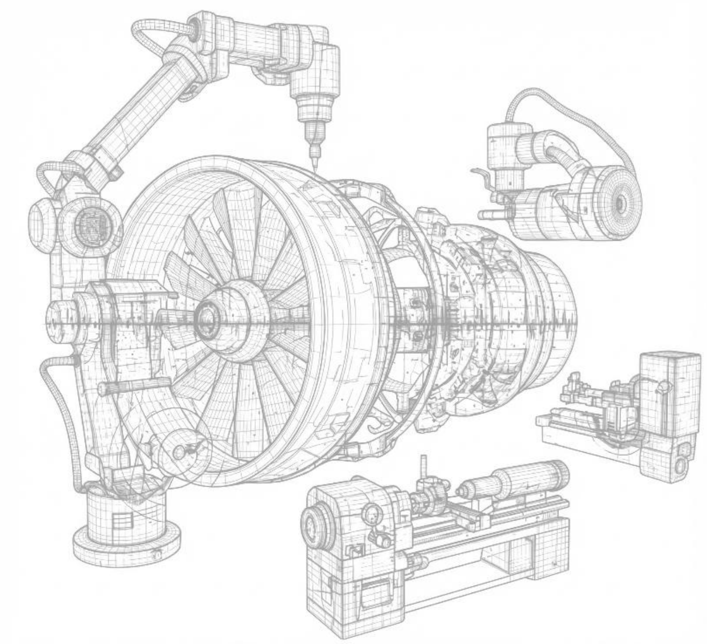
भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

VETOMAC 2025

20th International Conference on Vibration Engineering and Technology of Machinery

XX VETOMAC 2025

18 – 20 December 2025



ABSTRACT BOOK

Jointly organized by
Department of Mechanical Engineering
Department of Civil Engineering
IIT Guwahati

20th International Conference on Vibration Engineering and Technology of Machinery

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Abstract Book

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Foreword

It gives us great pleasure to present the Abstract Book of the 20th International Conference on Vibration Engineering and Technology of Machinery (XX VETOMAC 2025), being held during December 18–20, 2025 at the Indian Institute of Technology Guwahati, one of the most beautiful campuses in India, located in the heart of North-East India.

VETOMAC has established itself as a well-recognized international platform for researchers, academicians, and industry professionals to exchange ideas, share recent advances, and discuss future challenges in the broad areas of vibration engineering, machinery dynamics, and allied fields. The XX edition of the conference marks a significant milestone in this continuing journey of technical excellence, collaboration, and knowledge dissemination.

XX VETOMAC 2025 has received an overwhelming response from India and abroad, highlighting the growing global relevance of this conference. The conference features 35 keynote speakers, more than 150 oral presentations, and 20 poster presentations, covering diverse themes such as structural dynamics, rotating machinery, condition monitoring, acoustics, smart materials, control systems, and emerging technologies. This abstract book presents the summaries of the accepted contributions and reflects the depth and breadth of contemporary research in vibration engineering and machinery technology. After a rigorous peer-review process involving more than 250 dedicated reviewers, a high-quality technical program has been curated. The organizing committee sincerely acknowledges that without the invaluable efforts of the reviewers, it would not have been possible to complete the review process and maintain the high technical standards of the conference.

Over the three days of XX VETOMAC 2025, participants will have the opportunity to engage in insightful keynote lectures and parallel technical sessions that encourage meaningful discussions and interdisciplinary interactions. We hope that this abstract book will serve not only as a guide to the conference program but also as a valuable reference for researchers and practitioners beyond the event.

We express our sincere gratitude to all authors for their valuable contributions, to the reviewers for their time and expertise, to the keynote speakers for sharing their knowledge, and to our sponsors and partners for their generous support. We warmly welcome all participants to IIT Guwahati and hope that XX VETOMAC 2025 offers a rewarding academic experience, fosters new collaborations, and leaves you with pleasant memories of both the conference and the North-East region of India. We thank members of the advisory committee, the local organizing team, student volunteers and all others who have directly or indirectly contributed to make the conference successful.

We wish XX VETOMAC 2025 every success.

Sincerely,

Prof Rinku Kumar Mittal
Prof Hrishikesh Sharma
Organizing Secretary
XX VETOMAC 2025

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Plenary and Keynote Talks

Dynamics of a 1MW Back-Pressure Steam Turbine

Prof. Romuald Rządkowski, Institute of Fluid-Flow Machinery, Poland

A 1 MW back-pressure steam turbine was designed, built and implemented to generate electricity from the waste steam of a chemical factory. The dynamic of the turbine was analysed, including the vibration of the turbine casing and bearings using accelerometers at the two bearing casings and two generator bearings. The two displacement sensors in each turbine bearing were used to analyse the casing and rotor's relative vertical and horizontal vibrations. A tip-timing system measured the vibrations of the third-stage bladed disc. During the run-up, resonance appeared and the control system turned off the turbine. This paper analyzes the cause of this resonance using accelerometers on the turbine casing and bearings and inductive sensors for tip-timing blade vibrations. Two measuring systems were designed and produced. The first used (vertical) accelerometers in the two bearing casings, horizontal and vertical ones in the turbine casing above the third stage, and two ones in the generator bearing casing. To analyse the dynamic vibration of the turbine, two accelerometers were placed vertically in the two turbine-bearing casings and two generator-bearing casings. Two displacement sensors were placed in each turbine bearing to analyse the relative vertical and horizontal vibrations of the casing and rotor. A calculation of critical speed was carried out for the rotor. The Campbell diagram shows no critical speeds up to 3000 rpm for 1EO. Another two accelerometers were installed in the casing in the x and y directions above the third-bladed disc. Three inductive sensors were installed above the third-bladed disc to measure the bladed disc vibration using the tip-timing method (the second measuring system). It was found from the accelerometer measurements that a rotation frequency 2820 rpm caused the high level of vibration of the steam turbine's second bearing casing. The tip-timing measurements of the bladed disc show a minimal level of vibration. In the first step, the stiffness of bearing 2 was increased, but the turbine was turned off at 2940 rpm. The free vibration of the frame was analysed. It was found that the two natural frequencies of the frame coincide with 2820 rpm and 2940 rpm. The frame was attached to the foundation with 22 additional screws. The turbine reached a nominal speed of 3000 rpm.

Voltage Controlled Topologically Protected Wave Propagation in Dielectric Membrane-type Acoustic Metamaterials

Prof. C W Lim, City University of Hong Kong, Hongkong

Topological acoustic metamaterials have attracted enormous research attention in recent years. A significant hallmark of these structures is that they can support interface modes that are robust to structural disturbance and protected by topology. However, most of the studies are often limited to the passive structures that manifest wave propagation at fixed frequency ranges. In view of the shortage of non-passive topological acoustic metamaterials, this work has a primary motive to study the active control of topologically protected wave propagation in soft dielectric membrane-type metamaterials (MAM) based on quantum spin Hall effect (QSHE). The unit cell of the periodic structure is designed with symmetry. Then, the plane wave expansion method is adopted to analytically capture the system dispersion properties. A finite element model is further developed and excellent convergence with the analytical result is presented. By adjusting locations of spraying discs in the honeycomb unit cell, mode shape inversion is observed, separating the topologically trivial state from the nontrivial counterpart. Consequently, the topologically protected interface modes (TPIMs) are observed. Additionally, an electrical voltage that lies within the locking-up limit is applied to MAM to actively control the working frequency of the TPIM. Further, several waveguide paths are designed to control the robust wave propagation in the structure. Conclusively, a voltage-controlled topological metamaterial is designed to actively tune the working frequency range of the device.

Coupling Physics & Machine Learning for Modeling Dynamic Systems

Prof. C. Nataraj, Villanova University, Villanova, PA, USA

Machine learning is rapidly evolving and is increasingly being used for developing dynamic models and for analysis and diagnostics. However, these data-based models are often not robust and generalizable. On the other hand, physics – in particular, nonlinear dynamics - is able to satisfactorily explain many complex dynamic phenomena we observe in the physical world. We will explore how these physics-derived insights can help improve data-based models and especially optimize diagnostics. Engineering and biomedical applications will be provided to discuss the promising synthesis of physics and machine learning.

Key takeaway: Physics, encapsulating nonlinear dynamics, provides the most comprehensive description of dynamical system behavior, and can hence enrich the rapidly evolving field of machine learning.

Input Shaping and Minimum Time Control for a Vibratory System

Prof Alok Sinha, The PennState University, USA

Input shaping refers to elimination of residual vibration of a lightly damped structure via shaped inputs. First, fundamental ideas behind input shaping will be discussed. Algorithms will be presented for input shaping on the basis of the deadbeat state feedback control theory in discrete-time. These algorithms are easily extended to generate an input sequence robust to parametric uncertainties in a flexible structure. Numerical results are presented for both single and multi-input systems with one and many vibratory modes. Results corroborating the robustness of shaped inputs obtained using nominal parameters will be discussed.

A simple practical algorithm will also be presented to find near-minimum-time control inputs for a vibratory structure. The digital deadbeat control algorithm is modified to satisfy input constraints. The procedure to select the sampling period for minimization of the time required to reach the desired final state will be discussed. The issue of the system stability will be presented along with numerical results and theoretical analysis. Results will be compared to those from the classical time-optimal bang-bang control. It will be shown that the new algorithm is easy to implement and can lead to true time-optimal control or near time-optimal control.

The Just Transition: Empowering the Last Mile with Renewable Justice

Prof Pramod Shreshtha, Tribhuvan University, Nepal

The global push for renewable energy in developing countries often masks the complex justice dilemmas that emerge on the ground. While decentralized, off-grid systems are promoted as equitable solutions for energy access; their implementation can inadvertently reinforce existing social hierarchies and create new forms of exclusion. This paper tries to investigate these justice challenges in the renewable energy sector.

The benefits of technologies like micro-hydro and biogas are not distributed evenly in Nepal. Access is frequently mediated by pre-existing social capital, caste, and geographic location, leading to significant spatial inequalities. More critically, we argue that a narrow focus on distributive justice—who gets what—is insufficient. True energy justice hinges on procedural justice: the meaningful participation of marginalized groups in planning and decision-making, and the fostering of community capabilities to utilize energy for improved well-being.

Energy justice and Energy Dividend is a process, not just an outcome. An effective and efficient and successful energy transition must integrate rights with responsibilities and empower communities to co-create their energy futures. This presentation will provide a framework for designing renewable energy systems that are not only clean but also fundamentally just and equitable. Furthermore, the realization of energy justice in this context is not solely about the distribution of benefits (distributive justice) but also fundamentally concerns procedural justice—the role of individual agency, empowerment, and the enabling support of local actors.

Wind induced energy harvesting with nonlinear effects

Prof. G. Litak, Lublin Uni. of Technology, Poland

Wind-induced vibration energy harvesting has a great potential for utilizing wind energy to supply power for low-powered devices. To improve the working performance of energy harvesters effectively, a suitable structural design is crucial. We propose single and multiple beam-bluff-body energy harvesters to enhance the functional performance of aeroelastic energy harvesters in environments with variable wind speeds. A corresponding dynamic model is provided, and output characteristics are obtained at different wind speeds. Simulation results and experimental verification indicate that a variable air flow stream can realize efficient energy harvesting. Nonlinear suspension springs, passive channels, splitters and bluff body shapes are studied to optimize energy harvesting.

Artificial Intelligence for Condition Based Maintenance

Prof Pavan Kumar Kankar, IIT Indore

Availability of machines for production is essential for any industry. Conventionally, maintenance of these machines is carried out considering two maintenance strategies. One of them is breakdown maintenance, which occurs when plant operation halts due to a failure. The other is preventive maintenance, which occurs when the plant is shut down for essential maintenance activities. Over the past few years, advancements in computational facilities and the development of artificial intelligence-based algorithms have led to a shift toward condition-based maintenance to ensure the availability of plants and machines. Several researchers have contributed to the development of algorithms based on artificial intelligence for condition-based maintenance of mechanical parts/machinery, such as centrifugal pumps, hydraulic pumps, and rotor bearing systems. Artificial intelligence-based algorithms advise suitable actions in uncertain and complex plant conditions. These algorithms can learn from model data, real-time data acquired from machines, and/or hybrid data acquired from physics-based models and experimental data. These algorithms are not only efficient in detecting problems in the machine but also can update their models for unprecedented scenarios. Therefore, artificial intelligence-based condition maintenance significantly contributes to the plant's uptime by preventing catastrophic failure.

A new approach to modeling a shrink-fit assembly in rotors

Prof Ashish K Darpe, IIT Delhi

Shrink fits are commonly used in many rotor systems for mounting discs/machine elements. The shrink fits have the advantage of simpler mounting without the keyways in the shaft. However, an interference fit is needed to ensure reasonable positive drive and avoidance of slip. The contact pressure from the interference fit generates localized stress and deformation in the shaft and the mounted element. This induced stress influences the local stiffening conditions and the dynamics of the shaft. The increased stress may influence the natural frequencies and the dynamics of the shaft depending on the mounted disc-hub dimensions. This talk will highlight a new approach to account for the contact pressure and associated stress conditions. The analytical approach accounts for the shrink-fit of the mounted disc on the shaft for different interference fit levels and shaft-disc configurations (disc diameter and thickness). The proposed approach is validated using an experimental modal analysis and the results confirm the accuracy of the mathematical approach to model the shrink-fit assembly. In contrast to the empirical approach of modeling the shrink fit from the past literature, the present approach offers a more systematic and better way of modeling and of accurately predicting the associated bending natural frequencies of the shaft-disc assembly.

Development of an Active Pipeline Inspection Robot

Prof P M Pathak, IIT Roorkee

This talk presents the design, modelling, control, and experimental validation of a variable-diameter inline pipe inspection robot (IPIR) using an exclusive scissor-arm expansion mechanism for working in fluid-filled pipelines. The robot is composed of a waterproof, modular body with three scissor arm mechanisms spaced 120° apart, each end attached to traction wheels. A slider–rod actuator provides synchronised radial expansion to maintain stable wall contact across varying pipe diameters. The kinematic and dynamic models are formulated using the Euler-Lagrange method with holonomic constraints, precisely representing the robot's geometric adaptability and force distribution. A PID-based control scheme is developed for regulating position, velocity, and wall pressure, while Lyapunov stability analysis confirms closed-loop convergence under dynamic conditions. The overall system is validated through MATLAB/Simulink simulations and experimental test setups, demonstrating effective axial propulsion, radial adaptability, and robust dynamic stability. The results establish a scalable and efficient modelling-to-implementation pathway for self-adaptive robotic systems used for underwater pipeline inspection and maintenance.

Reliability, Availability and Maintainability of systems in energy transition

Prof B. Ravindra, IIT Jodhpur

Energy transition from fossil fuel based resources to renewable energy sources is a worldwide phenomenon to combat climate change. The quest for high efficiency of energy generating units need to be matched by their reliability. The reliability, availability and maintainability studies of energy generating systems such as hydro, thermal and gas turbines is an established practice and several engineering standards exist in this regard. The role of condition based maintenance and monitoring of these systems is also widely studied. The recent revision of existing standards to incorporate variable energy resource (VER) generation, such as wind and solar generating plants is necessary to monitor the effectiveness of energy transition and its impact on climate change. It has been observed that performance indexes defined in terms of generation quantities are gaining ground. Both generation-based and time-based indices of conventional and renewable energy generators are important to ensure reliability of systems in energy transition. Bottom-up predictive reliability models of solar, wind plants from subsystem reliability models are also necessary in this regard. This paper discusses a case study in the Indian context where some of these issues are addressed and recommendations are made to ensure smooth energy transition.

ML and AI-based protocols for materials, structures and systems

Prof. Alankar Alankar, IIT Bombay

Accurate life prediction of materials and structures is critical for structural health monitoring, reliability, and safety assessment of the designs for engineering applications. The material and structure life depends on the loads in operation, material, manufacturing process, geometry and environment conditions. Understanding the effect of all the variables for the next genera-tion design or inverse design is not trivial. This presentation will discuss the application of conventional machine learning (ML)-based models, physics-based models and will show how these are being replaced by the current generation AI models. The demonstrations will span from ML for data-driven models for material discovery and structure health to development of numerical solvers that can work with and with conventional solvers.

Metamaterial - Enabled Vibration Control in Railway Systems: Modeling, Measurement, and Applications

Prof. Arnab Banerjee, IIT Delhi

Effective mitigation of railway-induced vibrations hinges on a rigorous understanding of dynamic interactions across multiple subsystems, from wheel–rail contact to track–structure coupling. This talk presents a comprehensive framework for railway dynamics, beginning with advanced modeling of the wheel–rail contact using the Linear Complementarity Problem (LCP), which enables accurate prediction of normal and tangential contact forces, including stick-slip transitions. Further, a mechanics-driven solver is developed to evaluate the dynamic response of railway vehicles on viaducts and transition zones, capturing interactions between the moving load and structural discontinuities. These models are validated using both lab-scale and full-scale real life vibration measurements, highlighting the multi-scale nature of excitation and response. The talk presents the design, fabrication, and testing of a metamaterial-based rail pad,developed in-house and now secured as a patented technology. This rail pad utilizes locally resonant metamaterial principles to achieve broadband and tunable vibration attenuation,offering a transformative solution for vibration control in both urban and high-speed rail networks.

Notch strength for wide range of strain rate and temperature for metallic and polymeric materials

Prof N NODA, Kyushu Ins. of Tech., Japan

In this study, notch strength is investigated for wide range of strain rate and temperature in comparison with the standard tensile strength of smooth specimen at room temperature. High–speed tensile tests on notched specimens of PC (polycarbonate) and PDMS-PC (PC copolymerized with PDMS) shows that the notch strength of PC and PC-PDMS are expressed as a master curve as a function of the strain rate at the notch in conjunction with shift factors. High–speed tensile tests on high-Si DCI (high–Si ductile cast iron) and conventional DCIs shows that the notch strength are expressed as a master curve as a function of R parameter independent of the strain rate and temperature of each material. The master curves for those polymers and metals can be obtained by using the strain rate concentration factor, which is different from the stress concentration factor. The obtained notch strength is discussed in comparison with the standard tensile strength of the smooth specimen.

Emerging Trends in Mechatronics: Focus on Robotics and Unmanned Systems

Prof. Devdas Shetty, Uni. District of Columbia, USA

Mechatronics engineering plays a crucial role in Industry 4.0 by enabling the integration of physical systems with digital technologies. The integration of artificial intelligence into Mechatronics and Robotics is revolutionizing these fields by enabling innovative applications and significant advancements. Ideas that were impossible a decade ago are now possible with the advent of new technologies. These robotic products redefine personalization, specifically designed to deeply care for and engage with patients, one user at a time. They employ cyber physical systems to dynamically adapt to their users, fine-tuning interactions both in real-time and evolving over extended periods. Human-centered devices with a focus on socially assistive robotics and mechatronic devices are already in use. By closely monitoring the patient's performance and recovery, they offer tailored feedback and motivation. Mechatronics approach is used in the design and creation of unmanned systems such as unmanned aerial vehicles, unmanned surface vehicles, remote triggered and monitored hovering systems. The UAV based environmental sensing system monitors various water parameters in real-time like turbidity, pH, temperature, dissolved oxygen level, conductivity, etc. is becoming increasingly important for disaster management. While traditional laboratories require resources for setting up and maintaining physical equipment, virtual and remote laboratories offer a more cost-effective solution. This presentation examines case studies and highlights the versatility of mechatronics in solving complex problems. The future of mechatronics is one of incredible potential. The question is no longer "What's next?" but rather, "How will you be part of it?"

Cross-disciplinary Research in Mechanical and Electrical Machinery Technologies

Prof Ramesh Singh, IIT Bombay

One of the key activities in the Machine Tools Lab at IIT Bombay is the design, development, and performance characterization of special-purpose machines and complex mechanical and electromechanical systems. This talk highlights several cross-disciplinary projects undertaken in the lab. The first part focuses on the design and realization of India's most precise high-speed micromachining center, including its process dynamics and performance evaluation. This is followed by two industry-funded solution-oriented research efforts: prediction of thermal power plant life under frequent cycling of plant load factor for Tata Power, and root cause analysis of failure in BFNV steel coil transport wagons for JSW Steel. The final part of the talk presents interdisciplinary research on high-speed induction motor design and the development of fatigue design guidelines for high-voltage transformers. Collectively, these case studies illustrate the lab's integrated approach to advancing machinery technology through close collaboration between materials, mechanical engineering, electrical engineering, and manufacturing science.

Evaluation of Elastic Property for Axially Graded Powder Metallurgy Specimen by RFDA

Prof Poonam Kumari, IIT Guwahati

The metal-ceramics based FGMs are intensively used in various industries such as in aerospace, automobiles, electronics etc. for structural and thermal applications. The Cu/SiC metal-ceramic based system consists good mechanical and physical properties such as high thermal conductivity, high strength, a stable ceramic bonding at high working temperature, corrosion resistance, low cost etc. On the other hand, the SiC has very high working temperature, high hardness and high wear resistance. For further material design and analysis, obtaining the fabricated specimen's material properties is essential. Therefore, the aim of this research is to evaluate the material property of the sintered Cu/SiC-based samples through a non-destructive impulse excitation technique. A dynamic modulus system, i.e., RFDA-Basic instrument from Integrated Material Control Engineering (IMCE), has been used to estimate the effective property. For this experimentation, the cylindrical shaped specimens of pure Cu, and SiC are prepared. Three types of specimens say S1, S2 and S3 with a varying SiC wt% are considered in this experimentation. Here S1, S2 and S3 symbolically represent the pure copper [100/0], two-layered Cu/SiC [100/0 98/2] and 3-layered Cu/SiC [100/098/2 96/4] FGM specimens (see Fig 1). Further, the numerical FE analysis for all specimens has been conducted to validate the natural frequency for the corresponding Young's modulus of specimens. The elastic properties of specimens are obtained and further used for the numerical simulation on ABAQUS to validate their corresponding resonant frequencies. For this FE analysis, a 3-D model of S1, S2, and S3 has been modeled separately in ABAQUS software. The linear perturbation step is chosen to obtain the natural frequency of the specimen under the free-free (F-F) boundary condition. The periphery of the model has been divided into 40 elements and meshed with the 3D stress 20-node quadratic brick, reduced integration C3D20R element. The obtained natural frequency for different modes is presented in Table 1, and the corresponding difference (in %) is calculated.

Enhancing machine health through Cyber Physical Systems/ Digital Twins: A shift in paradigm

Prof. S G Rajasekharan, BITS Pilani, Hyderabad Campus

Conventionally machine health monitoring was performed using sensors mounted on machines and by periodically monitoring the deviation from the baseline values. Further with the developments in data driven and machine learning methods, attempts were made to classify the faults occurring in machines using these techniques and estimate the remaining useful life of components using various prognostic methods. In the past decade, with developments in cyber physical systems, attempts were made to replicate virtual systems, termed digital twins, which can mimic the performance as well as can capture the degradation of machine systems. These digital twins serve as the real-time digital counterpart of the physical equipment. The digital twin concept allows for a data driven model to constantly update the mathematical model that was initially developed for the system. The concept was first proposed in the early 2000s and was investigated and tested by the National Aeronautics and Space Administration in attempts to improve the physical model simulation of spacecrafts. Manufacturing, Automotive and Health care systems are now investigating and attempting integration of the digital twin concept in their respective sectors. With demand for reduction of downtime in industries, the concept is being applied to not only detect the faults but also to extend the life of machines using the concept of digital twins. This involves addition of feedback control systems to the digital twins which can provide timely feedback to the physical systems, which can alter the behaviour of physical systems in ways that can further enhance their life.

The Evolution of Sika Low Carbon, High-Performance Concrete (SLCC) : Transforming Modern Construction

Mr Nilotpol Kar, Sika India Private Ltd

"Sika's Low Carbon, High Performance Concrete is reshaping the way we build today — empowering structures that demand exceptional fresh and hardened properties of concrete in projects – residential and commercial high rises, infrastructure, etc. It has positive impact on fresh and hardened properties of concrete - self-consolidating, consistency retention, rheology, durability, and sustainability, amongst the key ones. Some key insights from recent innovations driving this transformation are covered in the presentation as case studies. Innovations in the construction industry through tailor-made admixture technologies in concrete, by way of introduction of state-of-the-art chemical & mineral admixtures elevates core concrete properties. Additionally, enhanced control over workability, setting times, self-consolidating characteristics and resistance to environmental stresses are essential for value delivery and return on investments.

Real-time applications and case studies though successful deployment of advanced admixtures in High-Rise towers, Bridges & long-span structures, Infra projects, special concrete types in aggressive environments are possible, thus demonstrating reliability in demanding, time-sensitive, and complex environments. Also, some cases of technology-enabled performance optimization are shown coupled with integration of real-time monitoring & tailor made technologies ensuring precise mixing, better on-site application, reduction in carbon footprint with predictable performance and delivery in sites.

Sika Low Carbon, High Performance Concrete demonstrates "Sustainability at the Core" with tailor-made admixtures support, thus reducing material waste, energy, optimising carbon dioxide emissions, improved life-cycle performance as well as lowering environmental impact across the construction value chain. It delivers a 3E concept from laboratory to reality – Economy, Ecology and Ergonomy.

For the Indian construction industry, it is thus relevant for "Continuous Innovation" to thrive which delivers value across the construction industry stakeholder chain as the construction landscape is evolving rapidly. Hence, Sika Low Carbon, High Performance Concrete innovations are highly beneficial and value adding to assure long-term structural integrity, through technology, speed, efficiency to meet future engineering demands and maintain environmental responsibility"

Dynamic Analysis of Single and Double Cantilever Beam based Piezoelectric Energy Harvester (PEH) under Various External Excitations

Prof. S K Dwivedy, IIT Guwahati

Piezoelectric energy harvesting (PEH) has gained substantial attention as an efficient mechanism for converting ambient mechanical vibrations into electrical energy for powering self-sustained microsystems, wireless sensor networks, and emerging Internet of Things (IoT) infrastructures. A direct or parametrically excited single cantilever beam attached with PZT/MFC patches is explored extensively to transform the available mechanical energy into useful electrical energy to power the low power microelectronic devices. Recent research trends emphasize expanding the operational frequency bandwidth, increasing harvested power, by exploiting nonlinear dynamic effects to enhance performance under realistic environmental excitation. Nonlinear strategies—including parametric resonance, internal resonance (of 1:2 and 1:3), and galloping-induced responses—have been explored to achieve wider frequency adaptability and improved robustness against fluctuations in vibration levels.

Contemporary nonlinear modeling approaches incorporating geometric, damping, inertial, and coupling nonlinearities provide more accurate predictive capabilities, while experimental studies have reported phenomena such as multiple voltage plateaus and extended constant-voltage response regions, enabling significantly higher energy conversion under diverse excitation conditions. Similarly, multi-beam and coupled-beam architectures with direct, parametric or simultaneous excitation, which is provided by interaction with vibrating structures or through fluid structure interaction (vortex induced vibration (VIV) and galloping) — often coupled magnetically, spring or both — that leverage nonlinear resonances and dynamic interactions to maximize harvested energy. Analytical and experimental investigations collectively demonstrate that such configurations can substantially improve efficiency, bandwidth, and adaptability in vibration-based energy harvesters.

Recent progress highlights several notable developments. Novel material systems such as ferroelectric polymers, composite piezoelectric laminates, and hybrid multifunctional structures have been introduced to improve sensitivity and mechanical compliance. Advanced structural designs, including metamaterial-inspired frameworks, multi-modal configurations, and bistable or multistable mechanisms, have demonstrated enhanced low-frequency response and improved efficiency across broad frequency spans. Application-driven innovations, such as harvesting from railway-induced vibrations and human–machine interactions, further underscore the growing practical relevance of PEH technology. These advancements establish a strong foundation for next-generation autonomous power systems designed for distributed sensing, structural health monitoring, and low-power electronic applications.

Impact Assessment for Energy Absorbing Materials using Shock Tubes

Prof. Niranjan Sahoo, IIT Guwahati

Energy-absorbing materials are a critical component in modern engineering applications, designed to absorb and dissipate kinetic energy in order to protect structures, devices, and people from impact forces. These materials function by converting impact energy into deformation, heat, or internal damage within the material, thus minimizing the force transmitted to the surrounding areas. Energy absorption capabilities for these materials is very much essential to diffuse the effects of impact forces. Composite sandwich structures are widely employed in high-performance applications owing to its superior stiffness-to-weight ratio and energy absorbing capacity. The performance of energy absorption capacity of lightweight structures is usually evaluated from specific energy absorption to compare the energy absorption to weight ratio. Accordingly, they qualify wide range of industries, including automotive, aerospace, defense, and sports, where safety, durability, and performance are critical. The present study aims to investigate the impact response of a dual-core hybrid sandwich panel comprising aluminium honeycomb and polymer-based foams as core material integrated with carbon fiber-reinforced polymer face sheets. Impact tests are experimentally conducted by using a shock tube under various strain rates. The shock tube facility (Fig. 1) is capable of creating solid projectile impact velocity upto 70 m/s. The responses are measured by incorporating semi-conductor starin gauges/piezofilms mounted in the specimen. The impact response can be evaluated through time histories of force and energy. The associated damage mechanisms, including indentation, inter-layer delamination, core crushing, and fiber fracture, can be systematically characterized to assess their role in energy absorption. These results highlight the potential of optimal dual core design sandwich configurations for advanced structural applications requiring lightweight impact-resistant materials.

Technology assisted innovative applications for high speed rotating machinery

Dr Arun Kumar, Ex Head, Propulsion Division NAL

In the recent couple of years the development of micro gas turbines has assumed huge strategic importance from power and defence sectors perspectives, with a very high market potential of a couple of billion dollars for the coming few years.

This presentation-keeping in view of the indian defence needs- essentially concentrates on different phases carried out during successful development of high speed rotating machineries with special reference to micro gas turbines and hydrogen blowers falling in the speeds ranging from 35000 rpm to 1,20,000 rpm.

This talk begins with details of a familiar conventional orthodox design approaches for finalising the basic schematic and goes on with details of some innovative applications employed during the development.

Applications of patented non contact power transmission for testing the equivalent rotor system, isolating the hydrogen blower from the motor (a specified requirement in case of hydrogen blower), possibility of external damping at high temperature zones and newly conceptualised foil bearings and their testing are briefly discussed.

Society 5.0 and Data-Driven Science

Prof Shyamanta M Hazarika, IIT Guwahati

Artificial Intelligence (AI) and Data-Driven Science have emerged as defining features of 21st-century scholarship, reshaping inquiry across the sciences, social sciences, engineering, and technology. From decoding protein structures in biology to analyzing social media dynamics in sociology, from documenting endangered languages to advancing Robotics and Automation, AI has established itself as a new paradigm of inquiry. This lecture introduces participants to the historical development of AI, tracing its evolution from early symbolic systems to today's Deep Learning and Big Data approaches. It further explores the scope of data-driven research, positioning it within the "fourth paradigm" of science, where large-scale data and advanced computational methods complement theory and experimentation. Through interdisciplinary case studies, the session illustrates how AI uncovers patterns, generates predictions, and supports decision-making across diverse domains.

Blast: Damage and Mitigation

Dr Inderpal Singh Sandhu, Joint Director (WHT&E)

Terminal Ballistics Research Laboratory, Chandigarh (India)

High-pressure blast waves with very sharp rise times, generated during explosive detonation, are the primary cause of injuries to personnel and of damage to vehicles and other critical structures during war and terrorist attacks. Blast waves can readily propagate as stress waves through most materials, including hardened structures, with little attenuation; their interaction with any target — living or non- living — can produce severe damage. As incidents involving improvised explosive devices (IEDs) against civilians and armed forces increase, the development of new lightweight protection systems has become a major focus of research. Key areas of interest include protecting soldiers from anti-personnel and anti-vehicular mines, shielding structures and critical assets from blast loading, and protecting civilians from terrorist attacks.

In terms of operating principle, blast-mitigation techniques are generally divided into four categories: impedance mismatch, geometric arrangements, blast-wave disrupters, and protective (sacrificial) cladding. This talk explains the basic concepts of these techniques and their application in different scenarios. It also presents the basic facilities used for blast measurement, its quantification and blast wave mitigation studies at TBRL.

The experimental results on the effectiveness of the sacrificial-layer technique— which is particularly promising because of its low weight penalty and its compatibility with other methods—are discussed. A sacrificial medium must be capable of undergoing a large volume change at nearly constant pressure. Most solids and liquids are essentially incompressible, and solid layers can also generate secondary fragments; therefore they are generally unsuitable. The materials that possess the required characteristics are low-density cellular solids for example, polymer foams, metallic foams, honeycombs, and auxetic structures — which are mainly used to protect targets from blast loading without fragmentation.

Estimation of Friction Torque of Ball Bearings

Prof Mayank Tiwari, IIT Palakkad

Ball bearings are crucial components in various machinery and mechanical systems, finding applications across numerous industries such as automotive, rail, aerospace, manufacturing, robotics, and household appliances. Although rolling element bearings have been used from a very long time, but now, due to critical applications such as Aerospace and EV, to name a few, where high speeds and low weight demand precision design and analysis of the dynamics of the bearings. However, since the performance of the bearings is a result of rolling sliding dynamics and effect of rolling friction, the estimation of friction is a part of the performance estimation. Analysis needs to be done of the interlinked dynamics of the rolling element (balls) cage and races with regimes of lubrication in the cage-ball and race-ball contacts. There are critical requirements for minimizing friction and wear in bearings, which is essential to enhance the efficiency, reliability, and lifespan of equipment. Friction moments in ball bearings occur due to rollingsliding motion at the ball-race contact and sliding between the ball and cage. The magnitude of these friction moments depends on factors such as surface topography, load, and speed. Understanding how surface topography influences the friction moments in these bearings is crucial. An analytical model is employed to estimate the friction torque within ball bearings, considering the total friction torque generated at the contact points between the balls and the race, as well as at the ball-cage interface. The model employs a mixed elastohydrodynamic lubrication approach to predict friction coefficients at these interfaces. Experimental data obtained from a torque rig, with the industry collaborator, is utilized to validate the developed model. The findings indicate that the total friction torque increases with higher loads and speeds, with load exerting a more significant influence. Additionally, it is observed that the force between the ball and the cage directly correlates with speed. Effect of Surface roughness is also studied in this work.

Hybrid Flywheel (Hy-FLY) Energy Storage System for Grid Inertia

Prof Karuna Kalita, IIT Guwahati

In the conventional power plant, any short-term grid imbalance event is addressed by the huge mechanical inertia of the spinning turbine and generators which buys time for the active control measures to take place and for the grid to recover without any deviation of supply frequency from the acceptable limit. With the retirement of the conventional power plant, the loss of inertia is compensated by the renewable energy generation and storage systems. The existing literature frequently discusses strategies focusing on emulation rather than the true replacement to address this issue. This talk discusses a novel hybrid flywheel energy storage option for short-term and prolonged power requirements in a microgrid setting. This system is also an inertia-providing system and primary frequency support to address supply/demand power imbalances. The concept aims to integrate a flywheel and a secondary energy storage system to supply power to a synchronous generator. By utilizing a differential drive unit (DDU) to combine these energy storage technologies, it is expected that the short-term quick response demand is supported by spinning down the flywheel, and for the prolonged energy demand, the synchronous generator will run at a constant synchronous speed while extracting energy from the flywheel and secondary energy storage (compressed fluid). The present design stands out from other hybrid systems due to the incorporation of a DDU. Essentially, this addition enables the extraction of energy either exclusively from the flywheel, resulting in real inertia, or solely from the secondary store, leading to synthetic inertia, or a combination of both.

Content

Paper ID: 7

RIDE AND STRUCTURAL DYNAMIC ANALYSIS OF A MILITARY RECOVERY VEHICLE

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This paper is focused on developing a detailed flexible body dynamic model of a military recovery vehicle to estimate the vibration responses at the crew locations and identify the predominant sources of noise during negotiation over required standard terrains. The detailed finite element model of the recovery vehicle was developed in Altair/Hypermesh and Abaqus/CAE. Substructuring technique has been adopted to develop the flexible body model of the vehicle chassis which in turn was assembled with the non-linear suspension and track assembly in Adams Tracked Vehicle (ATV) toolkit. The influence of variation in the suspension gas charging pressures and extra oil quantities on the comparative ride dynamic responses at the crew locations has been brought out in this paper. In addition, the predominant sources of noise could be identified during vehicle movement at different speeds over the standard terrains from the frequency spectrum. Based on the detailed flexible body dynamic analysis, suitable design inputs could be provided to the concerned users for preservation of crew comfort over drastic off-road conditions. The identified predominant sources of vehicle noise which were brought out from the detailed dynamic analysis, could provide good technical guidance for taking precautionary measures to reduce noise levels and enhance the operational performance of the crew. The present study establishes a suitable platform to assess the crew comfort and noise source identification in an integrated flexible body dynamic environment which in turn is very vital for design and development of military recovery vehicles and its future variants.

Paper ID: 9

BEARING FAULT DIAGNOSIS USING RECURRENCE ANALYSIS AND CONVOLUTIONAL NEURAL NETWORKS: A QUALITATIVE INVESTIGATION

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Most of the rotating machinery uses rolling element bearings as one of the main components. The performance of these bearings directly related to the reliability of a rotating machine. In this work, recurrence analysis (RA) is utilized to access the health of the bearings. Recurrence analysis is a nonlinear time-series analysis technique. The logged vibration signals from the various bearing’s conditions are used to assess the health of the bearings. Recurrence plots (RPs) examine the dynamical patterns of the signals and present detailed information. The

plots are then given as an input to the convolution neural networks (CNNs) to classify bearing conditions as healthy and faulty. The conventional bearing health estimation techniques rely upon the extracting best features. The present study utilizes the image patterns of RPs for analysis. The proposed method has been examined on the experimental data of healthy and faulty bearings. Results suggest the ability of the RA in aggregation with CNNs and highlight the overall accuracy.

Paper ID: 13

INTEGRATED FINITE ELEMENT AND EXPERIMENTAL APPROACH FOR SPUR GEAR FAULT IDENTIFICATION

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The demand for condition monitoring of gears in rotating machinery is increasing to ensure fault-free operation and prevent catastrophic failures. Gears play a crucial role in power transmission but operate under fluctuating loads, high stresses, and prolonged service conditions, leading to various faults such as broken teeth, pitting, and addendum wear. Early fault diagnosis is essential to minimize downtime, reduce maintenance costs, and enhance gear reliability. This study investigates gear fault diagnosis through dynamic analysis using Finite Element Analysis (FEA) and experimental validation. The vibrational response of faulty spur gears is analyzed under real-world loading conditions, and defect frequencies are identified using an fast fourier transform (FFT Analyzer. Results from FEA and experimental analysis show that vibration amplitudes increase significantly with fault severity, highlighting distinct frequency signatures for specific defects. The strong agreement between numerical and experimental results confirms the reliability of the proposed approach for detecting and characterizing gear faults. This study provides a robust framework for optimizing spur gear performance and improving predictive maintenance strategies.

Paper ID: 14

Experimental and Numerical Investigation of Bearing Internal Clearance Faults Using Vibration Analysis and FEA

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Bearing internal clearance significantly affects the dynamic performance and service life of rotating machinery. This study investigates internal clearance faults in spherical roller bearings through a coupled

experimental and finite element approach. The dynamic response of faulty bearings is modeled and simulated using Finite Element Analysis (FEA) in ANSYS, capturing stress distribution, deformation, and modal behavior under varying operating conditions. A parametric analysis is conducted for different radial loads and shaft speeds to evaluate the influence of internal clearance variations and localized defects on bearing behavior. The experimental setup records vibration signals for corresponding fault scenarios, and fault features are extracted using Fast Fourier Transform (FFT) spectrum analysis. The vibration signatures are correlated with simulation results to validate the FEA model. The study demonstrates that the combined vibration-FFT and FEA approach effectively characterizes clearance-related faults in spherical roller bearings, offering valuable insights into early fault detection and failure prevention in industrial rotating systems.

Paper ID: 19

ML-Based Detection of Aeration Fault in Electric Submersible Pumps

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Electric submersible pumps (ESP) are widely used multistage centrifugal pumps that finds applications in water treatment, agriculture, mining, and the oil and gas industry. Despite their extensive usage and wide applications, failures of ESPs remain unexplained and are regarded as the norm. Since ESPs operate while submerged, monitoring the factors that impact the service life of the pump is challenging. Aeration is one such critical factor that causes pitting and erosion on the impeller, leading to increased vibrations in the system. This can result in severe degradation of performance, increased maintenance costs, and premature failure of the pump. Therefore, in this study, an ML-based aeration detection framework has been proposed. The vibration data has been collected during normal and aeration conditions using an underwater accelerometer. This data is then converted from the time domain to the frequency domain to generate a robust feature identifier for differentiating the aeration from normal operation conditions. Multiple ML algorithms, including decision tree, support vector machines, and ensemble models, are evaluated to identify the most effective model for fault detection. The system is developed to enable real-time monitoring for early detection of cavitation with a focus on achieving high accuracy, low false alarm rate, and scalability for real-life on-field application. This work contributes to bridging the gap in condition-based fault detection in ESP by leveraging signal processing and interpretable ML techniques for targeted fault identification.

Paper ID: 21

Enhanced Vibration Damping in Additively Manufactured Ti Alloy and MMC using Optimized Control Strategies for Aerospace Applications

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This study investigates the potential use of Titanium Alloy and Titanium Metal Matrix Composites (Ti MMCs) reinforced with Boron Carbide (B_4C) in aerospace applications, focusing on their vibrational performance. The results of this research offer considerable potential for use in aircraft pylons, which are very important load-bearing structures linking external payloads and engines to the airframe. Pylons experience common complex flight environments in which low natural frequency and poor damping can result in structural fatigue as well as decreasing service life. Free vibration tests were conducted following ASTM E756 to determine natural frequencies and damping characteristics. Laser Directed Energy Deposition (LDED) was used to print the samples according to the standard. A numerical model based on the Euler-Bernoulli beam theory and the Finite Difference Method (FDM) was developed to simulate dynamic behavior. Subsequently, active vibration control techniques—including classical Fuzzy Logic, Adaptive Neuro-Fuzzy Inference System (ANFIS), Particle Swarm Optimization (PSO) optimized Proportional-Integral-Derivative (PID), and Self-Tuning Fuzzy Logic—were implemented using MATLAB/Simulink. Ti MMCs (~ 217 Hz) exhibited higher natural frequencies compared to Ti alloy (~ 180 Hz). The self-tuning fuzzy method and PSO-PID controller significantly outperform conventional approaches in damping effectiveness with the lowest peak amplitudes (< 0.08mm) and a settling time (<0.0002 s).

Paper ID: 22

COMPARING THE EFFICIENCY OF MESHLESS FEA TOOL WITH TRADITIONAL FEA TOOL AND TEST DATA IN PREDICTING THE DURABILITY OF A FIXED BEAM

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In today's competitive landscape, the need for shorter product development cycles necessitates rapid yet accurate simulations to meet performance metrics. Ensuring the durability, reliability, and longevity of physical products is a crucial component of this development cycle. Traditional Finite Element Analysis (FEA) software has been reliable for product development, providing correlated results to testing, which is time-consuming and expensive. With the rise of meshless tools, creating an accurate finite element mesh is no longer necessary, allowing multiple analyses directly on the product geometry.
This study focuses on a notched beam structure, fixed at both ends. Test data on the beam is collected through modal, harmonic (Frequency Response Function, FRF), and fatigue testing via Power Spectral Density (PSD)-based shaker table input, running the beam until failure. Measured strain data is used to calculate damage using commercially available software. Similar analyses are performed using both meshless and traditional FEA software. The techniques and settings used in the meshless FEA tool to achieve results comparable to traditional FEA are discussed. Additionally, the Dirlik Method is employed to calculate fatigue damage and usable life, utilizing response PSD stress data from the meshless FEA tool. By comparing test, analytical, traditional, and meshless FEA methods on a simple structure, this paper provides a comprehensive evaluation of their accuracy, efficiency, and applicability in predicting structural performance and durability.
The paper concludes with an evaluation of the advantages and limitations of the meshless FEA tool, highlighting its potential for efficient and accurate simulations in the product development cycle, while also shortening the product development timeline.

Paper ID: 23

Condition Monitoring and Machinery Diagnostics: Online Monitoring for Non-Traditional Industries (Railway, Marine Vessels, and Wind Renewable Energy)

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Condition Monitoring and Machinery Diagnostics have proven invaluable in optimizing the performance, reliability, and safety of industrial assets. While traditionally focused on manufacturing and heavy industries, the principles and techniques of online monitoring are increasingly recognized for their significant potential in diverse non-industrial sectors. This paper explores the application of online Condition Monitoring and Machinery Diagnostics in critical infrastructure and emerging energy domains, specifically focusing on railway systems, marine vessels, and wind renewable energy. We examine the unique challenges and opportunities presented by these applications, highlighting the specific parameters monitored, the sensor technologies employed, and the diagnostic approaches utilized to ensure operational efficiency, prevent catastrophic failures, and optimize maintenance strategies in these vital non-industrial assets. Furthermore, we discuss the specific benefits and potential advancements offered by real-time data acquisition and analysis in enhancing the safety, sustainability, and cost-effectiveness of these crucial sectors.

Paper ID: 27

DYNAMIC STABILITY ANALYSIS OF A PIECEWISE NONLINEAR SUSPENSION SYSTEM UNDER HARMONIC EXCITATION

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Dynamic systems often exhibit piecewise nonlinearity due to various factors such as slip and friction, gaps, cracks, and sudden impacts. These characteristics can lead to unusual bifurcations and chaotic behavior when exposed to external disturbances, potentially compromising their durability. To enhance safety and ensure sustainability, it is essential to have a comprehensive understanding of the dynamic behavior of such systems from both practical and theoretical perspectives. In the present study, frequency domain analyses of a piecewise nonlinear suspension (PNS) system have been conducted using the incremental harmonic balance (IHB) method combined with a pseudo-arc-length continuation approach. The analysis particularly focuses on the steady-state primary and subharmonic resonances of the PNS system under harmonic excitation. Stability assessments performed using Floquet's theory reveal multiple period-doubling (PD) and saddle-node (SN) bifurcation points on the frequency response branches. The subcritical and supercritical flip bifurcation phenomena leading to chaotic behaviour have been demonstrated via period-doubling routes. The findings are complemented by the application of the phase portraits, Poincaré map, Lyapunov exponents and Fourier spectrum for greater clarity. The stable responses obtained using the IHB method are validated by numerical

simulations (NS) of the equation of motion at discrete points. The results of both methodologies demonstrate a high level of consistency, highlighting the superiority of the IHB method over traditional approaches.

Paper ID: 28

Shock Response Analysis in Multicomponent PCBs using FEA-Derived Response Spectra and SHAP-Based Feature Attribution

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Printed Circuit Boards (PCBs) in missile and aerospace systems are frequently exposed to extreme shock loads, leading to potential failure in sensitive components. The current research presents a fully computational framework for analysing and interpreting shock-induced responses in multicomponent PCBs using finite element analysis (FEA), shock response spectrum (SRS), and SHAP-based machine learning. Explicit dynamics simulations are performed to model base-excitation shock events, and acceleration responses are extracted at critical component positions. The responses are post-processed to compute acceleration, velocity, and displacement SRS over a wide frequency range. From the SRS curves, frequency-domain features such as peak response, dominant frequency, and energy bandwidth are extracted. A regression model is trained to predict key structural outcomes. SHAP (Shapley Additive Explanations) is then applied to interpret the contribution of each SRS-derived feature to the model's output. The current label-free framework enables interpretable frequency-domain analysis of PCB shock behaviour without relying on experimental data. It supports early design-stage decisions, aiding in identifying vulnerable frequency bands and enhancing the reliability of electronics in high-G environments.

Paper ID: 29

THERMOELASTIC ANALYSIS OF AN FGM CYLINDRICAL PRESSURE VESSEL USING POWER LAW OF MATERIAL GRADATION

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With the increase in applications of functionally graded materials (FGM) in various fields, it is becoming more important to study and analyze the basic and fundamental response like stresses which are induced in structural components made of FGMs. For this reason, researchers are interested in studying the behavior and properties of the FGMs. This study is presented a thermoelastic behavior of an FG cylindrical pressure vessel with radially FG material properties following power law of material gradation, where the combined effect of temperature and pressure is taken into consideration. Here, the FG cylindrical pressure vessel is composed of aluminum oxide (Al2O3) as ceramic constituent at inner side and stainless steel (SUS304) as metallic constituent at outer

side. An analytical formulation is derived for the FG vessel to determine the radial, circumferential and axial stresses as functions of temperature and material gradient indices. Thereafter an in-house MATLAB code is developed to verify the derived FG formulations with the existing ones. In this study, it is also discussed that material gradient indices have a great influence on temperature variation, elastic material properties and thermo-mechanical stresses of the FG vessel. These results depict the efficiency of the derived stress formulation and shows the accuracy of formulation in this paper. This would help for better understanding of stress formation under the application of extreme pressure or temperature variation in structural cylindrical and spherical components made of FGMs.

Paper ID: 30

THERMO-ELASTIC BENDING BEHAVIOR OF AN AXIALLY FUNCTIONALLY GRADED BEAMS USING POWER LAW OF MATERIAL GRADATION

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Design of structural components made of axially functionally graded (AFG) materials requires understanding of stress distribution, deformation behavior, and strength under thermo-mechanical loads. This study aims to provide an analytical solution for the bending behavior of AFG beams using Timoshenko Beam Theory (TBT). In this study, stainless steel (SUS304) serves as the metallic content, while silicon nitride (Si3N4) is considered as the ceramic content of the FG beams. It is assumed that the content of SUS304 gradually decreases from right to left of the AFG beams. First, temperature-dependent material properties are obtained along the axial direction according to the power law of material gradation. Next, the steady-state one-dimensional Fourier heat conduction equation is used for the temperature distribution profile to achieve the desired thermo-elastic properties. Using Hamilton's principle, the equations of motion are derived for the bending of AFG beams, are developed an efficient MATLAB code based on this formulation and validated with the existing results to confirm the correctness of the derived formulations and the developed code. Finally, the validated code is used for the bending results and to examine the influences of the power law of material gradient indices, and temperature gradient on the thermo-elastic deflection of the AFG beams. The numerical results indicate that gradient indices and temperature gradients significantly affect the thermo-elastic bending responses of the AFG beams. These findings will aid in the development of optimized shaft designs for rotating components, such as turbines, in thermal environments.

Paper ID: 32

Misalignment-Induced Dynamics and Fault Identification in an Offset Disc Rotor System Integrated with Active Magnetic Bearing: An Experimental Approach

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This study addresses the critical issue of coupling misalignment in rotor systems, investigating its detrimental impact on vibration amplitudes and overall system performance. Through experiments on a rotor-bearing test rig featuring diverse faults such as misalignment and residual imbalance, the study aims to precisely identify the fault parameters influencing dynamic behavior. A distinctive aspect of this work is the experimental examination of fault parameter interactions in a rotor-train system employing an active magnetic bearing (AMB). Adding a unique dimension to the study, an AMB is integrated for controlling transverse vibrations and facilitating fault identification. The experimental test rig is composed of two flexible shafts linked by a flexible coupling, with a rigid disc mounted eccentrically on each shaft, creating a gyroscopic effect in the system. The proposed identification approach utilizes data from proximity and current probes, capturing rotor vibrations and AMB current signals in two orthogonal directions at different sets of rotor speeds. The algorithm targets fault parameters, including unbalance, additive dynamic coupling stiffness (ADCS), direct coupling stiffness, damping, alongside AMB parameters. The methodology's reliability and efficiency are validated through consistent standard deviations and the coefficient of variation of estimated fault parameters, affirming its robustness and accuracy. Ultimately, this research provides valuable insights for understanding and estimating faults in rotating machinery, promising enhanced system reliability and longevity.

Paper ID: 33

Axially traveling continua with fluctuating velocity in the presence of curved obstacles at both ends

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This research investigates the transverse vibrations of an axially traveling string against curved obstacles at both ends. The equations of motion have been derived using the Lagrangian approach, which transforms into a nonlinear partial differential equation after converting the moving boundary problem to the fixed boundary. In the first case, the linear vibration characteristics of the string traveling with constant velocity have been investigated through three approaches: stationary modes, the assumed mode method (AMM), and traveling modes. This analysis reveals that the non-traveling modes exhibit slow convergence. However, AMM predicts the natural frequencies better than the stationary modes, providing more flexibility in choosing the shape functions for the approximation. Additionally, we address the correctness and faster convergence properties of the traveling modes. To better align the system with real-world applications, we assume that the axial velocity of the string fluctuates about some mean velocity, which makes the system parametrically excited and leads to complex dynamics. Floquet theory is employed to conduct the linear stability analysis. Stability diagrams illustrate the regions of instability and stability in the operating parameter space spanned by the fluctuating part of the velocity and excitation frequency. It can be observed from the stability diagrams that increasing the mean velocity widens the instability region and generates new instability lobes at various excitation frequencies. An accurate depiction of the tension in the string is essential for defining the stability regions. In this context, three distinct scenarios regarding the tension in the string have been thoroughly examined: constant tension, tension dependent solely on velocity, and, particularly, non-uniform tension. Each scenario has been investigated to elucidate how these variations impact the stability diagrams.

Paper ID: 34

Numerical Study on Vibrational Behaviour of Sandwich Honeycomb Structure Embedded with Magnetorheological Elastomers (MREs)

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This study examines the vibration control potential of honeycomb sandwich beams enhanced with magnetorheological elastomers (MREs). Growing demands for lightweight structures that can adapt to changing conditions have driven interest in smart materials whose properties respond instantly to external stimuli. Using coupled electromagnetic–structural simulations in ANSYS, beams with PLA or ABS honeycomb cores and epoxy composite face sheets were analyzed under cantilever and clamped–clamped supports. The study assessed the influence of MRE containing 25 percent and 50 percent iron particles, along with magnetic field. The results show that higher iron content significantly improved stiffness control, leading to measurable shifts in natural frequencies and enhanced damping capacity. The findings highlight the promise of MRE-integrated sandwich beams as a lightweight, adaptable solution for aerospace, automotive, and other advanced engineering applications.

Paper ID: 38

DYNAMIC STABILITY AND VIBRATION CONTROL OF A MULTI-SHAFT SYSTEM FOR THE UNBALANCE AND COUPLING MISALIGNMENT FAULT ANALYSIS

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Multi-rotor systems, equipped with various flexible couplings, play a critical role in high-performance fields such as aerospace engines and marine propulsion systems. These components are essential for ensuring precision, reliability, and outstanding performance. It is crucial to maintain precise control and efficient functioning of the multi-rotor system, while flexible couplings significantly reduce vibrations and misalignments, greatly improving system durability. The integration of state-of-the-art multi-rotor technology with sturdy coupling mechanisms is vital to fulfill the rigorous requirements of modern machinery. Generally, these systems experience dynamic stability issues and high levels of vibration due to shaft misalignment, coupling flexibility, and inertial imbalance. This research employs a finite element model grounded in Euler-Bernoulli beam theory to explore the dynamic responses and misalignment forces present in the multi-rotor system. This paper investigates the role of flexible couplings in influencing the effects of both parallel and angular misalignment within the multi-coupled rotor systems. A motion equation for the multi-coupled rotor system is established to analyze critical speeds, resonance conditions, and vibration modes. Orbit response of the lateral shaft when subjected to misalignment forces, showing distinct circular paths that signify a consistent oscillatory motion. The simulations show a significant decrease in vibration amplitude and greater resilience to operational misalignments. The stability and performance of the multi-rotor system, responses are assessed in relation to two distinct frequency ranges against measurement inaccuracies. The results indicate that achieving precise alignment and optimized balancing is essential for enhancing performance and prolonging the lifespan of multi-shaft machinery. This research provides key insights for designing and maintaining multi-coupled systems in industrial settings, improving efficiency and reducing mechanical stresses.

Paper ID: 41

Dynamic Performance of Flapping Beams under Parametric Excitations

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Parametric excitation and resonance are critical phenomena in structures like helicopter blades and turbine rotors. This paper investigates the dynamic behaviour of flapping beams subjected to base excitation, combining analytical and experimental approaches. The equation of motion for a rotating beam with an offset hinge is formulated using Hamilton's Principle. An experimental model is fabricated to validate the results, with base excitation provided by an electrodynamic shaker. Parametric resonance is observed at specific rotational speeds, leading to significant flapping amplitudes. The inertial feedback on the shaker due to flapping is analysed, revealing a 22% increase in force feedback. Now, when a similar phenomenon occurs in helicopter blades during vertical flap, there are inertial loads coming as feedback to the connected components of the rotors like the swash plates, pitch rods etc. The findings provide insights into the design and stability of rotating structures in aerospace and rotodynamic applications.

Paper ID: 45

Application of an Improved Cluster-Based Algorithm for Parameter Identification From Experimental Data on a Friction-Induced System

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A novel method of identifying the parameters of a friction-induced vibration system through an improved Cluster Based Algorithm (CBA) is presented in this paper. The experimental setup consists of a single-degree-of-freedom spring block oscillator in frictional contact with a moving belt. The system exhibits stick–slip behavior and subcritical Hopf bifurcations. An exponential friction model is adopted to capture the observed nonlinear friction characteristics. The parameters of this model are identified directly from experimental measurements using the proposed CBA, which refines the parameter space iteratively through cluster-based screening without relying on gradient information. Challenges associated with the identification of parameters using the Sparse Identification of Nonlinear Dynamics (SINDy) algorithm are presented. Even though some conventional gradient based method including MATLAB's built-in solvers (fmincon, lsqnonlin) fail to converge for the noisy, non-smooth experimental signals, the CBA achieves stable and accurate parameter identification. The results show excellent agreement between experimental and simulated responses, confirming the efficacy and robustness of the proposed method. The work establishes CBA as a reliable tool for parameter identification in nonlinear systems with friction-induced dynamics and noisy measurements.

Paper ID: 47

Investigation of Nonlinear Dynamics in a Quarter-Car Model Equipped with a Modified Bouc-Wen MR Damper

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This study presents a comprehensive nonlinear dynamic analysis of a quarter-car suspension system equipped with magnetorheological (MR) dampers. To accurately capture the complex behavior of the MR damper, a modified Bouc-Wen model is employed. The primary objective is to investigate how this damper model influences the dynamic response of the suspension system when subjected to sinusoidal road excitations. Key parameters, such as the amplitude and frequency of the road input, are systematically varied to explore a wide range of dynamic behaviors. The displacement response of the sprung mass is analyzed using Poincare maps to identify bifurcations and nonlinear phenomena. The results reveal transitions between stable periodic motion, quasi-periodic oscillations, and chaotic dynamics. The analysis highlights the importance of accurate modeling in predicting system stability and performance. This work provides valuable insights for the design and tuning of MR dampers in semi-active suspension systems, with potential applications in improving ride comfort, handling, and safety in modern vehicles.

Paper ID: 51

Finite Element Simulation of Mechanical Response During Friction Stir Welding of Cu C11000 and AA6061-T6

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The study presents a finite element-based simulation of the friction stir welding (FSW) process between dissimilar materials of Cu C11000 and AA6061-T6 focusing on the development of key mechanical parameters

such as equivalent stress, frictional stress, and equivalent plastic strain with time. A coupled field transient analysis was conducted in ANSYS at three tool rotational speeds of 1000 rpm, 1150 rpm, and 1300 rpm. The simulation results indicate that equivalent (von-Mises) stress increases with tool rotational speed, with average values of approximately 2.4 GPa, 2.8 GPa, and 3.3 GPa for 1000, 1150, and 1300 rpm, respectively. Frictional stress, predominantly generated at the tool-workpiece interface, exhibited an average increase from 0.35 GPa to 0.52 GPa across the same RPM range and concentrated around the tool shoulder, reflecting the regions of highest contact and energy transfer. The strain patterns confirmed that higher tool speeds promote greater plastic flow, which is essential for achieving a strong bond between the dissimilar metals. The average equivalent plastic strain ranged from 0.58% at 1000 rpm to 0.85% at 1300 rpm, highlighting enhanced material deformation with higher energy transfer. The results shows that increased RPM not only improves plastic stirring but also increases stress fields, particularly near the interface zone. The analysis is significant for optimizing tool design and process parameters in dissimilar material welding, where mechanical stability and interface integrity are critical.

Paper ID: 52

Multi-Sensor Data Fusion for Fault Detection in Mechanical Systems: A Bayesian Modelling Approach

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This work looks into how combining data from multiple sensors can enhance the ability to detect faults in rotating machinery. Using a controlled lab setup, we simulated both normal operation and several common mechanical faults—specifically defects in the inner race, outer race, and ball components. Data were gathered from two accelerometers (measuring motion along the X and Y axes), as well as from sound and current sensors. To prepare the signals for analysis, we applied bandpass filtering to reduce noise, and then extracted a variety of features from both the time and frequency domains. Random forest techniques helped us narrow down the most informative features, and we used a Bayesian method to assign weights based on their relevance. We tested different combinations of these sensors to understand how each setup influenced the accuracy of fault classification. The model's performance was evaluated with an 80/20 train-test split, using metrics such as the Silhouette Score, Calinski-Harabasz Score, Davies-Bouldin Score, and average class distance comparisons. Results show that combining signals from multiple sensors provides a more reliable way to distinguish between healthy and faulty machine states. This suggests strong potential for applying multi-sensor fusion in real industrial fault diagnosis scenarios.

Paper ID: 53

Design and Analysis of a Quasi-Zero Stiffness Vibration Isolation System

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This study presents a low-cost passive vibration isolation system designed for low-frequency applications. Conventional isolators are effective only when the excitation frequency exceeds √2 times the system's natural frequency. To achieve isolation at lower frequencies, system stiffness must be reduced. Here, a Nonlinear Compensation Method (NCM) is employed to broaden the isolation bandwidth. The proposed design combines the nonlinear positive stiffness of repulsive permanent magnets with the nonlinear negative stiffness of a bio-inspired rhombus structure using horizontal springs. This interaction creates a Quasi-Zero Stiffness (QZS) region, enabling effective vibration isolation over a wide frequency range. Experiments conducted between 250 and 700 rpm show close agreement with theoretical predictions. At the resonance frequency of 329 rpm, the displacement transmissibility decreased to 0.48, while in the super-resonant region, displacement transmissibility decreased to 0.4. The results confirm that the NCM based isolators are effective for low-frequency and high load capacity which makes them suitable for precision instruments, laboratory platforms, aerospace systems, automotive components, and vibration-sensitive infrastructure.

Paper ID: 54

MILITARY VEHICLE LASHING DYNAMICS DURING AIR TRANSPORTATION

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This paper is focused towards development of a multi-body dynamics (MBD) model of a light weight military vehicle to simulate the influence of lashing during air transportation on a runway. The simplified MBD model of the military vehicle with linear suspension torsional stiffness and damping characteristics is developed in MSC. Adams. The anchoring chain system MBD model has been explicitly developed in MSC. Adams and associated with the vehicle MBD model and aircraft base platform at suitable locations. Suitable penalty contact conditions have been established between each chain link. Appropriate constraints are applied between the end links of each chain system as well as the vehicle and base platform. The effects of aircraft acceleration and braking on the anchored military vehicle dynamics have been studied by applying the required excitation to the base platform. Suitable remedial measures are also proposed to minimize the anchored vehicle movement and chain dynamic loads by incorporating front and rear wheel stoppers. Different vehicle and anchoring chain system combinations were analyzed to determine the influence of suspension stiffness, chain pre-tension, initial gap between wheel & stopper and their mutual contact stiffness on the vehicle movement and chain dynamic loads. This detailed lashing analysis methodology would provide an initial insight to successfully carry out air transportation of light weight military vehicles. This initial detailed study would also provide preliminary design inputs to develop light weight platforms, suitable for air transportation.

Paper ID: 55

AN INVESTIGATION OF THE COMBINED EFFECT OF LOAD, DEFECT AND MISALIGNMENT IN ROTOR-BEARING SYSTEMS USING THE BOX-BEHNKEN METHOD OF RESPONSE SURFACE METHODOLOGY

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The bearing failure represents one of the primary contributors to the malfunctioning of rotating machinery. Such failures can lead to downtime in the rotating machinery. This study proposes a dynamic model for forecasting the vibrational attributes of the rotor-bearing system using Dimensional Analysis. A well-founded theoretical framework was initially created by applying Dimensional Analysis via the matrix method to derive the crucial dimensionless groups that regulate the system's dynamics. Following this, an experimental investigation was performed on a specialized test rig, employing Response Surface Methodology (RSM) in

conjunction with a Box-Behnken Design (BBD) to plan the experiments and model the interactions among the input parameters. A Box-Behnken experimental approach was adopted to characterize the vibration amplitude response across a variety of the three operational parameters. The findings indicate that both load and misalignment significantly enhance vibration amplitudes, with their effects being particularly paramount. This study offers a robust approach vital for accurate forecasting of vibration metrics and assessing intricate failures in industrial rotor-bearing systems.

Paper ID: 57

Experimental Investigation on the Impact of Toolpath on the Machining Instability of WAAM Components

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In recent years, metal additive manufacturing (MAM) has evolved as a viable alternative to the conventional techniques of producing metal parts. The main benefits of the MAM components have been their superior mechanical properties in comparison to their commercially available counterparts. Out of all the prominent metal additive processes, wire arc additive manufacturing (WAAM) has been able to present itself as the most cost and material-efficient process. It is highly reliable in achieving large-scale near-net shape parts with higher deposition rates. However, there are many challenges and limitations associated with the WAAM-fabricated components; the most prominent among them are the rough surface, dimensional inaccuracy, distortion, and inherent anisotropic behavior, among others. These limitations result in the deterioration of the geometric integrity of the build component, which affects the further use of the part in the assembly. The issues can get further amplified based on the tool path considered during fabrication, which is a critical aspect of the metal additive process. To improve these inherent issues, post-processing in the form of machining becomes essential. A critical issue encountered during the machining of WAAM components is chatter vibration—a self-excited, unstable vibration that can severely degrade surface finish, dimensional accuracy, and tool life. Research regarding the machinability and the dynamic stability of the wire arc additively manufactured mild steels has been addressed. In this work, specimens following two different tool paths have been obtained. For post-processing, milling operations have been performed at different cutting conditions by varying the machining parameters. Sensors like accelerometers and microphones, along with machined surface topography, have been utilized for chatter detection.

Paper ID: 59

Impact of Time-Varying Frictional Torque, Runout, and Tooth Errors on Spur Gear Transmission Error

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This study investigates the effects of rotational speed and manufacturing errors on the dynamic behaviour of a spur gear system. A coupled dynamic model is developed, which includes time-varying mesh stiffness, profile error, runout error, and an instantaneous sliding frictional torque. The model equations are solved in the time domain to evaluate the dynamic transmission error (DTE) and dynamic mesh force (DMF) values over a wide range of pinion speeds. DTE and DMF exhibit periodic and steady responses at low rotational speeds, primarily driven by the mesh frequency (fm) and its harmonics. At high speeds, severe impacts occur, as reflected by negative peaks in DTE and DMF, indicating intermittent loss of tooth contact. Frequency-domain analysis highlights dominant mesh frequency components, higher-order harmonics, sidebands linked to rotational frequency (fr) and manufacturing deviations. Parametric analysis reveals that runout error has a negligible effect on RMS DTE and dynamic load factor (DLF) when profile error is held constant, suggesting that the coupled model inherently accounts for shaft deflection effects. The findings provide valuable insights into the speed-dependent dynamic behaviour of spur gears, supporting improved prediction of vibration characteristics and the development of quieter and more reliable gear systems.

<u>Paper ID: 63</u>

MATHEMATICAL VIBRATION MODEL OF A TANK GUN RECOIL SYSTEM

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This paper focuses on developing a detailed vibration mathematical model of a gun recoil system, which is used on Armored Fighting Vehicles (AFVs). An existing recoil system of a tank gun is considered for developing the vibration models, which is subsequently coded in MATLAB as well as in Simscape Fluids. The recoil system is modeled as a single degree of freedom mass, spring and damper system, which is subjected to external time variant firing force. However, unlike conventional vibration models, in this case, the non-linear fluid mechanics equations are incorporated across different flow paths of the fluid through fixed and variable length orifices to arrive at the actual damping force during the recoil and recuperation phase. These non-linear fluid mechanics equations are integrated with the single degree of freedom vibration mathematical model to determine the recoil distance, recoil and recuperation velocity as well as the transmitted force magnitude. Suitable conditional statements are incorporated in the MATLAB code to represent the fluid flow phenomenon across the variable length and fixed orifice regions. The same is established in Simscape Fluids by using appropriate blocks. The developed non-linear single degree of freedom vibration mathematical model responses are validated successfully with relevant experimental findings. This study has established a very vital platform for design and development of recoil system variants for light weight armoured platforms, which can further be used for evaluating the vehicle stability. This present research provides deep insight towards designing and optimizing advanced recoil systems for armoured vehicle platforms.

Paper ID: 64

Design and Analysis of a Resilient Passive Isolation System for Satellite On-Board Micro-Vibration

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Disturbance of micro level vibrations (acceleration of the order of micro-g) is observed on-board spacecraft, even though the different wheels (like reaction, momentum, cryo-cooler, gyroscopes) are precisely balanced to minimize emitted vibration due to static and dynamic imbalances. The unbalanced forces generated by the spinning reaction wheel (at the spin frequency and its harmonics) vibrate the spacecraft bus and degrade the pointing accuracy of the camera/pointing payload. A passive vibration isolation platform comprising of a combination of multiple folded beams and a resilient member in specific telescopic assembly is proposed here to isolate vibratory disturbances in the plane of rotation of the wheel. The concept of introducing the telescopic resilient assembly is the novelty in this work. This provides good isolation in the plane of rotation of the wheel, but marginal isolation in other planes. Thus, it does not hinder any transmission of quasi static or low frequency torque required to rotate the whole satellite. Stiffness along different coordinates is derived by applying Castigliano's theorem. By considering the reaction wheel and the platform as an integral system, an equivalent dynamic model is developed. Simulation results show that a properly designed vibration isolation platform can very effectively attenuate the resulting micro-vibrations. The efficiency of isolation was tested by comparing the force and moment transmitted to a Force/moment transducer table when the wheel-isolator system with and without the telescopic member is mounted on the table, with the wheel in running condition. Thus, this paper presents the proposal, design methodologies, and experimental validation of a simple, novel, low-cost and efficient, passive micro-vibration isolator for sensitive payloads on-board a spacecraft.

Paper ID: 66

KINEMATIC ANALYSIS AND REALIZATION OF A COMPOUND PLANETARY GEAR TRAIN FOR COMPACT HIGH-TORQUE APPLICATIONS

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A simple planetary gear train-based actuator has a limited reduction ratio and size. Even with multiple stages of a basic planetary gear train, high reduction ratios can be achieved; however, the length and weight increase significantly. For aerospace applications like control surfaces, weapon bay door actuators, and similar uses, high torque and compactness are essential to operate surfaces and doors efficiently. Combining a simple planetary gear train with a compound planetary gear train offers the advantages of high-speed reduction, along with reducing mass and space. Designing and configuring such combined planetary gears requires innovation

and specific machining orientations for the planetary gears. This study presents the design and kinematic analysis of a compact, two-stage planetary gear system that provides high reduction ratios suitable for actuator applications needing high torque at low speeds. The proposed design integrates a simple planetary gear with a fixed ring in Stage I and a compound planetary gear with stepped planet gears in Stage II. The system achieves an overall speed reduction ratio of approximately 1:126 while maintaining a coaxial and space-efficient layout. Detailed geometric design, gear tooth selection, and meshing feasibility criteria are used to ensure smooth operation and compatibility during assembly. Mathematical models validate gear placement rules and inter-stage coupling conditions. The results demonstrate the mechanical feasibility and robustness of the proposed system. This approach offers a modular and scalable solution for high reduction ratios in constrained environments, with potential uses in robotics, aerospace, and electric mobility systems.

Paper ID: 68

TWO-STAGE CONVOLUTIONAL AUTOENCODER FRAMEWORK FOR STRUCTURAL DAMAGE AND TRANSDUCER DEBONDING DETECTION IN MULTI-SENSOR GUIDED WAVE SHM

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Structural Health Monitoring (SHM) techniques have gained significant attention due to the increasing demand for real-time and reliable assessment of structural integrity. Among various methods, Guided Waves (GW) have emerged as a popular choice because of their ability to travel long distances with low attenuation and their sensitivity to small damages. Advances in sensor technologies have further enabled the practical implementation of GW-based SHM.
For effective real-time monitoring, actuators and sensors are permanently mounted on the host structure. However, structures often operate under varying Environmental and Operational Conditions (EOCs) such as temperature changes, moisture, and vibrations. These conditions influence GW propagation and pose challenges to reliable SHM performance. Furthermore, EOCs can degrade the performance of sensors themselves, leading to issues such as partial bonding, debonding, and sensor deterioration. These degradations may result in altered signal responses, causing false damage predictions. To address these challenges, this study proposes a framework to detect debonding in sensors and to accurately identify structural damage without false alarms. Experiments are conducted on an aluminium plate where sensors with varying degrees of debonding are bonded. A two-stage Convolutional Autoencoder (CAE) is implemented to simultaneously detect sensor debonding and structural damage. The proposed approach is compared with the conventional Maximum Amplitude Spectra (MAS) method. Results show that MAS performance heavily depends on sensor placement, while the proposed model reliably identifies sensor faults regardless of actuator–sensor distances. This framework enhances the robustness and reliability of GW-based SHM systems under varying EOCs.

Paper ID: 70

DESIGN OF LOCALLY RESONANT MATRYOSHKA SONIC CRYSTAL USING GENETIC ALGORITHM FOR OPTIMIZED SOUND ATTENUATION

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Locally Resonant Matryoshka Sonic Crystal (LRMSC) can be great for environmental noise control as they can attenuate multiple frequency bands, with widened bandwidth, within dimensional constraints, and with ventilation. This paper investigates the effect of opening angle of the scatterer's resonant cavity on the first band gap (BG) of C-shaped LRMSC. A Multi-Objective Genetic Algorithm is developed for tuning the opening angles of scatterers for optimizing this central frequency and bandwidth. Increase in the combined opening angles leads to lower frequency BG due to reduced frequency of local resonance. Widest opening angle of innermost scatterer with smallest opening angles of remaining scatterers minimizes the central frequency and maximizes bandwidth. The optimization algorithm is demonstrated and numerically validated (mean error 2.18%) for minimized central frequency with maximized bandwidth of the first band gap. This paper proposes a key approach for tuning the frequency and bandwidth of sound attenuation without changing the dimensions of the structure.

Paper ID: 71

A New Acoustic Metasurface with Coplanar Labyrinthine and Perforated Panel

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Achieving effective sound absorption below 1000 Hz remains a persistent challenge for conventional acoustic barriers and absorbers, yet it is critical for mitigating noise generated by industrial and household machinery. Although passive acoustic metasurface (AMMs) offer promising low-frequency performance, they are often constrained by narrow bandwidths and bulky configurations. To overcome these limitations, we propose a compact metasurface comprising a perforated outer panel with multiple holes and Coplanar labyrinthine channels positioned behind it. Numerical simulations were performed using COMSOL Multiphysics to analyze the effect of perforation diameter and panel thickness on sound absorption. The proposed AMM achieves near-perfect sound absorption (α = 0.99) at 460 Hz with a broad bandwidth of 110 Hz and with the thickness of only 23mm. It is found that increasing the hole diameter from 0.8 mm to 1.2 mm raises the peak frequency from 400 Hz to 510 Hz while increasing the panel thickness from 1 mm to 4 mm lowers the peak frequency from 560 Hz to 430 Hz. Owing to its compact, subwavelength configuration, the proposed AMMs offers an efficient and space-saving solution for low-frequency noise control in industrial and domestic environments.

Paper ID: 72

A Diagnosis of Unbalance and Bearing Surface Defects in the Rotor Bearing System with Central Composite Rotatable Design(CCRD)

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The rotor bearing assembly constitutes a fundamental element within rotating machinery, serving as an essential component across various industrial sectors. Dual rotor forms one of the key structure of larger gas turbines and aero engines because of its improved efficiency. The sound performance of this system has a direct relationship with the safety, reliability, and efficiency of any working assembly. In industries such as power generation, manufacturing, and aerospace, rotating machinery is integral to operations. However, bearing defects and rotor unbalance are leading causes of machinery failures, leading to increased maintenance costs and potential safety hazards. Understanding these effects is crucial for enhancing the reliability and performance of rotating equipment. An experimental setup was developed to simulate different fault conditions in a dual rotor bearing system. Vibration data set were collected and analyzed using Fast Fourier Transform (FFT) to identify characteristic frequencies associated with each fault. Central Composite Rotatable Design (CCRD) was employed to systematically plan experiments and assess the interaction effects of the variables. The analysis revealed that bearing defects and unbalance significantly influence the vibration spectra, with distinct frequency components emerging under each condition. Speed variations further modulate these effects, indicating complex interactions between the fault parameters. The combined application of FFT and CCRD provides a comprehensive approach to diagnosing and understanding faults in dual rotor bearing systems. This methodology facilitates predictive maintenance and enhances the operational safety of rotating equipment.

<u>Paper ID: 73</u>

Forced Synchronization in Nonlinear Aeroelastic Systems under Dual Sinusoidal Forcing

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Synchronization theory has emerged as a powerful framework for analysing and interpreting the dynamic responses of fluid-structure systems, owing to their inherent nonlinearities and coupled modal behaviour. Synchronization-based aeroelastic studies commonly assume parametric or longitudinal flow conditions, which can induce self-excited nonlinear instabilities such as limit cycle oscillations (LCOs). The nonlinear aeroelastic response is highly sensitive to both the qualitative and quantitative characteristics of vertical flows. Recent studies on nonlinear aeroelastic systems from the authors have underscored the role of external sinusoidal forcing to dramatically affect the forced synchronized characteristics compared to its unforced counterpart. This present work serves to be a direct extension of the same by considering dual sinusoidal forcing, i.e. considering two external forcing terms, say $f\sin(\omega t)+g\sin(\delta t)$, wherein f and g are intensities

of the external forcings and ω and 8 are the frequencies of the external forcings. To that end, a two-degree-of-freedom system with cubic nonlinearity is considered and is assumed to be subjected to dual sinusoidal forcing representing fluid forcing in the vertical direction. The use of dual sinusoidal forcing frequencies enables the exploration of complex resonance phenomena, frequency interactions, and synchronization behaviour under multi-frequency excitation, offering a more realistic representation of external aerodynamic disturbances. The study also elucidates the physical mechanisms of forced synchronization phenomenon induced by the dual vertical aerodynamic gust excitations in the coupled nonlinear aeroelastic system with cubic stiffness. The axial (parametric) flow components are modelled using a standard unsteady aerodynamic formulation, while the vertical (external) wind load is represented as a set of sinusoidal forcing function. Numerical simulations and phase-locking metrics are employed to characterize the transitions in response dynamics from asynchronous to phase-synchronized states. Arnold tongue structures delineate synchronization thresholds and reveal how variations in amplitude and frequency influence energy exchange between the pitch and plunge modes and the external forcing. The findings demonstrate that changes in amplitude ratio and frequency spacing between two successive forcing critically influence synchronization behaviour, offering valuable insights for controlling flow-induced instabilities and enhancing energy extraction strategies. These insights are particularly relevant for aeroelastic systems subjected to turbulent, gusty flows, where engineered gust excitations could be harnessed to stabilize the structure.

Paper ID: 74

Research on the Vibration Characteristics of Deep Groove Ball Bearing Considering Outer Race Surface Defect and Bearing Tilt

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Rolling element bearings are crucial components in many rotating machines, and their failure can have a profound impact on the equipment's operation. Early detection of bearing faults enables timely and accurate interventions, thereby reducing safety risks. However, the early diagnosis of fault frequency characteristics in compound defect signals hinders the accuracy of fault diagnosis. To address this challenge, we propose a mathematical model and numerical techniques to establish the vibration characteristics of compound defects. The effects of rotation speed, outer ring defect and bearing tilt on vibration characteristics are analyzed. Finally, the compound defects vibration characteristics experiments are verified by the test rig. The results indicate that outer race defects and bearing tilt significantly increase the excitation of the rotor bearing system. The results suggest that the vibration amplitude and frequency intensity of the rolling bearing increases as the defect rises. Specifically, as the amplitude of vibration on the radial raceway increases, the vibration levels initially rise before stabilizing within a specific fluctuation range. This study also examines the impact of bearing tilt conditions and outer race defects on the vibration characteristics of the deep groove ball bearing, offering a deeper understanding of how these factors contribute to the overall dynamic behaviour.

Paper ID: 75

A Data-Driven Design Strategy for Over-Molded Composites Using Machine Learning

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Over-molded composites are made by injecting short fiber polymers onto continuous fiber inserts. This hybrid structure offers high strength, stiffness, and good formability, thereby supporting their use in structurally demanding components with complex geometries. However, designing over-molded composites is challenging due to the large and complex design parameter space and the intricate relationship between structural configurations and mechanical properties. Traditional trial-and-error approaches or those relying heavily on scientific intuition are often time-consuming and costly when aiming to optimize performance. To address this issue, we propose a machine learning (ML)-assisted framework to efficiently predict the tensile properties of over-molded composites. A finite element model was created to analyze the composite's behavior to tensile loading, and its accuracy was validated through experimental testing. Using this validated model, various combinations of continuous fiber-reinforced composites and over-molded resin systems were modeled, generating a dataset of 24 samples. Subsequently, three machine learning (ML) models-Random Forest (RF), Support Vector Regression (SVR), and Artificial Neural Networks (ANN)-were utilised and trained using this dataset to predict the tensile strength of over-molded composites. The ANN model showed the closest agreement with experimental results, highlighting its effectiveness in capturing the composite's tensile behavior.

Paper ID: 76

Data-Driven Fault Detection in Rotating Machinery: FEA-Guided Machine Learning for Deep Groove Ball Bearing Diagnostics

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The condition of bearings is fundamentally linked with the reliable operation of rotating machinery, as the mechanical stability and operational efficiency is maintained by these components. Amongst various types of bearings used in industries, Deep groove ball bearings are versatile which are extensively employed for industrial applications because of their ability to withstand combined axial and radial loading conditions. If bearing faults are remained undetected, can lead to severe system failures, high maintenance cost and unexpected machinery downtime. Unlike the previous researchers applied FEA and Vibration based ML

independently, this research integrates both domains through kutosis-SVM framework and introduces intelligent fault detection method for rotor bearing systems. Even if Finite element analysis provides valuable results of system dynamics and through computational modeling, its accuracy still depends on the experimental validation. In this study a detailed parametric model is developed in ANSYS workbench which incorporates critical parameters in it which affects vibrational behavior. The experimental validation is conducted on rotor test rig with integrated vibration monitoring capabilities which can acquire the response data across multiple speeds. This research gives a framework in advancing condition monitoring methodologies by effectively combining ANSYS based simulations with machine learning algorithms which develops more accurate and efficient bearing fault detection systems.

Paper ID: 78

DESIGN AND ANALYSIS OF FRUSTUM-BASED HOLLOW HEXAGONAL METAMATERIAL UNIT CELL FOR LOW-FREQUENCY BAND GAP FORMATION

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This paper presents the design and analysis of a Frustum-based Hollow Hexagonal Unit Cell (FHHUC) developed on the principle of local resonance to achieve low-frequency band gaps within compact geometry. The proposed unit cell, with an overall size of 30 mm, integrates three distinct materials: a lightweight polyurethane (PU) foam forming the outer frame, a central silicon rubber beam, and a tungsten frustum as the resonating mass. The structural arrangement, with the heavy mass concentrated at the inner core and lighter materials toward the periphery, promotes efficient resonance-induced attenuation. Numerical simulations conducted using COMSOL Multiphysics confirm the formation of multiple band gaps below 100 Hz, with the first gap appearing near 17.5 Hz. Analytical validation performed using an equivalent fixed–fixed beam with a concentrated mid-span mass, yielding results consistent with the numerical model and within ~12% error. Transmission loss spectra further verified the band gap behavior, showing distinct attenuation in the corresponding frequency ranges. The findings demonstrate that the Frustum-based Hollow Hexagonal Unit Cell is compact, practically feasible, and highly effective in producing low-frequency band gaps, making it suitable for advanced vibration and noise control applications.

Paper ID: 80

DESIGN AND EXPERIMENT OF NEGATIVE-STIFFNESS ELECTROMAGNETIC SPRING FOR LOW-FREQUENCY VIBRATION ISOLATION

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When paired with a positive stiffness element, say a mechanical spring, a negative stiffness mechanism constitutes a vi- bration isolator with reduced stiffness, lower natural frequency, and thereby an increased isolation bandwidth. A practical application is realised using an Electromagnetic Spring Assembly (ESA), a coaxial arrangement of a permanent magnet and a coil winding. Its advantages include tunable (negative) stiffness based on the current supplied to the coils and contactless operation, eliminating any mechanical wear. In this work, a negative-stiffness vibration isolator based on a multi-layer Electromagnetic Spring Assembly (ESA) is presented. A mathematical model based on the filament method is developed in Python to predict axial force-displacement behavior, and its accuracy is evaluated by comparing against both Ansys Maxwell simulations and load-cell measurements, resulting in average deviations of 16.4% and 5.3%, respectively. A sim- ple dynamic model for force evaluation is reliably approximated using curve fitting (R2 > 0.99998). A six-layer ESA-based isolator prototype is fabricated with a mechanical spring of nominal stiffness 2.3 kN/m, with all key components housed within a 3D-printed support structure. Under a sinusoidal excitation of 10 Hz, the payload acceleration is reduced from 4.50 m/s² (no current) to 1.48 m/s² at 4 A. In addition, the peak negative stiffness of the assembly reached 469.9 N/m under the same current setting, demonstrating current-based tunable vibration isolation capabilities. The Python code implemen- tation for the filament method is available on GitHub (/RachitRijal/Filament_Method).

<u>Paper ID: 82</u>

ANALYSIS OF PARAMETRIC EXCITATION IN A PLAYGROUND SWING

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This paper examines the dynamic behavior of a child-pumped playground swing using a lumped parameter model for pumping from the standing position. The novelty of this work lies in the model itself, which captures how vertical body motion amplifies swing oscillations without requiring multiple degrees of freedom. The system comprises a pendulum representing the swing and a second mass attached via a spring to model the child's center of mass, constrained to move vertically. This eliminates the need for a dedicated dof to model separate forward-backward motion. Using the Euler-Lagrange equation, a nonlinear differential equation coupling translational and angular motions is derived. Under the small-angle approximation, the system is linearized and analyzed for stability using Floquet's theory, yielding stability diagrams that reveal the main unstable regime near twice the natural frequency and other interesting regimes at the natural and two-thirds natural frequencies. The method of multiple scales is applied to the nonlinear equation to obtain approximate analytical solutions capturing resonance, amplitude modulation, and the influence of pumping phase. This work presents a novel model and offers insights into internally actuated parametric systems.

Paper ID: 83

EFFECT OF WIND VELOCITY AND INSTALLATION ANGLE ON PRESSURE AND VELOCITY DISTRIBUTION ON PV MODULE FOR VIBRATION CONTROL USING CFD APPROACH

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The life of solar PV module can be significantly affected by various source of vibration including wind load, seismic activities, structural resonance, transportation, thermal cycling and other similar influences. Wind forces and the angle at which solar photovoltaic (PV) modules are installed can greatly affect their vibrational behaviour and structural stability. In this context, a computational fluid dynamics (CFD) simulation was performed using ANSYS Fluent to analyze the effect of varying wind speeds and tilt angles on the aerodynamic variation of a solar PV module. The primary objective was to investigate how module tilt angles and wind velocities influence pressure distribution and flow behaviour, which directly affect the structural stability and vibration response of PV modules. To ensure the accuracy and dependability of the numerical method, the CFD model was verified using the standard drag coefficient of the cube prior to the full-scale simulation. Four PV modules were modelled in tandem arrangement and simulated under varying tilt angles and wind velocities. The results indicate that wind velocity has a more dominant effect on pressure build-up compared to tilt angle. A dual-inlet case, simulating multidirectional wind exposure at 25° tilt, showed a significant rise in aerodynamic pressure along with complex recirculation and flow separation zones. The results provide vital information for optimizing the structural design and mounting arrangement to control vibrations of the PV module to improve the robustness and performance.

Paper ID: 84

DRAFT: UNSUPERVISED TOOL-WORKPIECE CONTACT DETECTION USING STFT FEATURE EXTRACTION AND K-MEANS CLUSTERING

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Micromachining is a precision machining process capable of producing micro-scale components at lower cost compared to many other techniques. However, one of its critical challenges is the accurate detection of initial contact between the micro tool and the workpiece. Even small errors in tool setting lead to dimensional inaccuracies, poor surface quality, excessive tool wear and catastrophic tool failure. Conventional methods, such as applying voltage between the tool and workpiece, or electronics circuit based approach are reliable but limited to electrically conductive materials. Sensor-based approaches can work for both conductive and non-conductive materials, but the initial impact signal has very low amplitude and is easily masked by background noise. To address this problem, this study introduces the use of the Wavelet Packet Transform (WPT) combined with a Transient-to-Noise Ratio (TNR) metric. The TNR criterion is used to select the optimum

wavelet function and decomposition level to effectively suppress noise while preserving the transient initial tool workpiece contact signal. From the selected WPT subband, statistical features such as TNR, energy, and kurtosis are extracted from short-time windows. Finally, a K-means clustering algorithm, together with a baseline TNR threshold, is applied to automatically detect tool–workpiece contact events. The proposed method successfully distinguishes weak impact signals from noise, enabling reliable contact detection in both conductive and non-conductive workpieces. This makes it a reliable and flexible method for improving the accuracy of the tool setting process for non conductive workpiece.

Paper ID: 85

ANALYSIS AND DEVELOPMENT OF OPTIMUM STRUCTURE FOR AUTOMATED TAP TESTING OF MICRO CUTTING TOOL

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This study presents the design, development, and validation of an automated tap-testing system for accurate modal analysis of micro cutting tools. Conventional impact testing of micro-end mills faces challenges such as inconsistent excitation, multiple hits, and poor repeatability due to the small tool dimensions. To address these issues, a structurally optimized impact system was developed using a 3D-printed flexible hammer holder actuated by an electromagnet and controlled via an Arduino-based circuit. Three hammer holder designs were fabricated and evaluated to determine the optimal balance between stiffness and flexibility for single and consistent impacts. Experimental modal analysis was performed on a 0.5 mm diameter micro ball-end mill under stationary conditions, with measured the tool responses using a Laser displacement sensor. The results demonstrated that the optimized structure provided stable and repeatable force and displacement responses, minimizing damping interference and ensuring clear identification of modal frequencies. Frequency response function (FRF) analysis confirmed accurate capture of the tool's dynamic behavior, validating the system's reliability for micro tool testing. The developed automated tap-testing setup offers a practical, high-precision, and repeatable method for characterizing tool dynamics and advancing the understanding of micromilling process dynamics.

Paper ID: 87

ANALYSIS OF A COMPOUND PENDULUM EXCITED BY A ROTATING MASS

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This work examines the dynamic behavior of a driven compound pendulum. The work is motivated by the resonances that can occur as a result of the interaction between rotating machines installed on and the rolling motion of ships. The system investigated is a pivoted compound pendulum, which is excited by a point mass rotating at a constant angular velocity. The differential equation governing the motion of the system is derived by employing the Euler-Lagrange equation and the resulting equation is found to comprise terms that arise due to both parametric excitation and conventional external forcing, is further reduced to model small angular displacements. The solution to the governing equation is obtained by numerical integration and thereafter analytically by the generalized harmonic balance method. The excitation frequency is varied and at each frequency step, the steady-state response is extracted. Further the dominant frequency components are identified through a fast Fourier transform. Phase portraits are also constructed at various excitation speeds. The transition of Floquet multipliers of the monodromy matrix across the unit circle was ivestigated, and the intersecting superharmonic and subharmonic resonances were observed.

Paper ID: 88

Physics-Informed Neural Network Based Approach for the Analysis of Vibration Energy Harvesting Using Piezoelectric Bimorph Cantilever Beams with a Tip Mass

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The growing demand for sustainable energy sources has positioned energy harvesting as a critical area of research. Among various techniques, piezoelectric energy harvesting (PEH) has gained significant attention due to its potential to enable battery-free, sustainable power for sensors and wearable devices. This study investigates piezoelectric energy harvesting for a bimorph cantilever beam with a tip mass, employing a Physics-Informed Neural Network (PINN) to model the beam's electromechanical behaviour. The PINN framework predicts voltage by integrating the governing equations derived from beam theory, electromechanical coupling, and geometric constraints. Unlike traditional deep learning methods, PINNs incorporate the governing equations, ensuring that the model learns not only from experimental and/or simulation data but also adheres to the underlying physics. This approach improves generalization and reduces dependency on large datasets, with the PINN achieving an average coefficient of determination (R^2) of 0.9988, Root Mean Squared Error (RMSE) of 0.125 V, and Mean Absolute Error (MAE) of 0.0207 V, indicating close agreement with Finite Element Method (FEM) simulations while offering significantly higher computational efficiency

Paper ID: 89

3-D FINITE ELEMENT ANALYSIS OF A SIDE INLET AND SIDE OUTLET ELLIPTICAL EXPANSION CHAMBER MUFFLER WITH MEAN FLOW

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This work presents the combined effects of non-uniform flow and elevated temperature on the transmission loss (TL) performance of side inlet and side outlet (SISO) elliptical expansion chamber mufflers using 3-D finite element analysis (FEA) based on COMSOL Multiphysics. A hybrid simulation framework, integrating steady-state computational fluid dynamics (CFD) with frequency-domain pressure acoustics, is employed to predict the TL spectrum. The steady flow field within the muffler is first determined using the Shear Stress Transport (SST) turbulence model, accurately capturing internal flow behavior. This background flow is then mapped onto the acoustic domain using the Background Fluid Flow Coupling interface, serving as input for solving the Linearized Navier-Stokes Equations (LNSE) in the frequency domain. This approach effectively accounts for both convective and viscous effects of the mean flow on the acoustic response. The CFD mesh is generated with higher resolution than the acoustic mesh to accurately capture flow details. Numerical simulations are conducted using air as the working fluid at Mach numbers of 0.05 and 0.1, and at temperatures of 293K, 600 K and 700 K to represent realistic operating conditions. The pressure acoustic in the frequency domain module in COMSOL Multiphysics is used for a stationary medium, i.e., Mach number of 0 at the same temperatures, to predict the TL spectrum. The inlet and outlet tubes are positioned such that the quarter-wave resonators formed by the end-chambers eliminate three-fourths of the troughs corresponding to the equivalent simple expansion chamber (SEC) muffler to produce double-tuned broadband attenuation performance.

Paper ID: 91

A NOVEL STACKED GRU AUTOENCODER FOR UNSUPERVISED LOOSENING DETECTION WITH LAMB WAVES IN BOLTED ALUMINUM LAP JOINT

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Health monitoring of bolted joints is crucial for the prompt identification of loosening, enabling quick corrective measures to maintain structural integrity and ensure safety. Guided wave-based structural health monitoring (GW-based SHM) systems have the capability of detecting minute damages and scanning large areas with a limited number of transducers, and hence, are preferred for thin plate-like structures. In this work, experiments are carried out using piezoelectric transducers on an aluminium lap joint with two bolts to assess the Lamb wave propagation across the joint during loosening. Torque values ranging from 10 Nm to 3 Nm, with a step size of 0.5 Nm, are applied on the bolts, along with three additional conditions: hand-tightened, bolt present with no torque, and bolt absent. Seventeen different excitation frequencies ranging from 52 kHz to 260 kHz are employed for generalization. A clear reduction in the signal amplitude is observed as the bolts loosen. The central goal of this study is to develop an unsupervised learning framework for anomaly detection in bolted lap joints. This strategy uses a Gated Recurrence Unit-based Autoencoder (GRU-AE), with stacked GRUs in encoder and decoder, which employs time-series data directly without any additional signal processing requirements. The model is trained directly on the signals representing the torqued conditions by minimizing the reconstruction error. The trained model is then tested with unseen signals representing loosened conditions, returning high accuracy. We further investigate the influence of noise and the amount of training data on the performance of the model.

Paper ID: 93

Tuning Mode Shapes and Modal Frequencies of Simplified Beam Model Using Quantum-behaved PSO and Adaptive PSO

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Numerical models are vital tools in structural analysis, but due to necessary simplifications, such as idealizations and assumptions, they often fail to fully capture real-world structural behavior. To reduce this gap, we integrate experimental data with finite element model updating techniques, enhancing the accuracy and reliability of simulations. This study presents a practical and robust methodology for tuning the mode shapes and natural frequencies of a simplified beam-based structural model using advanced optimization algorithms. A complex structure is approximated by an equivalent beam model, with cross-sections carefully chosen to match the local rigidity of the original system. Joint flexibility, a critical factor in capturing realistic dynamic behavior, is modeled using rotational springs to simulate local compliance at structural connections. To improve the fidelity of the model, we apply optimization algorithms like Quantum-behaved PSO and Adaptive PSO. These algorithms adjust geometric dimensions, elastic properties, and joint stiffnesses to minimize the discrepancy between numerical and experimental modal data.
Each method is evaluated based on convergence speed, accuracy in replicating target dynamics, and resistance to local minima. Among them, hybrid and adaptive approaches—QPSO and APSO—demonstrate good performance in both precision and computational efficiency. This work underscores the value of combining optimization algorithms with model updating to produce high-fidelity structural models. The proposed approach offers a powerful tool for dynamic simulation and structural health monitoring in engineering practice.

Paper ID: 94

MODELLING AND CHRACTERIZATION OF GEOMETRICAL ERROR IN ROBOTIC MICROMILLING

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Robotic micromilling represents a promising direction for achieving flexible, precise, and complex micromachining operations. By combining the versatility of robotic manipulators with the precision of microscale cutting, this approach has the potential to transform small-batch or on-demand manufacturing. However, widespread adoption is hindered by unresolved challenges related to the structural compliance and dynamic stability of robotic systems. While these issues have been extensively studied in macro-scale robotic milling, their implications in robotic micromilling remain unexplored. One such phenomenon, variation in

cutting force and depth of cut along the machining path because of changes in local stiffness is well documented at the macro scale but has not been systematically analyzed for microscale processes. Unlike traditional CNC milling machines, which are built to be very stiff, robotic systems can easily deflect with small force changes, causing uneven cutting in the Z direction. This study aims to fill that gap by characterizing the depth of cut variation in robotic micromilling using a 500 µm end mill. Robot positional stiffness and trajectory error along the cutting length have been modelled and correlated with the depth of cut error. It is found that, because of the low stiffness of the robot, the trajectory error is very high and the robot stiffness also varies significantly in a 100 mm travel length in the X direction. The major source of error is trajectory error, while the stiffness variation also causes a minor error in depth of cut variation. A 0.3 mm trajectory is itself found in a robot with no-load conditions. The maximum error in depth of cut is found as ± 100 µm, and that is closed to the oscillation lobe of trajectory error. The increasing stiffness of the robot in the Z direction results in a decrease in the depth of cut.

Paper ID: 99

ASSESSING WELL-TO-WHEEL EMISSIONS OF ALTERNATIVE POWERTRAINS FOR LIGHT DUTY COMMERCIAL VEHICLES IN INDIA

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Light-duty commercial vehicles (LDCVs) are vital for India's urban freight movement due to their compact size, cost-effectiveness, and suitability for last-mile delivery. However, they rely heavily on fossil fuels, contributing to greenhouse gas (GHG) emissions, air pollution, and energy insecurity. Although Battery Electric Vehicles (BEVs) produce zero tailpipe emissions, they overlook upstream emissions from electricity generation. In India, nearly 74% of electricity is still generated from non-renewable sources, as NITI Aayog (2025–26) reported. To emphasize the impact of emissions from both energy generation and vehicle propulsion in the transportation sector, this study presents a comparative Well-to-Wheel (WTW) emissions analysis of different powertrain types: Compressed Natural Gas (CNG), Hybrid Electric CNG, and BEVs. An analysis was conducted using an analytical approach under Indian urban driving conditions (Representative Drive Cycle), considering vehicle dynamics to estimate WTW emissions. It accounts for key powertrain-specific factors such as engine efficiency, maximum vehicle speed, and India's fossil-fuel-dominated grid. Analytical results indicate that Hybrid CNG vehicles emit 16.40 kg CO_2-eq per cycle, which is approximately 32% lower than BEVs (24.04 kg). Hybrid CNG systems emerge as a strong transitional solution for decarbonizing LDCVs. With further focus on total life cycle emissions along with fuel consumption, they could provide a balance of fuel savings, reduced emissions, and improved energy security. Unlike BEVs, they avoid the challenges of limited charging infrastructure. This approach aligns well with India's goal to reduce emission intensity by 45% by 2030 (CEEW data).

Paper ID: 101

Dynamic stability of textured journal bearing considering non-linear bearing forces

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The purpose of this work is to investigate how surface texturing affects the dynamic and stability behaviour of textured journal bearings as compared with plain ones through linear and nonlinear evaluations. The performance of plain, full-textured, and middle-textured journal bearings was investigated to evaluate how texture distribution influences rotor–bearing performance. To determine the system's stability and response, linearised dynamic coefficients were used to find the critical mass and orbit response about the equilibrium position, and nonlinear transient simulations were used to find the trajectory of the journal centre. The results reveal that texturing the bearing surface enhances system stability through improved dynamic stiffness and damping characteristics. The critical mass, representing the threshold of instability, increases with textured bearing, confirming improved resistance to self-excited whirl. From both linear and nonlinear orbit analyses, the middle-textured bearing provides smoother, more circular orbits, demonstrating better control of rotor dynamics. Pressure and film thickness profiles further show that proper texturing in the mid-region strengthens pressure recovery in the converging area and minimises destabilising cross-coupled effects. Overall, the findings confirm that selective surface texturing, with emphasis on the middle region, yields an effective balance among load capacity, damping, and stability, representing a viable means of improving hydrodynamic bearing dynamics.

Paper ID: 102

Vibration Isolation Using Bio Inspired Compliant Springs

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Bio-inspired compliant springs are designed and fabricated for the isolation of vibrations of a base-excited system. Thermoplastic polyurethane (TPU) and polylactic acid (PLA) materials are used to 3D print the compliant springs. Load-displacement curves of the springs obtained from a universal testing machine show a peculiar negative stiffness characteristic under quasi-static loading. Dynamic experimental analyses are performed on a test setup consisting of two such springs positioned between vertically separated plates. The bottom plate is mounted on a shaker through with excitation is imparted, and experiments are conducted at

different excitation frequencies. Two single point laser displacement sensors are used to measure the oscillations of the top and bottom plates. The amplitudes of oscillations are plotted against the excitation frequencies to determine the frequency response diagrams. Experiments are conducted by applying different static loads to the top plate, varying from 0.5 kg and 2 kg so as to achieve the spring characteristics near the negative stiffness zone.A distinct regime where the top plate oscillations remain isolated from those of the bottom plate is observed at high excitation frequencies.

Paper ID: 107

Primary Resonance Features of Electrostatically Actuated Circular Ring Resonators

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Coriolis vibratory gyroscopes are modern inertial sensors that comprise flexible structures which operate at resonance. The resonating structure is typically designed to be axisymmetric, and the interaction between a pair of degenerate modes is utilized to measure parameters such as angular displacement and velocity. In this paper, a thin circular ring, which is a representative model for such axisymmetric resonators, is investigated under (capacitive) electrostatic actuation. The ring is centrally located and concentrically surrounded by an array of electrodes that are evenly distributed in a circular pattern. The electrodes and the ring are radially separated by a small distance so that vibrations of the ring resonator can be excited upon application of a voltage across itself and the electrode. The equations of motion governing these vibrations are presented, and non-linear terms arising due to capacitive excitation are introduced. The original partial differential equation governing the ring’s dynamics is discretized in terms of the mode shapes of the working modes of the gyroscope, and is transformed into a pair of coupled ordinary differential equations.
In this work, emphasis is placed on deciphering the effect of electrostatic forcing and hence the applied rotation rate is assumed to be negligible. This assumption further simplifies the model into a single degree of freedom system. The forcing terms appear as polynomial non-linearities, which act alongside parametric and harmonic excitation that arises due to the combined action of a constant and an alternating voltage. The primary resonance is investigated in detail through the application of the method of harmonic balance and through numerical integration of the governing equation, and the effect of various parameters such as the magnitudes of the voltages, and damping factor are explored. In addition, stability charts are developed by employing Floquet theory for the case when the ring deflections are small when compared to the electrode gap. This investigation is expected to help designers select the working range of various engineering parameters such as voltages, and electrode gap so as to avoid parametrically-excited resonances and electrostatic instabilities which can lead to failure of capacitive ring gyroscopes.

Paper ID: 109

A Pseudo Spectral Approach Towards Analyzing Gas Foil Bearings Performance and Improvement Using a Parametric Study

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Gas foil bearings (GFBs) are extensively utilized in high-speed turbomachinery owing to their oil-free operation, durability in harsh conditions, low frictional losses, and self-acting pressure generation. The incorporation of flexible foil structures in these bearings mitigates several limitations of rigid gas bearings, especially in enhancing damping characteristics and pressure distribution. Also, it allows rotor misalignment and structural or thermal deflections. This study examines the impact of material and geometry parameters of bump foils on output measures such as load carrying capacity, stiffness and damping coefficients of gas foil bearings within a rotor dynamic context. A coupled model is established by resolving the Reynolds equation for compressible flow in conjunction with the elastic deformation of the foils. The pseudospectral method (PSM) is utilized to solve the governing equations, providing minimized computational effort compared to traditional numerical techniques such as FDM & FEM, especially at higher eccentricities. The design of experiments (DOE) methodology is employed to investigate the parameter space systematically and determine configurations that improve performance measures, including load capacity and peak pressure. Comparative simulations of compliant and rigid bearings demonstrate the crucial impact of foil flexibility on enhancing pressure homogeneity and effective load support. The results underscore the significance of structural customization in GFB design, facilitating the development of more resilient rotor-bearing systems in sophisticated turbo-machinery applications. Future efforts will concentrate on the coupled rotor-bearing system and obtaining steady-state responses of the rotor with the help of dynamic coefficients of the bearing evaluated.

Paper ID: 111

FINITE ELEMENT MODELLING AND ANALYSIS OF COCHLEAR IMPLANT ELECTRODE ARRAYS

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Cochlear implants are advanced devices that help people with severe hearing loss by sending electrical signals to the auditory nerve. The electrode array, which is inserted into the cochlea, plays a key role in delivering these signals and stimulation of the nerve. The shape, flexibility, and mechanical properties of the electrode are crucial for minimizing trauma during insertion which could result in increased stiffness of middle ear system. In this study, Finite Element Method (FEM) was used to examine the behaviour of the cochlear implant electrode; both structural and modal analyses were carried out to evaluate the mechanical and vibrational response of the electrodes. To guide the design process, a trajectory of the electrode array has been generated using MATLAB with data from the anatomical literature. Subsequently, a 3 Dimensional (3D) spiral electrode model with 16 protrusions, varying in spacing across cochlear regions, was developed and analyzed in ANSYS software. Modal analysis indicated the first natural frequency at around 18.6 Hz, well below the physiological excitations range of middle ear system and avoid any interference in auditory transmission. A transient structural simulation of the electrode insertion showed the greatest deformation at the free end and localized stress near the curved sections and protrusions. The peak von Mises stress was 3.59 MPa which is within safe limits for the medical-grade silicone with metallic reinforcements used in cochlear implants, confirming the design's stability under insertion forces. The results confirm that FEM is a reliable tool for optimizing cochlear implant designs, helping engineers create safer and more effective electrode arrays suited for the cochlea's complex anatomy.

Paper ID: 112

AN ARTIFICIAL INTELLIGENCE ASSISTED TOOL FOR THE MODAL ANALYSIS OF FUNCTIONALLY GRADED BEAMS

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This study integrates finite element simulations and machine learning approaches to analyze and predict the free vibration behavior of Functionally Graded Material (FGM) beams. The finite element analysis was performed in Abaqus using a user-defined material subroutine (USDFLD), with numerical results validated against an existing benchmark study for a Steel–Ceramic FGM beam under simply supported boundary conditions, where material gradation was defined by a Power-law distribution. Extending beyond the reference work, two additional material combinations: Aluminium–Ceramic and Aluminium–Steel were investigated under three boundary conditions (Cantilever, Simply Supported, and Fixed-Fixed) to capture the influence of support constraints on natural frequencies. Material properties were graded according to both Power-law and Sigmoid-law distributions, with the gradation index "k" varied from 1 to 10, and the computed natural frequencies were normalized to obtain non-dimensional frequencies for meaningful comparison across cases. To complement the FEM analysis, a neural network model was trained to predict the natural frequency of an FGM beam across varying boundary conditions, gradation laws, and material combinations, while XG-Boost and Gradient Boosting regression techniques were employed to predict the gradation index and mode number using combinations of frequency, mode, Young's modulus, and density as inputs. The results demonstrate that ensemble learning models such as XG-Boost and gradient boosting outperformed conventional regression approaches for gradation index and mode number prediction, enabling rapid and accurate prediction of vibrational characteristics and material gradation parameters, thereby providing a powerful surrogate framework to complement FEM simulations.

Paper ID: 114

ANALYSIS OF INFLUENCE AND BALANCING OF MULTI-PARAMETER SWEEP FOR ENHANCED RIDE COMFORT AND ROAD HANDLING

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This study presents a multi-parameter sweep influence and balancing of a passive suspension system (PSS) using the Quarter Vehicle Model (QVM) to enhance ride comfort (RC) and road handling (RH). The system's dynamics are modelled mathematically to derive transfer functions representing the displacement, velocity, and acceleration responses of sprung and unsprung masses under harmonic road input. Bode plot analysis is focused on sprung and unsprung mass displacement transfer function (|Ys/Yr| and |Yus/Yr|, respectively) for RC and RH enabled frequency domain evaluation to identify comfort-sensitive frequencies (≥0.5 - ≤1.5 Hz) and handling-dominant frequencies (≥8 Hz - ≤12 Hz) for the vehicle.
A parametric sweep used eight discrete levels for analysis over each suspension parameter: sprung mass (Ms), unsprung mass (Mus), suspension stiffness (Ks), tire stiffness (Kt), suspension damping (Bs), and tire damping (Bt). The fixed configuration of suspension parameters Ms = 260 kg, Mus = 40 kg, Ks = 26000 N/m, Kt = 130000 N/m, Bs = 520 Ns/m, and Bt = 265.73 Ns/m is used to minimize transmissibility (both comfort and handling domains) in the desired frequency range.
The results validated the parametric sweep findings and revealed a critical design space that suppresses resonance and enhances dynamic stability. This approach, combining mathematical modelling with simulation using MATLAB coding and a Simulink model, provides an effective range of recommended suspension parameters to enhance ride comfort, handling, and vibration isolation, which is ideal for mid-segment vehicle suspension tuning.

Paper ID: 120

ADVANCED GEARBOX FAULT DIAGNOSIS USING TRANSFER LEARNING AND CNN-BASED HYBRID RECURRENT ARCHITECTURES

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Gearbox fault diagnosis is hindered by structural complexity and variable operating conditions, resulting in inconsistencies between training and testing vibration signals. This study introduces three advanced methods CNN-BiLSTM, CNN-LSTM-GRU, and Deep Transfer Learning designed to enhance diagnostic accuracy using vibration signals. CNN-BiLSTM captures bidirectional temporal dependencies in vibration-derived features, improving accuracy and generalization. CNN-LSTM-GRU processes time-frequency representations of vibration data, combining spatial feature extraction and long-term sequence modeling, achieving over 98 % accuracy even in noisy environments. Deep transfer learning utilizes FFT-transformed vibration signals to

learn transferable features, enabling robust fault diagnosis across varying domains. Collectively, these models form a strong framework for accurately and reliably detecting gearbox faults using vibration-based analysis in complex industrial applications.

Paper ID: 121

A HYBRID DEEP LEARNING AND ENSEMBLE APPROACH FOR BEARNING FAULT DIAGNOSIS

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A bearing is one of the important components in rotating machinery, and its efficient functioning is essential for maintaining performance stability and reducing failure. An extensive study on vibration-based fault diagnosis in various existing models struggles to capture multiscale features related to faults and achieve robust generalization under abnormal operating conditions. After addressing the research gap, the present study introduces a hybrid model that integrates a Convolutional Neural Network (CNN) with Random Forest (RF) classifiers and Multiscale CNNs with RF classifiers. CNN captures features, while MSCNN captures both local and global features; the Integration of these models with RF enhances classification robustness via ensemble learning. The Case Western Reserve University (CWRU) dataset used in the hybrid model yields superior accuracy and fault classification compared to traditional machine learning and deep learning models alone. This hybrid model, which innovates deep feature extraction with ensemble classification, offers a practical solution for rotating machinery fault diagnosis used in Industrial applications.

Paper ID: 122

BRITTLE FRACTURE BEHAVIOR AND ADHESIVE STRENGTH OF ADHESIVELY BONDED BUTT JOINTS

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Adhesive bonding has become increasingly popular in recent years due to the need for lightweighting and high performance. Although ductile adhesives are widely used, adhesive joints often exhibit brittle fracture behavior even under static loading. In this study, we show that in static tensile tests, even when ductile adhesives are used, the fracture of adhesive joints exhibits brittle behavior. The finite element method (FEM) analysis shows that the plastic zone size of the adhesive layer is small and does not depend on the adhesive layer thickness, and then the small-scale yield condition is established. Therefore, the strength of the adhesive joint can be expressed as a constant value of the intensity of the singular stress field (ISSF) generated at the adhesive interface edge, which is similar to the stress intensity factor of a material with a crack. Furthermore, we proposed a new butt-joint specimen that does not generate stress concentration at the interface edge, and experimentally measured the adhesive strength that is independent of the singular stress field. It was found that

the adhesive strength of the proposed butt joint specimen is higher than that of ordinary adhesive specimen in which a singular stress field occurs.

Paper ID: 124

Transfer Learning-Based Chatter Detection Using Short-Time Fourier Transform of Cutting Force Signals

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Chatter vibrations, a form of self-excited instability, frequently emerge during turning operations. These vibrations not only undermine machining efficiency but also compromise machined surface quality and accuracy, posing a significant challenge in precision and autonomous manufacturing. Accurate chatter detection requires both transient and spectral features to reflect the complex features associated with the cutting state. Therefore, in this study, cutting force signals acquired from different machining conditions are transformed into short-time Fourier spectrograms, which effectively capture the time–frequency characteristics of the underlying dynamic behaviour. A VGG19 convolutional neural network, pre-trained on large-scale image datasets, is subsequently fine-tuned using these spectrogram representations to enable accurate classification among stable cutting, regenerative chatter, and air-cutting conditions. The integration of deep learning with time–frequency analysis facilitates a data-driven approach for efficient intelligent process monitoring. The proposed methodology demonstrates robust performance in chatter recognition, thereby contributing to enhanced real-time monitoring capabilities critical for the autonomous manufacturing.

Paper ID: 128

Dynamic Analysis of Rotary Drilling: Coupled Axial-Torsional Motion Influenced by the Hoisting Mechanism and Top Drive

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This work studies the axial-torsional dynamics of a drill-string including the dynamics of the hoisting system and drive motors, using a lumped parameter model. We have done a linear stability analysis and also studied the effect of various other parameters on operating regimes corresponding to stable steady drilling. It is observed that a proper choice of the rock-specific strength, rotary inertia, top table mass, and damping coefficient increases the stable region. A numerical simulation has been performed to understand the non-linear dynamics of the system, and it is observed that the sticking appeared near the unstable regime, while stable drilling solutions appeared in a given stable parametric space.

Paper ID: 130

SURFACE-INTERFACE EFFECTS ON RAYLEIGH-TYPE WAVE PROPAGATION IN ROTATING MAGNETO-VISCOELASTIC STRATIFIED STRUCTURE

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This study investigates the propagation characteristics of Rayleigh-type wave in a rotating layered structure that consists of a dissimilar magneto-viscoelastic layer overlying another magneto-viscoelastic substrate within the framework of the surface and interface elasticity theory. Utilizing the Stroh formalism technique, the exact secular relation for the propagating wave in the considered geometrical structure is established. The derived secular relation concurs well with the previously reported results in the literature as special cases of the study. Additionally, numerical simulation is performed to graphically illustrate the impacts of wave number, rotation, magnetoelastic parameters as well as surface and interface parameters on the phase velocity and the attenuation coefficient of the Rayleigh-type wave. This comprehensive analysis provides valuable insights into how the aforementioned affecting factors significantly influence Rayleigh-type wave propagation in the considered layered structure. The consequences of the study may be applied in the design of surface acoustic wave devices.

Paper ID: 131

NOISE CHARACTERIZATION OF TRAILING-EDGE SERRATIONS ON UAV PROPELLER BY BEAMFORMING MAPPING AND ACOUSTIC SPECTRA

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This experimental study presents a detailed aeroacoustic characterization of small-scale multicopter propellers with baseline and sawtooth trailing-edge (TE) serration configurations, aimed at noise reduction for unmanned aerial vehicle (UAV) applications. The investigation employed a cross-spectral matrix beamforming algorithm to identify and compare acoustic source distributions and attenuation characteristics between the two configurations. Beamforming spectral maps at the blade passing frequency (BPF) revealed that the serrated propeller produced a noticeably weaker and less number of main lobe intensity compared to the baseline propeller, indicating effective suppression of dominant tonal components. The incorporation of sawtooth serrations along the trailing edge contributed significantly to broadband noise reduction and moderate tonal noise attenuation, particularly at frequencies above 1000 Hz. Additionally, the overall sound pressure level (OASPL) directivity patterns measured using a semi-circular microphone array showed a consistent decrease in radiated noise, with reductions between 4 and 6 dB(A). The results conclusively demonstrate that sawtooth TE serrations enhance the aeroacoustic performance of propellers by mitigating both tonal and broadband noise emissions, thereby improving UAV acoustic stealth and environmental compatibility.

Paper ID: 132

H Link Optimization : Optimization of H Link Linkage in Case of Bucket Arm & Rock Breaker Excavator

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Hydraulic excavators are mainly used for constructing & mining purposes and is considered one of the most common machine for these kinds of operation. An excavator's arm is made up of a boom, two hydraulic cylinders, and an attachment that is used for specific tasks. The attachment is fixed to a bracket that attaches to an excavator's arm and matching link. The length of a connecting linkage that joins a hydraulic excavator's bracket to the matching bucket and rock breaker attachment is the main subject of this article. An ideal H-link length has been suggested for the efficient operation of an excavator used for bucket and rock breaker applications. For best performance, the reaction forces on the bracket can be reduced to cylinder forces with the help of this adjustment in the length of the H link and its corresponding side link.

Paper ID: 133

INFLUENCE OF RE-ENTRANT CORE ANGLE ON NATURAL FREQUENCY OF HIGHER ORDER AUXETIC SANDWICH PANELS

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Auxetic sandwich panels (ASP), due to their negative Poisson’s ratio, possess distinct deformation mechanisms that enhance their load-bearing and energy absorption capabilities. In this study, the effect of the re-entrant core angle on the vibration response of ASP is investigated using a finite element formulation based on higher-order shear deformation theory (HSDT). Among various auxetic geometries, the re-entrant honeycomb is widely studied due to its geometric simplicity and tunable deformation behavior. In this configuration, the reentrant angle plays a critical role in controlling the degree of auxeticity and consequently, the structural stiffness and dynamic response. In this work, the sandwich panels consist of a re-entrant honeycomb auxetic core bonded to facesheets, modeled using a nine-noded isoparametric plate element using HSDT. In this study a comprehensive parametric analysis has been performed to analyze the effects of varying reentrant angles, core geometries, and boundary conditions. The results demonstrate that increasing the core angle significantly reduces the panel’s stiffness and natural frequencies, due to changes in auxeticity. The

findings contribute to the optimized design of lightweight high-performance structures with customized dynamic behavior, relevant to applications in aerospace, automotive, and acoustic control systems.

Paper ID: 134

MODELING OF ADDITIVE MANUFACTURING PROCESS PARAMETERS USING DIMENSIONAL ANALYSIS AND SUPPORT VECTOR REGRESSION

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The growing use of Fused Deposition Modeling (FDM) in industrial and prototype fields makes it essential to understand and predict the impact of process parameters on component quality. To predict the mechanical behavior of FDM fabricated specimens, this study presents a hybrid modeling method that combines Support Vector Regression (SVR) and Buckingham π dimensional analysis. Seven important process parameters, including material density, print speed, nozzle diameter, layer height, nozzle temperature, bed temperature, and infill line distance, are converted into non-dimensional π-groups in order to determine the physical connections between parameters. Fifteen polymer tensile specimens, designed according to ASTM D638 specifications, were tested using a Tinius Olsen H50K Universal Testing Machine at a crosshead speed of 1 mm/min. SVR and Multivariate Linear Regression (MLR) are used to model the data for comparison, to predict Young's modulus. The proposed SVR model obtained an R2 value of 0.80 and showed a significant reduction in RMSE (3.7×10^8 MPa) and MAE (2.9×10^8 MPa) when compared to the MLR model (R2 = 0.76), which shows the high prediction accuracy of the hybrid dimensional machine learning model. The proposed method provides a versatile and data-efficient tool for advanced additive manufacturing research by enabling precise mechanical behaviour prediction with fewer experiments.

Paper ID: 135

Acoustical Performance of an Array of Intruded-Neck Helmholtz Resonators

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The traditional porous materials widely used for noise reduction are often ineffective at addressing low-frequency broadband noise. To address this issue, this study proposes an array of Helmholtz resonators with varying intruded neck lengths. Initially, this study investigates the sound transmission loss (STL) performance of different intruded neck lengths of Helmholtz resonators (HR1–HR4), which are investigated through computational simulations, validated using the Transfer Matrix Method (TMM), and reveal that increasing the intruded neck length lowers the resonant frequency without significantly affecting peak STL. To broaden the STL bandwidth, different resonator array configurations: linear (Case 1), linear–parallel (Case 2), and radial (Case 3) are evaluated. Among these, Case 1 demonstrated the highest and broadest STL performance, with an energy storage capacity nearly twice that of Case 3 within the 300–500 Hz range. Although Case 3 offers a more compact design, its performance can be enhanced by adopting periodic linear arrangements. Band diagram analysis confirmed a bandgap ranging approximately 300–920 Hz. These findings not only validate the effectiveness of the proposed design but also provide crucial insights into developing advanced noise control solutions for diverse industrial applications where low-frequency noise attenuation is essential.

Paper ID: 136

Numerical Assessment of Residual Flexural Capacity in RC Slabs Subjected to Close-In Detonations

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Reinforced concrete (RC) slabs form critical elements in civilian and defense infrastructure, where blast loading poses a severe threat to their integrity. While conventional blast assessments emphasize peak deflection, spalling, or crater size, they often overlook the residual flexural capacity—a key metric for post-event safety evaluation, repair prioritization, and resilience planning. This study develops and validates a high-fidelity finite element framework in LS-DYNA, employing the S-ALE technique for blast wave propagation. A three-stage methodology was adopted: (i) establishing initial flexural capacity under quasi-static loading, (ii) simulating close-in blast events (100–2000 kg TNT) at standoff distances of 5 m, 7.5 m, and 10 m, and (iii) re-evaluating residual moment capacity post-blast. Results showed reductions in flexural strength of up to 70% at lower scaled distances, with effective plastic strain distributions confirming progressive material degradation. Importantly, a scaled distance paradox was observed, wherein identical scaled distances but different absolute standoffs produced varying damage outcomes due to pressure–impulse interaction. The findings establish a direct link between blast intensity and residual capacity, offering a mechanics-based basis for predictive maintenance, resilience-oriented design, and risk-informed decision-making for RC structures under extreme loading.

Paper ID: 140

Developing a digital model of a centrifugal pump for performance analysis

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The increasing industrial reliance on centrifugal pumps necessitates advanced methodologies for their performance evaluation. This study presents a novel implementation of a Digital Model (DM) for dynamic performance analysis of a centrifugal pump, focusing on two critical parameters: pressure and volumetric flow rate. The proposed DM architecture leverages data derived from Computational Fluid Dynamics (CFD) simulations to replicate the operational behaviour of the physical pump system. The digital model is developed using ANSYS Fluent, where inlet boundary conditions—including inlet pressure and volumetric flow rate—are specified as input parameters. Corresponding outlet parameters, such as pressure distribution and mass flow rate, are meticulously analysed. To accurately simulate the interactions between rotating and stationary components, the Sliding Mesh Model (SMM) is employed, enabling time-dependent flow field analysis. The simulations assume a non-compressible fluid (water) and are conducted across multiple operating flow rates to emulate realistic operational conditions. The standard k-ε (k-epsilon) turbulence model and transient analysis approach are adopted to capture dynamic flow characteristics and the intricate transient interactions within the pump. The digital model is validated through a comprehensive comparison with experimental performance data, particularly by comparing the simulation-derived characteristic curve (Head vs Flow Rate) with the experimental characteristic curve. The study's results demonstrate that the digital model effectively and accurately predicts the centrifugal pump's performance under varying operational conditions. This digital model not only reduces the reliance on extensive experimental testing but also enables performance evaluation across a wide range of operational conditions.

Paper ID: 141

NUMERICAL SIMULATION OF COMPOSITE SANDWICH PANEL UNDER LOW VELOCITY IMPACT

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This study presents the low-velocity impact response of composite sandwich panels featuring three distinct in-plane core configurations: Honeycomb, Reentrant, and Auxetic. Using finite element modelling, the research evaluates the performance of these core architectures in terms of energy absorption capacity, maximum impact force, residual velocity, and progressive damage behaviour. The MAT054 model was employed to accurately simulate the composite face sheets, incorporating the Chang-Chang failure criteria. Numerical simulations were conducted under varying impact energy levels (70 J, 40 J, and 20 J) to replicate real-world loading conditions and assess the structural integrity of each core design. Results demonstrate that the Reentrant core outperforms both Honeycomb and Auxetic cores across key performance metrics. It exhibited superior energy absorption efficiency, higher peak impact forces, and greater reduction in residual velocity, particularly at mid to high-energy impacts. The inward-collapsing mechanism enabled by its negative Poisson's ratio geometry allows for enhanced stiffness and delayed core collapse, contributing to more stable and progressive energy dissipation.

Paper ID: 142

Assessment of microstructural defects on vibrational behaviour of graded beams using high-order beam model

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In this study finite element approach is used to analyse the free vibrational behaviour of functionally graded beams (FGB) with microstructural defects using higher order shear deformation theory (HSDT). Functionally graded materials (FGMs), offers smooth transitions between different material properties, and are used in high-performance engineering applications such as aerospace structures, thermal barrier coatings, and biomedical devices due to their superior resistance to thermal and mechanical stresses, to study the FGM a beam is considered, the beam material properties are described by a simple power law distribution in terms of the constituent's volume fractions. The distribution of the porosity along the thickness direction of beam is considered as even and uneven type. The problem is solved using a two-node finite element with four DOF on each node. The comparison and validation study have been performed to check the efficacy of the problem, and the frequency parameter have been obtained. A parametric study is conducted to examine the effects of varying porosity distribution, slenderness ratio, porosity coefficient and boundary condition on the non-dimensional frequency.

Paper ID: 148

AN EFFICIENT LOW COST METHOD TO MEASURE VIBRATIONS IN MACHINES AND IDENTIFY DEFECTS USING DISCRETE SIGNALS OF RMS ACCELERATION

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Vibration analysis is a vital aspect in the design and maintenance of mechanical and mechatronic systems, particularly where operational integrity and longevity are crucial, such as in mobile combat platforms and industrial machinery. Traditional vibration testing relies heavily on high-precision instrumentation—accelerometers with high sampling rates and sophisticated Data Acquisition (DAQ) systems—to capture high-frequency dynamic responses and convert time-domain signals into the frequency domain using advanced digital signal processing (DSP) techniques, such as Butterworth filtering. However, this approach is often prohibitively expensive for regular diagnostics and inaccessible to maintenance-level personnel. This research proposes an alternative low-cost methodology employing low-refresh rate accelerometers and compact DAQs to evaluate vibrational characteristics. Assuming machine-induced vibrations to behave as stochastic signals with definable Power Spectral Densities (PSD) and Probability Density Functions (PDF), this study treats them as manifestations of random vibration theory. Experimental investigations were conducted using a custom-designed vibration simulator under varying operational conditions—torque, rotational speed, and induced mechanical defects. A full factorial design of experiments (DoE) was implemented, generating over 3,000 RMS acceleration samples per condition. A representative subset of 1,200 discrete time-domain RMS samples from each trial was subjected to statistical analysis. Univariate distribution demonstrated over 98% conformity for different random 1200 sample subsets. Notably, inter-experiment variability was observed in peak amplitudes, curve spread, and area under PDF curves, effectively distinguishing different machine states and defects. The proposed approach demonstrates a robust, accessible technique for vibration characterization with high statistical reliability and diagnostic potential, highly useful for maintenance engineering.

Paper ID: 151

Notch strength for wide range of strain rate and temperature for metallic and polymeric materials

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In this study, notch strength is investigated for wide range of strain rate and temperature in comparison with the standard tensile strength of smooth specimen at room temperature. High–speed tensile tests on notched specimens of PC (polycarbonate) and PDMS-PC (PC copolymerized with PDMS) shows that the notch strength of PC and PC-PDMS are expressed as a master curve as a function of the strain rate at the notch in conjunction with shift factors. High–speed tensile tests on high-Si DCI (high–Si ductile cast iron) and conventional DCIs shows that the notch strength are expressed as a master curve as a function of R parameter independent of the strain rate and temperature of each material. The master curves for those polymers and metals can be obtained by using the strain rate concentration factor, which is different from the stress concentration factor. The obtained notch strength is discussed in comparison with the standard tensile strength of the smooth specimen.

Paper ID: 153

Dynamic Response of Sandwich Beams with Solid, Honeycomb, and Re-Entrant Auxetic Cores using Finite Element Method

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This study presents the free vibration analysis of layered auxetic sandwich beams using First-Order Shear Deformation Theory (FSDT) and Higher-Order Shear Deformation Theory (HSDT). The sandwich beam consists of isotropic face sheets and a core made of either solid, conventional honeycomb, or re-entrant auxetic cells. The effective mechanical properties of the honeycomb and re-entrant cores are determined using analytical homogenization relations. Finite element modeling is employed to derive the mass and stiffness matrices, and convergence studies are performed to ensure the accuracy of the results. A detailed parametric investigation is carried out to examine the influence of cell geometry, including cell angle, thickness ratio t/l1, and length ratio l2/l1, on the natural frequencies of the beams. Comparative studies are also conducted between the three core configurations to highlight the effect of auxetic topology on the dynamic response.

Paper ID: 154

3D BIO PRINTING OF THE ALGINATE AND GELATIN-BASED AUXETIC SKIN GRAFTS: A RHEOLOGICAL CHARACTERIZATION

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Tissue engineering has grown rapidly with the progress of 3D bioprinting, which makes it possible to build intricate, biomimetic tissue structures. Among various bioinks, alginate–gelatin hydrogels are often selected because they are biocompatible and their mechanical and rheological properties can be adjusted easily. But still finding the right composition for the soft tissue constructs is still a challenge.

In this work, we prepared an alginate–gelatin hydrogel with a polymer ratio aimed at improving extrusion-based printing performance. We carried out rheological measurements such as amplitude sweep tests to examine its print behavior. The results showed a clear shear-thinning response and viscoelastic recovery, with the storage modulus (G′) remaining well above the loss modulus (G″). These properties of the ink will help the printed strands maintain their form without needing for extra support. This study primarily focuses on the material's rheological performance. In future we will focus on the 3D bioprinting with the formulated ink compositions, experiments with cell-laden inks, and in-vitro assessments to determine how effectively the scaffolds promote soft-tissue regeneration.

Paper ID: 155

High-Gauge Factor Flexible Strain Sensors for Structural Health Monitoring of Aerospace Components

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Structural Health Monitoring of aircraft components is very crucial and demands high precision. This is typically accomplished using foil-based strain gauges or optical sensors, such as Fiber Bragg Gratings. The conventional foil-based strain gauges offer a very low gauge factor (~2.2), poor flexibility, and complicated wiring. Optical sensors are precise but costly and need complex evaluation systems. In this study, a highly sensitive carbon nanocomposite-based flexible strain sensor was developed for structural health monitoring, capable of detecting strains as low as 500 με. Sensors were screen-printed on a Polyethylene Terephthalate (PET) substrate, which exhibited a gauge factor of 69.06, almost 32 times higher than that of the conventional foil-based strain gauge. These screen-printed sensors, when tested on aerospace-grade coupons, showed excellent linearity (R^2~0.96). The Young's modulus of aerospace coupon B2 was estimated by a flexible sensor and strain gauge, valued at around 67.785 ± 5.05 GPa and 72.172 ± 0.279 GPa, respectively. For coupon B4, the estimated Young's modulus was valued at nearly 57.994 ± 2.54 GPa and 67.843 ± 0.697 GPa, using a flexible sensor and strain gauge, respectively. The flexible sensor showed a resolution of 125.43 microstrains. This innovative, flexible sensor can be an effective alternative to commercially available strain gauges.

Paper ID: 156

EXPERIMENTAL INVESTIGATION USING RESPONSE SURFACE METHODOLOGY FOR CONDITION MONITORING OF MISALIGNED CYLINDRICAL ROLLER BEARING IN DUAL ROTOR SHAFT SYSTEM

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Most of the rotating machinery's stable operation is significantly hindered by bearing flaws and misalignments, necessitating timely fault detection. This research investigates how interactions among misalignment, defect size, and speed influence the vibrations of a dual rotor shaft bearing system. To assess these interaction effects on system performance, Response Surface Methodology (RSM) is utilized, with vibration signatures serving as the response. Experiments are structured using a Design of Experiments (DoE) approach, and data analysis is conducted via Analysis of Variance (ANOVA). The study incorporates bearing defects and angular bearing misalignment to examine their impact on the system's vibration spectra. The planning and analysis of experiments leverage the DoE methodology to evaluate the effect of operating conditions on vibration amplitude. A dual rotor shaft bearing system is employed for the experimental tests, with misalignment. The study's conclusions are consistent with the experimental findings. Ultimately, DoE and RSM are applied to characterize the dynamic response of the dual rotor shaft bearing system.

Paper ID: 158

Comparative study of residual stress distribution in i-beam and rail beam during the roller straightening process by an analytical levelling model

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Residual stresses develop in rail and I-beam sections during manufacturing, significantly influenced by the roller straightening process used for levelling. This process involves alternate bending and reverse bending along both the strong and weak axes, which induces persistent strain and forms residual stress. The location of elastic–plastic transition points, or demarcation points, is governed by the applied curvature and the cross-sectional geometry of the beam. In particular, asymmetry in the cross-section plays a crucial role in altering the final stress distribution. This study developed an analytical model based on elastic–plastic mechanics to investigate and compare the residual stress patterns in rail and I-beam sections during straightening. Due to its lack of horizontal symmetry and variable flange thickness, the rail section shows notable differences in stress response compared to the symmetric I-beam. The analysis revealed that during strong axis straightening, asymmetry in the rail section causes demarcation points to shift unevenly across the cross-section, resulting in residual stress differences of up to 15 MPa compared to the I-beam. In contrast, weak axis straightening produces symmetric stress distributions in both beams, with minor deviations (around 3 MPa) primarily due to geometric differences in flange width and thickness. The bending stress pattern exhibits a characteristic 'X'-shaped profile, with plastic deformation in the outer layers and elastic behavior in the inner core. This study underscores the importance of cross-sectional symmetry in residual stress formation and provides insights for optimizing straightening processes in rail manufacturing.

<u>Paper ID: 161</u>

DIGITAL TWIN-BASED PREDICTIVE ANALYSIS OF DERAILMENT RISK ON RAILWAY TRACKS WITH GEOMETRIC IRREGULARITIES

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Railway track irregularities, such as vertical and lateral misalignments, uneven stiffness distribution, and rail surface defects, are key factors contributing to the dynamic instability of rail vehicles, thereby increasing the risk of derailment. Traditional maintenance approaches often rely on periodic inspections, which may fail to detect critical degradation in time. This study proposes a digital twin-based predictive maintenance framework to assess derailment risk on the railway tracks under varying irregularity scenarios. The digital twin (DT) integrates a high-fidelity multibody dynamics model developed using Simpack with real-time sensor data and machine learning algorithms. The simulation model replicates the rail-wheel interaction under realistic operating conditions and irregularity inputs, allowing for the evaluation of dynamic responses, including lateral forces, vertical forces, and the derailment coefficient. The axle box acceleration data was fed to the digital twin with current condition metrics, while predictive models trained on historical and simulated data forecast potential failure scenarios. The proposed system facilitates continuous monitoring and early detection of critical conditions, enabling targeted, condition-based maintenance interventions. Results demonstrate that this integrated approach significantly enhances safety margins by proactively identifying conditions that are prone to derailment before failure occurs. Additionally, it lowers maintenance costs and downtime by optimizing inspection schedules based on actual track health rather than fixed intervals. This research advances the development of intelligent, data-driven infrastructure management systems that align with Industry 4.0 goals, paving the way for safer and more efficient railway operations.

Paper ID: 164

ENSURING DESIRED DYNAMIC PERFORMANCE OF COMPOSITE STRIP LIKE STRUCTURE UNDER STOCHASTIC CONDITION

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This study investigates the dynamic behavior of thin anisotropic composite strip-like structure under stochastic environmental conditions. The analysis considers various boundary conditions within a unified stochastic computational framework for vibrational response assessment. The stochastic modeling framework is derived from deterministic First Order Shear Deformation Theory (FSDT). Uncertainties have been incorporated in the form of probabilistic variations in the material properties and geometrical parameters, including laminate thickness, fiber orientation and stacking sequence. These uncertainties are introduced at the mesoscale i.e., ply level, within a single cohesive stochastic modeling strategy. Python based scripting has been utilized for the automated generation and implementation of the stochastic model, embedding the uncertainties directly into the computational code. Free vibration characteristics are evaluated through Finite Element Simulations conducted in Abaqus [1], with the primary objective of quantifying the stochastic natural frequencies corresponding to wide range of uncertain parameter combinations. The stochastic results are benchmarked against deterministic solutions and validated using experimental data. The coupled influence of material and geometrical uncertainties on the free vibration is systematically analyzed across multiple probabilistic scenarios. A parallelized search algorithm based on Bayesian Optimization is integrated into the framework to efficiently reduce the high dimensional parameter search space, minimizing the number of simulations and the computational cost. This enables the identification of optimal parameter sets that yield the desired dynamic performance of composite strip- like structure.

Paper ID: 167

Boosting Peltier Cooler Performance Using PCM-Integrated Heat Sinks for Better Renewable Energy Utilization

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As the demand for sustainable technologies continues to grow, solar-powered Peltier cooling systems are emerging as an environmentally friendly option for localized cooling applications. Nevertheless, their efficiency is often hindered by inadequate heat removal from the Peltier module's hot side. In this work, a comprehensive numerical study is conducted on phase-change materials (PCMs) utilization integrated into the aluminium heat sink to enhance thermal management and system performance. The inclusion of PCM allows the heat sink to store excess thermal energy, thereby sustaining a consistent temperature difference across the Peltier module. A transient, three-dimensional thermal model was developed and evaluated by a numerical analysis to analyze the influence of PCM characteristics, heat sink design, and input current to the module. The findings indicate significant enhancements in heat dissipation, extended periods of stable operation, and

overall improvements in cooling efficiency. This study highlights the potential of PCM-assisted thermal control to advance the practical application of solar-driven thermoelectric cooling, supporting wider adoption of renewable energy-based active cooling systems.

Paper ID: 170

NON-LINEAR DYNAMICS OF A BI-STABLE MECHANICAL OSCILLATOR WITH A TOGGLE SPRING MECHANISM

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This paper presents the dynamics of a bi-stable mechanical oscillator which finds application in switching mechanisms, analyzed along the lines of the well-studied Duffing oscillator. The oscillator consists of toggle mechanism using two springs arranged along the same axis with rigid connector links placed in between. When displaced from the central configuration, the connector links apply force in a direction perpendicular to the axis of springs. This arrangement of rigid links and springs results in a unique mechanical oscillator with a pitch-fork type of bifurcation. The investigation includes a study of the system parameters contributing to the dynamics which comprise the geometrical dimensions, forcing amplitude and frequency. The numerical investigation demonstrates the existence of period doubling under certain parameter values which is one of the routes to chaotic behavior when forcing frequency is varied. The time responses, phase portraits, Poincaré maps are presented for these oscillations. The result of this analysis helps to gain more insights into the working limits of forcing functions to achieve bi-stable states in switches and identify potential risks.

Paper ID: 171

VIBRATION AND ACOUSTIC ENERGY HARVESTING OF LINEAR AND NONLINEAR SYSTEMS UNDER RANDOM EXCITATION AND STOCHASTIC ANALYSIS BY NEURAL NETWORKS AND RADIAL BASIS FUNCTIONS APPROACH.

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Numerical investigation to highlight the role of nonlinearities to improve the broadband transduction capabilities of the piezoelectric acoustic and vibration energy harvesters (VEH) is considered. The influence of the height of the energy barriers, potential function asymmetries, and their distributed position on the performance of energy harvesting is analysed by varying the polynomial coefficients of nonlinear restoring force. Different models and mechanisms such as classical, single, and double well potential Duffing oscillator, tri-stable energy harvesting, the Helmholtz resonator, the quarter-wavelength resonator, and the acoustic metamaterial with piezoelectric coupling driven by environmental excitation are considered and compared. The joint probability density function and voltage generated are numerically obtained by solving the

corresponding Fokker-Planck equation using the radial basis functions and neural networks approach, and results obtained are verified using Monte Carlo simulation.

Paper ID: 172

MACHINE LEARNING BASED FAULT DETECTION IN ROTATING SYSTEM

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Condition monitoring is critical for ensuring the operational efficiency, safety, and longevity of rotating machinery widely employed across manufacturing, energy, and transportation sectors. Faults such as unbalance and misalignment, if left undetected, can lead to severe equipment damage, unexpected downtime, and increased maintenance costs. To address this, the present study proposes a machine learning-based diagnostic approach for the early detection and classification of such faults through vibration signal analysis. A customized experimental setup was designed to replicate three operating conditions, healthy, unbalanced, and misaligned within a rotary machine system. Vibration data were captured using a tri-axial accelerometer and processed using signal analysis techniques, including Fast Fourier Transform (FFT) and time-domain statistical feature extraction. These features were used to train and evaluate various supervised machine learning algorithms such as Random Forest, Support Vector Machine, and XGBoost. Each model was assessed based on performance metrics, and the model with the highest classification accuracy was selected for fault detection. The novelty of this work lies in the development of an integrated machine learning framework combining experimental vibration data acquisition, optimized feature extraction, and comparative model evaluation for reliable fault classification in rotating machinery. The results affirm that integrating machine learning with vibration-based condition monitoring provides a reliable, scalable, and efficient tool for predictive maintenance and fault diagnosis in rotating machinery, contributing to improved industrial productivity and asset management.

Paper ID-173

Accelerating Structural Topology Optimization via U-Net Variational Autoencoder Guided SIMP Hybrid Approach

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The density-based structural topology optimization (STO) methods, such as Solid Isotropic Material with Penalization (SIMP), can generate accurate and reliable optimal topologies. However, these methods are computationally expensive because the response of a structure is quantified using finite element analysis. One of the remedies to address this challenge is to train deep learning models that can predict topologies within allowable error. Still, topologies generated by these models may result in disconnected, infeasible structures or exhibit significant deviations in compliance values. This paper presents a hybrid approach in which a U-net variational autoencoder (Unet-VAE) is trained to generate an intermediate topology for the given set of boundary conditions and input parameters. The intermediate topology is then fed to the SIMP method as an initial solution. The hybrid approach is tested on a cantilever beam problem by minimizing its compliance, which is subjected to a constraint on volume fraction. Results demonstrate that the hybrid approach can generate similar topologies as generated by the SIMP method with a marginal difference in the compliance value (less than 10% error), with a significant reduction of 30% in the computation time.

Paper ID: 175

A TWO-WAY COUPLED CHEMO-MECHANICS NUMERICAL SCHEME TO DETERMINE ELECTROCHEMICAL PERFORMANCE OF BATTERIES

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A coupled chemo-viscoelastic is developed for electrochemical characterization of batteries. Butler-Volmer expression is incorporated in the framework for this purpose. The differential equations are solved using Finite Element method with the help of deal.II, an open source C++ library. The differential equations are non-linear in nature due to two-way coupling effects and implementation of Butler-Volmer expression at the boundary of electrode particle. Newton-Raphson method was adopted to solve the non-linear finite element equations. The developed numerical framework was validated and used for conducting cyclic voltammetry experiments for elastic and viscoelastic electrodes at different sweep rates of voltage. The current-voltage plots show that the peak current is larger for elastic electrodes compared to viscoelastic electrodes. Sweep rate variation leads to larger peak current for higher sweep rates. Higher value of sweep rate does not allow much time for the stress relaxation to take place. The results show a correlation between the mechanical behavior of the electrode and the current developed in the electrode. Thus, the framework is successful in conducting cyclic voltammetry experiments, facilitating electrochemical analysis of batteries.

Paper ID: 176

EVALUATION OF VEHICLE STABILITY FOR PASSENGER COMFORT

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This study explores key aspects of vehicle stability, with a primary focus on lateral dynamics. It centres on the bicycle model, a simplified two-dimensional representation of a vehicle's lateral response. The model is developed in a linear state-space form using variables such as side slip angle and yaw rate, and is simulated in MATLAB across four different steering inputs to study how the vehicle reacts during cornering. To bring the simulation closer to real driving conditions, roll dynamics were added to account for body movement caused by lateral acceleration. To evaluate and compare handling characteristics, the study uses a four-parameter

framework based on yaw gain, natural frequency, damping, and phase delay. These results offered useful insights into how different vehicle setups and speeds influence stability and comfort. The overall findings contribute to better control system design, and enhanced comfort for both drivers and passengers.

Paper ID:178

DYNAMIC ATTRIBUTES AND MODE SWITCHING FOR A CRACKED CANTILEVER HONEYCOMB BEAM USING MODAL ASSURANCE CRITERIA

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Engineering structures require early detection of damage to ensure safety and prevent catastrophic failure. Modal based vibrational analysis is one such fundamental tool in structural health monitoring, to evaluate dynamic behavior and to detect damage based on changes occurring in modes. In this regard, the present work proposes a modal based technique for a cantilever beam with honeycomb profile by incorporating the effect of cracks at various locations, depths and orientations. Modal analysis is executed using Ansys Workbench and the first six mode shapes were considered for understanding the dynamic behavior of the beam for different crack scenarios. Subsequently, the modal data of the six fundamental modes is utilized to explore the mode switching phenomena for a cracked beam using Modal Assurance Criteria (MAC). The frequencies of different cracked orientations are also reported and compared with the intact beam.

Paper ID: 179

Dynamic Behavior of Orthotropic Circular Plates Under Moving Loads on Elastic Foundations

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The dynamics of a plate subjected to a moving load is a critical area of study in manufacturing industries. This includes applications such as cutting a circular annular plate from a full circular plate using a pointed cutting tool, or cutting wood and pipes using circular saws etc. These tools often experience excessive vibrations during operation, which can impact performance and precision. A thorough analysis of their dynamic behavior is essential to optimize their functionality and mitigate adverse effects. To understand the deeper insight into the dynamics of the plate, this work investigates the flexural vibrations of a thin, orthotropic circular plate on elastic foundation. Kinematic relations are developed with von Karman strain-displacement relations. The dynamical equations are derived using Hamilton's principle, yielding three coupled partial differential equations in the transverse, radial, and tangential directions. The material symmetry about the two orthogonal directions leads to a fourth-order ordinary differential equation with variable coefficients in the spatial domain. Frobeneous series method is used to solve the resulting fourth-order ordinary differential equation with variable coefficients to obtain the mode shapes for simply supported and clamped boundary conditions.

Further, the deflection at any point on the plate is determined using axi-symmetric and asymmetric eigenfunctions within the mode summation framework. The effect of orthotropy ratio, moving load frequency and foundation stiffness are analysed. It is found that symmetric modes, due to their zero diameter, are not excited by the moving load and exhibits only the natural frequencies in the frequency spectrum. In contrast, asymmetric modes with non-zero nodal diameter capture both natural and moving load frequencies. It is also observed that the plate vibrates about a shifted non-zero equilibrium, primarily due to axisymmetric contributions. The effect of foundation stiffness is systematically analyzed, showing significant influence on fundamental frequencies in symmetric responses, while having limited impact on higher modes and asymmetric responses. These findings provide valuable insights into the dynamic behavior of circular plates on elastic foundations and highlight the roles of modal symmetry and foundation stiffness in their nonlinear response under moving loads.

Paper ID: 180

Nonlinear Backbone Curve Characterization of a Piezoelectric Energy Harvester Under Axial Preload and Base Excitation

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Piezoelectric energy harvesters (PEH) has gained prominence as a sustainable approach for powering miniature and autonomous electronic systems. While linear dynamic models provide limited accuracy under real-world vibration conditions, nonlinear analysis offers a more realistic and stronger framework for designing efficient energy harvesters. In this study, a fixed–fixed piezoelectric harvester under constant axial preload is experimentally investigated to explore its nonlinear dynamic behavior under varying base excitation levels. This study focused on characterizing the resonance shift with varying base excitation amplitude. To evaluate this nonlinear response, step-sine testing is conducted across a range of base acceleration amplitudes. The peak voltage at each base excitation amplitude is recorded to create the backbone curve, which describes how the system behaves with varying base excitation amplitude. This approach provides insight into the nonlinear dynamic behavior, which shows both hardening and softening characteristics depending on the excitation level, and highlights the importance of backbone curve analysis in predicting and optimizing broadband energy harvesting performance. The findings aim to support the development of more adaptable and efficient piezoelectric harvesters for real-world vibration environments.

Paper ID: 188

FATIGUE LIFE PREDICTION OF METAL STRUCTURES UNDER FREQUENCY DOMAIN RANDOM VIBRATION LOADS USING MODELICA LANGUAGE

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Fatigue life prediction has become an essential step in validating structures subjected to random vibration loads. While several commercial tools are available in the market today to predict the fatigue life of structures, the underlying principles are still obscure, leading to inaccurate results due to erroneous inputs and settings. This paper focuses on developing a mathematical tool based on theoretical calculations from first principles, using the Modelica language to understand the underlying principles behind fatigue life calculations and calculate the damage of structures under a frequency domain random vibration load. Modelica's capabilities in modelling complex systems and its flexibility in integrating various components were crucial in our development process. Moreover, the results from the tool were correlated with results from commercial software for validation.

A beam structure was subjected to random vibration loads. Frequency and stress response from FEA random vibration analysis were given as input to the damage calculation tool being developed in Modelica. Next, the Lalanne Probability Density Function (PDF) was used to calculate the expected number of cycles in the frequency domain signal for each stress value and the exposure duration. Parallelly, the number of life reversals the beam material can undergo was calculated from the strain-life equation, by solving a non-linear algebraic equation with the help of iterative solvers. Finally, the total damage to the beam structure was evaluated using Miner's rule, where cumulative damage was calculated for each stress range. In addition, it was found that the approach could be further refined for better computational efficiency, accuracy and correlation with test data.

Paper ID: 191

Statistical Model for Estimating the Remaining Useful Life of Bearing under Dynamic Operating Conditions

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Rotating machines are the backbone of modern industry, driving force across generations, manufacturing, and transportation applications. Bearings are a crucial part of these rotating machines, and their failure leads to the abrupt shutdown of machines, resulting in increased downtime and maintenance costs. This research proposes a statistical model for estimating the Remaining Useful Life (RUL) of bearings under dynamic operating conditions. This research can overcome the limitations of the huge availability of datasets required in training a machine learning model to estimate the RUL. The effectiveness of the proposed statistical model-based RUL estimation is validated on two experimental datasets of bearings. Furthermore, a state-of-the-art comparison is made based on the computation time and Root Mean Square Error (RMSE), which shows the superiority of the statistical model for estimating the RUL. Keywords: Model-based approach, signal processing, prognostics, predictive maintenance

Paper ID: 192

DAMPED VIBRATION ANALYSIS OF MOTORCYCLE HANDLEBAR WITH MECHANICAL INSERTS

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Motorcycle riders has lengthy exposure to hand-arm vibrations from motorcycle handlebars. This can result in Hand-Arm Vibration Syndrome (HAVS), a condition that causes symptoms such as hands, fingers numbness, arms tingling, causing vascular, neurological and musculoskeletal issues result in impaired functionality of the hands and arms. The handlebar vibrations may arise due to various reasons. Some of them may be engine vibration, suspension system vibration, road condition, braking and load. According to the European Directive 2002/44/EC and ISO5349-1 and ISO2631-1, an HAV(Hand-Arm Vibration) exposure action value of 2.5 m/s² while 5 m/s² represents the maximum permissible level to safeguard health of human. In this study, the primary goal is to design and construct an experimental setup in the laboratory that allows to analyze the hand-arm vibration induced by motorcycle handlebars while riding over different road surfaces, including sand and a rubber mat, to assess the impact of surface conditions on vibration exposure. By employing vibration transducer, a Piezotronics single-axis accelerometer which has integrated amplifier and is of the Integrated Circuit Piezoelectric (ICP) type. The 9171 chassis and the 9234 DAQ card together make up the testing apparatus known as the National Instruments Data Acquisition System and FFT (Fast Fourier Transform) analyzers. It measure and understand the exact vibration exposure levels experienced by motorcycle riders. This research lays the foundation for a deeper comprehension of Hand-Arm Vibration (HAV) specific to handlebars. Through experimental analysis, it was observed that 98-gram inserts significantly reduced handlebar vibrations by 40–60% at higher speeds, while 60-gram inserts showed a moderate reduction of 8–30%, indicating their effectiveness in enhancing ride comfort and control.

Paper ID: 194

Study of Spur Gear–Rotor Dynamics with Tooth Profile Deviations Using a 14-DOF Mathematical Model

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Spur geared-rotor systems are critical in power transmission across automotive, aerospace, and industrial machinery. However, the real-world operation often introduces imperfections such as angular misalignment and pinion-gear tooth profile deviations, resulting from manufacturing tolerances, assembly inaccuracies, or operational loading. These imperfections lead to transmission error (TE), which degrades efficiency and excites the system in torsional modes. The resulting torsional excitations generate oscillatory torques that can lead to mechanical failure. Since excitation caused by faults significantly influences the system, accurately modelling these deviations is crucial. Consequently, in this work to analyse torsional vibrations, analytical models for profile deviations and misalignments are used with a one-dimensional torsional finite element model with four degrees of freedom, representing the motor, pinion shaft, gear shaft, and load. The flexible shafts and gear mesh are modelled using torsional spring-damper elements, and the system equations are assembled element-wise into global mass, damping, and stiffness matrices. The model is developed to solve for shaft angular displacements arising from motor-driven input and applied load torque, under varying operating conditions and profile undulations. The developed 1D torsional finite element model is expected to demonstrate how profile deviations and misalignments introduce fault-induced excitations that significantly affect the system's torsional response. It establishes a structured analytical basis for assessing torsional dynamics in precision gear applications. Keywords: Spur Geared-Rotor System; Transmission Error (TE); Torsional Vibration; Finite Element Method (FEM); Angular Misalignment; Profile Deviations; Rotor Dynamics.

<u>Paper ID: 196</u>

REDESIGN OF A HYBRID JOURNAL BEARING TO OVERCOME HIGH PAD TEMPERATURE AT OPERATING SPEED

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An existing hybrid journal bearing has been redesigned in order to overcome high pad temperature at operating speed for uprated rotor train which increased static loading on bearing. Increasing bearing liner length is expected to provide benefit in reducing the pad temperature rise but due to geometrical constraint, liner length could not be increased to the required extent. Since, the liner length was constrained, location and orientation of hydrostatic pockets has been explored with an objective of improving the hydrodynamic performance while meeting the hydrostatic requirements. Hydrostatic pockets location and size have been modified to provide sufficient bearing area in hydrodynamic regime. The modified bearing is evaluated on hydrodynamic parameters as well as hydrostatic parameters. The bearing design has been optimised considering the parameters such as pad temperature, lift-off speed, oil flow requirement.

Paper ID: 197

NONLINEAR DYNAMICS OF QUASI-ZERO STIFFNESS METAMATERIALS FOR ADVANCED VIBRATION ISOLATION: A COMPUTATIONAL AND EXPERIMENTAL INVESTIGATION OF NOVEL QZS DESIGNS

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This research addresses the inherent limitations of linear isolators in achieving effective low-frequency vibration isolation by focusing on engineered nonlinearity. The primary objective is to design, computationally analyze, and experimentally validate novel 3D metamaterial unit cells exhibiting Quasi-Zero Stiffness (QZS) behavior, a hallmark of advanced nonlinear systems. The novelty resides in developing distinct QZS designs: a monolithic structure and a composite system integrating negative stiffness mechanisms with a positive stiffness component, strategically leveraging nonlinearity to overcome conventional linear constraints. The methodology employs comprehensive computational mechanics, utilizing SolidWorks for modeling and ANSYS Workbench for rigorous numerical simulations to characterize the highly nonlinear static force-displacement responses. These analyses were crucial in confirming the vital QZS region, which is characterized by High Static Low Dynamic (HSLD) stiffness. The metamaterial's nonlinear restoring force equation was empirically derived through the least squares method, providing a robust analytical tool for dynamic analysis. To ensure geometric stability and enhanced payload capacity in a practical system, unit cells were integrated into a metastructure, which subsequently underwent compression testing to validate its nonlinear QZS characteristics. Dynamic performance was meticulously assessed via the Harmonic Balance Method for frequency response and the Perturbation Method for stability analysis. Key observations, including characteristic jump phenomena in the amplitude-frequency response, emphatically demonstrate the system's inherent and beneficial nonlinearity. This work underscores the efficacy of computational modeling coupled with experimental validation in advancing nonlinear vibration control.

Paper ID: 200

TOPOLOGY OPTIMISATION OF A VEHICLE LIFTING DEVICE MEMBER USING DYNAMIC LOADING INPUT AND EXPLORING ITS MASS-MANUFACTURING FEASIBILITY

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Topology optimisation is a strong computational method for designing robust and lightweight mechanical members. In order to lower the weight of a crucial load-bearing member, topology optimisation was used in this work to design a member of a vehicle lifting system. A multi-body dynamic simulation in ANSYS Workbench was used to assess the forces acting on the device during the lifting process to establish dynamic loading conditions. With appropriate boundary conditions, the simulation's maximum load served as the input for topology optimisation. The optimised shape was obtained after selecting a solid circular cross-section

Computer-Aided Design (CAD) model for optimisation. ANSYS SpaceClaim was utilised to refine the shape of the end result. After that, structural analysis was carried out on the optimised member to evaluate how it responded to loading in terms of stress and strain. Two commercially available members (structural steel tubes) with hollow circular cross-sections of different dimensions were also examined under the same loading conditions for comparison. According to the results, the optimised member had a lower maximum stress and strain than the hollow members, but greater total deformation than one of the other members. However, because of the optimised shape, it came to light that the cost of manufacturing the optimised member was far greater because it required either metal 3D printing or lathe machining. Even while the optimised part has better mechanical performance, these approaches are less suitable for mass production, decreasing economic viability. The study concludes that while topology optimisation enables the creation of customised, high-performance parts, it does not necessarily reduce manufacturing costs. Design decisions should, therefore, balance performance gains with economic feasibility, especially when considering large-scale production.

Paper ID: 201

GEARBOX HEALTH IDENTIFICATION BASED ON TIME VARYING MESHING STIFFNESS AND DAMAGE INDEX

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Gearbox meshing stiffness is a critical dynamic parameter that reflects gear teeth' structural integrity and operational condition. Progressive faults such as wear, pitting, and micro-cracks result in measurable changes in the meshing stiffness, which can be extracted from vibration signals. This work introduces a physics-informed methodology for identifying the health state of a single-stage gearbox using time-varying meshing stiffness (TVMS). Vibration data are collected throughout a run-to-failure experiment under constant speed and load. TVMS is computed from the recorded signals and processed to capture local variations associated with gear degradation. A novel damage index is formulated using a stiffness deviation, accumulating over time to compute a cumulative damage function. Based on this, a health index (HI) is derived to quantify the continuous health state of the gearbox. The proposed approach enables early detection of faults and interpretable health tracking without relying on frequency-domain transformations. The HI curve's progression reveals degradation trends consistent with known fault events. This methodology offers a physically meaningful and data-efficient strategy for health assessment, laying the groundwork for integration with digital twin platforms and predictive maintenance systems.

Paper ID: 203

PERFORMANCE ANALYSIS OF MACHINE LEARNING MODELS FOR VIBRATION-BASED FAULT CLASSIFICATION IN CENTRIFUGAL PUMP

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Reliable operation of centrifugal pumps is essential for industrial processes, where even minor faults can lead to costly downtime and increased maintenance demands. In this study, a comprehensive comparative analysis of machine learning models is presented for diagnosing incipient and developed suction blockage faults in a centrifugal pump using multi-axis vibration data. Experimental investigations involve a Crompton MBM22 pump operating under five conditions: healthy and four suction blockage levels, with vibration signals acquired via a tri-axial accelerometer at a 5.12 kHz sampling rate. The acquired data undergo segmentation, and both time- and frequency-domain statistical features are extracted, normalized, and used to train four classifiers: Artificial Neural Network (ANN), Support Vector Machine (SVM), Random Forest (RF), and Extreme Gradient Boosting (XGBoost). Hyperparameters are optimized through cross-validation, and model performance is evaluated using accuracy, precision, recall, specificity, and F1-score. Results indicate that the ANN achieves the highest accuracy of 99.67%, surpassing SVM (99.44%), XGBoost (98.78%), and RF (98.11%), with confusion matrix analysis confirming its superior ability to distinguish closely related fault states, particularly between healthy and early-stage blockages. These findings underscore the potential of ANN-based diagnostic frameworks for enhancing predictive maintenance, enabling early fault detection, reducing downtime, and improving the operational reliability of centrifugal pump systems.

Paper ID: 208

Deflection Approximation of Geometrically Nonlinear Elastic Beams

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This paper investigates the slope and deflection behavior of a geometrically nonlinear cantilever beam subjected to transverse loading. Traditional linear beam theories, while effective for small displacements, fail to accurately represent the structural response when deformations become large. To address this limitation, a nonlinear mathematical model is developed that incorporates geometric nonlinearity by considering the coupling between bending and axial stretching effects. The resulting nonlinear differential equation provides a more accurate representation of beam behavior under significant loads. An approximate analytical solution to the nonlinear equation is also obtained using Galerkin method. This approach involved selection of appropriate trial functions that satisfy the boundary conditions, allowing the transformation of the complex nonlinear equation into a solvable algebraic form. From closer matching with reference studies, the good

convergence and reliability of the method are demonstrated. MATLAB simulations are carried out to compare linear and nonlinear responses, revealing notable differences, especially at higher load levels, where effects such as geometric stiffening become significant. Validation of the proposed solution is conducted through graphical comparisons with benchmark data, showing excellent agreement as the order of approximation increased. The study clearly highlights that incorporating geometric nonlinearity leads to more realistic prediction of slope and deflection, which are crucial for the safe and efficient design of flexible structural elements. The presented methodology provides a strong foundation for further research in nonlinear structural analysis and can be extended to dynamic, thermal, or material gradient scenarios in the future.

Paper ID: 209

A Robust Approach to Incorporate Dissipative Behaviour in the Linear Constitutive Relationship of Material Model

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Energy gets dissipated due to internal and external damping whenever a structure undergoes the dynamic deformation. The quantification of this dissipative behaviour is not precise to this date. Instead of the conventional approaches like Rayleigh damping or hysteric damping, viscoelastic damping is used to model the internal dissipation in the present work. In metallic structural members internal damping can be overlooked but in case of composite or polymeric materials internal damping needs to be addressed accurately. Therefore, in this work an attempt is made to apply the Lagrange's principle to find out the equations of motion for structures of linear-viscoelastic materials. In this approach, very often the effect of dissipation is either included as a part of non-potential generalized force or is included by modifying the functional, e.g. the Lagrangian by including a dissipation function (Raleigh's dissipation function) generally denoted as '$\mathcal{D}$'. This approach works for simple material models. However, the energy dissipation mechanism in polymers and composites happens to be too complex to be represented by simple model, necessitating the representation of dissipation by using more spring and dashpot elements. In these cases, writing the dissipation function '$\mathcal{D}$' becomes very cumbersome. Therefore, this paper proposes the application of a linear time differential operator, which upon operating on the dynamic deformation yields the equation of motion of the structure and takes care of the material properties. In this process both restoring and the dissipative behaviours get encapsulated inside the operator, requiring no special treatment explicitly. Therefore, the operator is used in this formalism to work only as a modulus representing energy restoration for formulating the Lagrangian. The application of this modulus operator technique paves a way for studying the effect of internal damping on the dynamics of complex structures. This technique however is simple in application but ultimately is a subject to the precise estimation of a viscoelastic model.

Paper ID: 210

Transformer mechanism based stacked BiLSTM framework for predicting remaining useful life of rolling bearings

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Roller bearings are crucial components of rotating machinery, significantly influencing the efficiency and reliability of the equipment. With failure posing a significant risk of complete production shutdowns, one single fault in a bearing can cascade into substantial breakdowns. Therefore, highlighting the necessity for data-driven prognostics for the bearing health monitoring. By leveraging advanced AI techniques, predictive models can be developed to accurately estimate the Remaining Useful Life (RUL) of bearings, enabling timely maintenance and preventing catastrophic failures. In this paper, the bearing degradation analysis was conducted using data from the IEEE PHM 2012 (PRONOSTIA platform).

Raw signal data were collected, and both time-domain and frequency-domain features were extracted for prognostic evaluation. Features were meticulously selected based on monotonicity and trendability, ensuring the incorporation of relevant information for accurate Remaining Useful Life (RUL) predictions. Accurately predicting bearing degradation trends is essential for estimating RUL, yet this task is inherently challenging due to the complexities of long-term forecasting. To address these challenges, Long Short-Term Memory (LSTM) variants, both individually and in combination with Attention and Transformer mechanisms, were employed. Among the evaluated methods, the Stacked Bidirectional LSTM with Transformer mechanism demonstrated superior performance, offering the most accurate RUL predictions. This comprehensive approach ensures reliable predictions, facilitating timely maintenance and significantly reducing the risk of bearing-induced production failures.

Paper ID: 211

PIPELINE LEAKAGE DETECTION: BY EMPLOYING THE EULER–BERNOULLI BEAM USING AN ITERATIVE ALGORITHM WITH A MACHINE LEARNING APPROACH

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Pipelines play a crucial role in transporting liquids, gases, and slurries across extensive distances in sectors such as oil and gas, petrochemicals, and water treatment. However, factors like aging infrastructure, joint or seal failures, corrosion, and pressure fluctuations make pipelines vulnerable to leakage. The present work aims towards a simulation-based supervised learning approach for a real-time leakage monitoring system in pipelines using MATLAB Simulink with an embedded classification learner tool to predict potential leaks in pipelines. Using MATLAB Simscape, an embedded physical model for a pipe system was developed for modelling fluid flow and related wall vibration in healthy and faulty conditions. The Euler-Bernoulli beam theory is used to build a lumped parameter model to simulate the vibration response of a pipe due to leakage. Furthermore, the pressure fluctuation in the pipe due to turbulent flow is introduced through a Von-Karman spectrum-based model. The model was coupled with an accelerometer to acquire vibration data from the pipe wall near the leak. This data is input for the leak detection mechanism. The time-series data of vibrations were collected, pre-processed, and further utilized to train the Support Vector Machine (SVM) and Naive Bayes machine learning models to classify and predict instances of leakage and the magnitude of the leakage. The results obtained from the SVM model and the Naïve Bayes indicate an accuracy rate of 85% and 79%, respectively. Hence, the results from these two methods show good agreement.

Paper ID: 213

ROTOR DYNAMIC ANALYSIS OF AN ELECTRIC ENGINE ROTOR SYSTEM

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A 100-kW electric engine ground test facility is being established at the Propulsion Division, CSIR-NAL, for the performance evaluation of the Motor, Propeller, and associated accessories used in the electric aircraft. This paper presents a detailed rotordynamic analysis of the motor-propeller drive system designed for this test facility using the finite element method. The primary objective here is to assess the dynamic behavior of the rotor system and to identify the potential resonance zones of the system within the operating regime. A finite element model of the rotor system is created, considering the motor, propeller, torque meter rotor, couplings, anti-vibration mounts, and support truss. Their masses, inertia, material properties, geometry, and boundary conditions are defined. In this study, in addition to the basic rotordynamic analysis, a coupled static structural-rotordynamic analysis is also carried out to understand the influence of static deflection on the dynamics of

the system. The analysis evaluates the system's natural frequencies, mode shapes, critical speeds, and their corresponding responses, considering gyroscopic effects, damping, and unbalanced forces. The results obtained from the finite element analysis provide valuable insights into the safe operating regimes of the test rig envisaged.

Paper ID: 214

Modelling and Analysis of Reaction Wheel with Hybrid Magnetic Bearing

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Reaction wheel (RW) finds its application in the attitude control of satellites. It consists of a rotating mass, a motor, a controller, bearings, and an enclosure. Magnetic bearings are used to avoid contact between the rotor and the stator, and provide movement control. These magnetic bearings can be active, passive, or hybrid. The active magnetic bearing (AMB) includes an electromagnetic actuator, whereas the passive magnetic bearing (PMB) includes permanent magnets. The hybrid magnetic bearing (HMB) comprises AMB and PMB with different configurations. Therefore, a mathematical model of a RW with HMB is presented for a single plane motion where axial and lateral direction control are done with PMB and AMB, respectively. The linearized magnetic cross-coupling effect of PMB for the lateral and tilt movement of RW is considered. Moreover, through finite element analysis (FEA) of PMB, the magnetostatic forces are obtained using Maxwell equations, and thus, the effective stiffnesses are calculated for axial, lateral, and tilt motion. The obtained cross-coupled stiffness is analyzed to understand the effect of PMB and AMB in RW with HMB. Furthermore, the results can be used in a flywheel or a high-speed rotor for different machinery applications. Keywords: Hybrid Magnetic Bearing; Permanent Magnet Bearing; Active Magnetic Bearing; Magnetic Coupling; Finite Element Simulation; Stiffness.

Paper ID: 222

Acoustic Signal processing based on Wavelet denoising for source identification

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Acoustic signal processing for source identification faces challenges due to the presence of severe ambient noise that requires a strong denoising and classification approach. This work presents a synergic approach of integrating adaptive wavelet thresholding and improved complete ensemble empirical mode decomposition

(ICEEMDAN) with adaptive noise for noise removal. The wavelet decomposition technique isolates high-frequency noise, and ICEEMDAN extracts intrinsic mode functions to preserve signals. The denoised signals are analyzed using Hilbert-Huang Transform for time-frequency characterization and spectrogram for visualization. The input signals from three different sources with varying levels of noise are considered and the denoised signals are first obtained. Further statistical features derived from the signal's intrinsic mode functions and their instantaneous frequencies are employed to characterize the signal. Based on the signals and source type, a generalized regression neural network-based classification model is developed, and the effectiveness of the classification is illustrated. Further, the noise levels are modified, and the accuracy of classification is also predicted.

Paper ID:224

Model Free Active Vibration Control of Linear SDOF Systems Using Reinforcement Learning

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Vibration is unavoidable in many engineering systems. While it can be beneficial in certain applications—such as vibration-based energy harvesting, non-destructive testing and communication systems it often leads to undesirable effects including structural failure, fatigue, noise generation and reduced safety. This study proposes a Deep Reinforcement Learning (DRL)-based active vibration control method for a Single-Degree-of-Freedom (SDOF) dynamic system subjected to random initial disturbances. The proposed Soft Actor-Critic (SAC) controller operates without prior knowledge of system dynamics, enabling a model-free framework adaptable to varying conditions. The SDOF system, modeled as a linear mass–spring–damper, is simulated under high-frequency disturbance conditions. The SAC agent is trained in a custom simulation environment to learn optimal control strategies for rapid vibration suppression. Simulation results demonstrate that the SAC controller significantly reduces displacement amplitude and ensures system stability within 0.15 s. indicates that SAC achieves faster vibration attenuation and smoother control force application in these simulations. These findings highlight the potential of model-free DRL methods for real-time active vibration control in systems with uncertain or time-varying dynamics.

Paper ID: 227

CONTROLLING FOOT BRIDGE VIBRATION USING TUNED MASS DAMPERS

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Foot bridges, sometimes ornamentally called sky walk, are very common structures providing connectivity to the important locations for the pedestrian traffic. Unscientific design and non- engineered construction may sometimes lead to excessive deformation or collapse under high density rhythmic crowd. In the present paper,

a continuous model of slender foot bridge has been developed for carrying out dynamic analysis under pedestrian load. A pedestrian load model capable of synchronizing girder lateral mode has been adopted for the dynamic analysis. By taking the Millennium Bridge of the city of London, as a case study, the response of the bridge structure is investigated due to dynamic load imposed by crowd. The simulated dynamic response was tested for control using tuned mass damper. Optimum location of tuned mass dampers and mass ratio has been suggested. It was found two tuned mass dampers unsymmetrically placed shows better performance since the torsional mode excited due to lateral vibration could be controlled with such configuration. To keep the lateral acceleration out of human perception, mass ratio of each damper in double damper unsymmetrical configuration was recommended.

Paper ID: 228

Machine Learning Methods to Predict the Natural Frequencies and Mode Shapes of Mechanical Components

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Conventional modal updating techniques are often limited by their dependence on manual parameter tuning and sensitivity to idealized modeling assumptions, particularly in systems with complex material behavior. This study presents a machine learning-based framework to develop a surrogate model to estimate the modal parameters, enhancing the accuracy and efficiency of modal parameter-based material property estimation. A synthetic dataset was generated for a thin cylindrical structure composed of orthotropic material by performing Monte Carlo simulations to produce a diverse material (G) matrix. These material properties were then used in finite element analysis to extract corresponding modal parameters. Multiple regression models, including linear, nonlinear, and ensemble approaches, were developed to predict material properties from the modal data. The predicted G-matrix was employed to iteratively update the numerical model, reducing the discrepancy between original data and predicted data from surrogate models. This approach addresses key limitations in traditional modal updating by offering a reliable, automated, and transferable method. This method has potential for improving correlation between numerical simulations and experimental observations in the dynamic analysis of mechanical systems.

Paper ID: 229

Cymatics-Driven Self-Cleaning System for Mitigating Soiling Losses in Solar Photovoltaic Panels: A Sustainable Non-Contact Approach

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The contamination of photovoltaic (PV) panels resulting from the buildup of dust, contaminants, and organic matter can significantly diminish energy output, especially in arid and semi-arid areas. Conventional cleaning techniques, including hand washing or robotic systems, are characterized by high water use, significant energy usage, or substantial operating costs. This work presents an innovative, non-contact cymatics-based self-cleaning technology that utilizes regulated mechanical vibrations to reduce soiling on photovoltaic panels. The system employs piezoelectric actuators to produce surface-resonant frequencies in the solar module's glass layer, forming standing wave patterns that mechanically displace and redistribute dust particles into nodal zones, thereby improving the likelihood of passive removal through gravity or ambient wind. The appropriate excitation range (3–6 kHz) was established using modal analysis and frequency-domain simulations, considering the panel's material and geometric properties. Experimental validation on test modules showed constant dust removal and a power output enhancement of up to 15% relative to untreated panels throughout a 30-day field cycle. This cymatic method provides a waterless, low-maintenance, and scalable substitute for traditional cleaning, particularly crucial for areas experiencing water shortages and elevated particle air pollution. The use of adaptive vibration-based devices might markedly improve the long-term sustainability and operating efficiency of solar PV installations.

Paper ID: 232

PREDICTIVE MAINTENANCE OF WIND TURBINE GEARBOX USING SPECTROGRAM-BASED CONVOLUTIONAL NEURALNETWORKS

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Purpose: This study addresses the critical need for efficient fault detection in wind tur bine gearboxes to minimize downtime and enhance renewable energy reliability. The research question focuses on whether spectrogram-based convolutional neural networks (CNNs) using power output data can accurately classify fault severity, overcoming limitations of traditional vibration-based methods.

Methods: Power output data was simulated using a MATLAB model with six fault levels (5%, 10%, 15% as mildly faulty; 20%, 25%, 30% as highly faulty) under varying wind speeds. The data was transformed into spectrograms via Short-Time Fourier Transform (STFT) with a 256 sample Hanning window and 512-point FFT. A CNN with two convolutional layers (20 and 50 filters), ReLU activation, and softmax output was trained using stochastic gradient descent with momentum (SGDM) over 10 epochs, validated on a 70-30 train-test split.

Results: Spectrogram analysis revealed distinct frequency patterns, with high-frequency variations for mild faults and low-frequency amplitudes for severe faults. The CNN achieved a 91% test accuracy (46/50 mild, 45/50 severe correct), with 80% training accuracy, indicating good generalization despite potential data imbalance.

Conclusion: The proposed method offers a practical, scalable solution for real-time gearbox fault detection, leveraging accessible SCADA data. Future work will validate the model with real-world data and optimize noise handling, enhancing its industrial applicability. This approach contributes to predictive maintenance advancements in wind energy systems.

Paper ID: 235

NONLINEAR DYNAMICS OF A DOUBLE CANTILEVER-BASED PIEZOELECTRIC ENERGY HARVESTER UNDER COMBINED GALLOPING AND PARAMETRIC EXCITATION

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In this work, the combined effects of parametric excitation and aerodynamic galloping are investigated for a double cantilever-based piezoelectric energy harvester (PEH). In order to create flow-induced galloping, the system includes cantilever beams with surface-bonded piezoelectric layers at the base of the beams and bluff bodies at their free ends. Two individual beam-bluff body systems are coupled by magnetic repulsive force. Parametric excitation is introduced by periodically varying base displacement. In order to study resonance phenomena and voltage generation of the system, a coupled nonlinear electromechanical model is created and examined. Numerical simulations reveal that the combination of parametric excitation and galloping greatly increases power production. Notably, significant resonance amplification takes place when the parametric excitation frequency becomes close to twice the system's natural frequency. Even without base excitation, galloping produces self-sustaining, wideband oscillations. This study highlights the potential of hybrid-excited PEHs to overcome the frequency-matching restrictions of conventional harvesters and deliver sustained power output over a wider range of ambient conditions. The proposed design is especially suitable where both wind flow and structural vibrations coexist; such as in bridge decks, transmission lines, and offshore platforms.

Paper ID: 240

PERFORMANCE-BASED SEISMIC EVALUATION OF CONCRETE-FILLED STEEL TUBE COLUMNS IN HIGH-RISE BUILDINGS WITH SOIL-STRUCTURE INTERACTION CONSIDERATION IN THE NORTH-EASTERN PART OF INDIA

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In seismic design, controlling structural response to ground-induced vibrations is critical, particularly for high-rise buildings. Concrete-filled steel tube columns (CFSTCs) have become high-performance alternatives to conventional Reinforced Cement Concrete (RCC) columns due to their superior energy dissipation, enhanced stiffness, and improved ductility under dynamic loading. The composite interaction between steel and concrete facilitates efficient attenuation of seismic vibrations, making CFSTCs highly effective in seismic zones. However, the influence of Soil-Structure Interaction (SSI), especially in soft soil conditions, remains underexplored in the seismic performance of CFST-supported systems. This study presents a numerical investigation of a 20-storey building with CFSTCs, explicitly incorporating SSI effects through coupled pile foundations. The structural response was analyzed using a finite element approach, calibrating material properties to capture wave propagation and vibrational damping characteristics. Dynamic response parameters such as natural period, base shear, lateral displacement, inter-storey drift ratio, and buildings' performances were evaluated in fixed-base and SSI conditions as per FEMA-356 guidelines. Results indicate that while CFSTCs effectively reduce vibrational amplitudes and enhance seismic resilience, SSI significantly alters the vibrational behavior by increasing flexibility and extending natural periods. Soil stratification further amplifies these effects, underscoring the importance of integrating SSI in design. The study concludes the use of CFSTC in seismically prone areas for the superstructure and foundation systems to ensure structural integrity under vibrational excitation.

Paper ID: 241

METHODOLOGY TO DESIGN THROTTLING GROOVES FOR LOW NOISE ENERGY RECOVERY DEVICES

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In seawater reverse osmosis (SWRO) systems, energy recovery devices (ERDs) play a vital role in improving overall system efficiency by reclaiming pressure energy from the high-pressure brine stream exiting the reverse osmosis (RO) membrane. These rotating machines transfer pressure from the high-pressure, high-salinity brine to the low-pressure, low-salinity feedwater, thereby reducing the load on the high-pressure pump. However, due to their rotational dynamics, ERDs are prone to noise generated by fluctuating hydraulic pressures, which can affect both performance and reliability. This study aims to identify and characterize the primary noise sources within the ERD and explore strategies for noise level mitigation. A design of experiments (DOE) approach is employed to determine the ideal pressure profile of the cylinder during the transition between high-pressure (HP) and low-pressure (LP) zones. The goal is to minimize the primary contributors to noise. The study outlines the characteristics of pressure profiles that are likely to result in quieter operation. This foundational work can, in turn, be used in future research, where optimization algorithms will be employed to design groove geometries that replicate the ideal pressure profile. These methodologies will ultimately lead to quieter and more efficient ERD performance.

Paper ID: 244

DYNAMIC ANALYSIS OF BOLTED JOINT ROTOR SYSTEM SUBJECTED TO MULTIPLE NONLINEARITIES

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Bolted joints are widely used in aero-engine rotors and gas turbines. The dynamic analysis of such joints is complicated to model due to the inherent nonlinearities due to stick-slip friction forces. The nonlinear behaviour included in assembled structures mostly depends on the interface properties. In several systems, the stator-rotor rub impact forces also arise due to several unbalance effects. In this paper, dynamic analysis of

rotor bearing system with bolted joint disk system is presented with multiple excitations including contact interface dynamics as well as rub-impact forces and disk unbalances, bearing forces. A finite element model of the rotor system with 2-node Timoshenko beam elements is used to discretize the rotor system and different forces are applied at appropriate nodes in the assembled model. The resulting system of differential equations is solved by fourth-order Runge-Kutta time integration method to obtain the dynamic response. In order to identify the interface and contact stiffness properties using dynamic response, a multilayer perceptron neural network model is trained. The results are presented at different speeds of operation.

Paper ID: 246

A simplified analytical framework for non-circular tunnels under in-plane seismic P-wave excitation with soil-tunnel interface effects

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This study presents a streamlined analytical formulation for evaluating non-circular tunnel response subjected to in-plane P-wave loading with particular emphasis on the influence of surrounding soil stiffness, interface slip conditions, and tunnel lining thickness. The formulation follows a pseudo-static approach under the assumption of long seismic wavelengths, with conformal mapping applied to transform irregular tunnel geometries into an equivalent circular domain. The proposed model is benchmarked against established analytical results for both circular and non-circular tunnel configurations. An important contribution of this study is the use of spatiotemporal response maps for hoop stress and circumferential displacement, which allow detailed visualization of peak magnitudes and their angular locations along the tunnel lining. The results show that increasing ground stiffness reduces deformation demand, whereas greater interface flexibility suppresses stress but amplifies displacement. Lining thickness significantly affects the structural response, with thicker linings developing higher hoop stresses while experiencing smaller circumferential displacements. Overall, the proposed formulation offers a computationally efficient approach for preliminary seismic assessment, capturing the magnitude and distribution of critical tunnel responses under earthquake loading.

Paper ID: 247

FORMULATION AND RESPONSE SURFACE OPTIMIZATION OF BAMBOO-FIBER LIME JAGGERY MORTARS FOR ENHANCED CARBON SEQUESTRATION AND CLIMATE RESILIENCE

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A low-carbon, climate-resilient mortar was formulated by reinforcing a moderately hydraulic lime matrix with renewable industrial-waste untreated bamboo fibres and unrefined jaggery. An 81-run Central Composite Design, each replicated 50 times (totaling 4050 observations), varied fibre and jaggery contents between 1.0 and 5.0 wt % as per earlier studies of Pilak Shyam Sundar Ashram, Tripura, India. Five performance indicators compressive strength; capillary water absorption; thermal conductivity; drying shrinkage; and 90-day carbonation depth were evaluated. Second-order polynomial models demonstrated excellent fit (adjusted $R^2 > 0.97$) and revealed significant synergistic effects between the bio-additives. A multi-response desirability function identified the 3.0 wt % fibre and 3.0 wt % jaggery mix as optimal, yielding an average compressive strength of 5.56 MPa; the thermal conductivity of 0.49 W m^{-1} K^{-1}; shrinkage of 0.049 %; and carbonation depth of 4.61 mm, while effecting approximately a 60 % reduction in embodied carbon relative to conventional cement mortars. Enhanced freeze-thaw durability and moisture-buffering capacity were also observed. These results substantiate that bio-based additives can be harnessed to engineer lime-based composites that advance renewable-resource valorization and contribute to climate change mitigation in sustainable construction and heritage conservation.

Paper ID: 250

Performance Study of Braced Buildings with Plan Irregularities

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This study examines how building geometry and lateral load-resisting systems affect seismic performance, focusing on irregular plans such as L-shaped buildings with re-entrant corners that cause torsional effects and uneven seismic force distribution, increasing earthquake risk. Starting with a regular square frame, the model was incrementally altered into L-shaped configurations by removing portions of the frame, introducing varying plan irregularities. Three bracing systems—X-bracing, V-bracing, and Chevron bracing—were added at each stage. Seismic response was analyzed using the response spectrum method, emphasizing lateral displacement as the key performance metric. The study evaluated how each bracing type influenced lateral displacement across different shapes. Results showed that X-bracing most effectively controlled displacements, especially in highly irregular configurations, enhancing structural stability. This highlights the critical role of selecting appropriate bracing for irregular buildings to ensure seismic resilience. Additionally, the study considered the impact of building mass, finding that while heavier buildings experience greater inertia forces, they may exhibit lower drift ratios if properly stiffened. Comparisons with a lighter, less reinforced building model revealed that the lighter design reduced drift more effectively and improved cost efficiency. Overall, this research emphasizes the importance of addressing geometric irregularities, optimal bracing selection, and reinforcement strategies in seismic design to improve the safety and resilience of buildings in earthquake-prone areas.

Paper ID: 257

VOID NUCLEATION AND INTERACTION IN SOLIDS

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Void nucleation is a fundamental phenomenon in the study of fracture mechanics, playing a critical role in the failure of ductile materials. Under the application of mechanical loads, especially near a pre-existing crack, different deformation zones typically develop, such as the elastic zone, plastic zone, HRR (Hutchinson–Rice–Rosengren) singularity zone, and the fracture process zone (FPZ). Among these, the fracture process zone is of particular interest, as it is the region where actual damage mechanisms occur. In this zone, voids nucleate at particular sites, grow under increasing load, and eventually coalesce to form or extend cracks, leading to material failure.

Void nucleation in ductile materials is primarily driven by material inhomogeneities (such as second-phase particles or inclusions) and specific stress states. When the local stress exceeds a critical threshold, voids begin to form. These voids are generally microscopic, much smaller than the dimensions of the structural component, and can be modelled as small holes embedded in an infinite medium. At the nucleation stage, the interaction between neighbouring voids is minimal and can be neglected.

The problem can be idealized and analyzed in three stages. First, void nucleation occurs under a specific stress state in a material initially free of voids. Second, the stress and displacement fields around a single void modeled as a hole in an infinite plate are examined under various far-field loading conditions. Finally, the derived solution is integrated with an incremental finite element method (FEM) using a novel elasto-plastic superposition approach, enabling accurate simulation of nucleated voids in plates without requiring modifications to the mesh configuration. This hybrid analytical numerical technique provides an efficient framework for predicting crack initiation and growth in ductile materials, offering significant applications in fracture mechanics and structural integrity assessment.

Paper ID: 258

ACTIVE MAGNETIC BEARING SUPPORTED FLYWHEEL ROTOR DESIGN USING MULTIDISCIPLINARY OPTIMIZATION

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Flywheel energy storage systems and momentum wheels of orbit control systems use active magnetic bearings to support the rotor without solid-solid contact to minimize frictional energy losses and increase the system operating life. This work presents the design and optimization of the rotor for such a magnetically suspended flywheel energy storage system. In this work, the parametric design of the rotor is optimized considering modal frequencies and mode shapes, sensor placement, polar moment of inertia, and magnetic bearing sizing requirements for the estimated axia loads. The modal analysis is done using open source rotordynamics analysis tool. The methodology for optimal rotor design that maximizes the angular momentum while satisfying the design constraints is presented.

Paper ID: 259

AR-based human-machine interface for tool condition monitoring using 1D CNN

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Tool Condition Monitoring (TCM) is essential in Industry 4.0 for achieving smart manufacturing through real-time data analysis and decision-making. This work presents an Augmented Reality (AR)-based TCM system for predicting micro-drill breakage during the micro-machining of titanium alloy—one of the most difficult materials to machine. Unlike conventional TCM systems that rely on multiple displays and cause operator distraction, the proposed approach integrates a Human-Machine Interface (HMI) using Microsoft HoloLens, enabling real-time, immersive visualization directly within the operator's view. The system employs a lightweight deep learning model combining a Variational Autoencoder (VAE) and a 1D Convolutional Neural Network (1D-CNN) for anomaly detection and tool condition classification as fresh, worn, or critical based on force data from a dynamometer. Optimized for CPU execution, the model maintains over 95% accuracy across 100 epochs with minimal latency, making it suitable for real-time deployment. The AR interface displays live force–time graphs and tool condition alerts directly in front of the machine, reducing cognitive load and improving operator responsiveness. Validation through controlled machining sessions showed that the system effectively detects tool wear and enhances user comfort and situational awareness. The proposed AR-based TCM framework demonstrates the feasibility of combining advanced AI with immersive AR for intelligent, low-latency, and user-friendly monitoring in precision manufacturing.

Paper ID: 262

A Compound CNN-ISTM based bearing Fault diagnosis of switched reluctance Motor

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Amid increasing efforts to reduce greenhouse gas (GHG) emissions, electric transportation solutions are being increasingly adopted by both individuals and businesses. Due to their simple construction and absence of permanent magnets, switched reluctance motors (SRMs) present a cost-effective alternative, positioning them as prime candidates for electric vehicle and traction applications. Despite the promising electrical fault tolerance of SRMs, their bearings are susceptible to brinelling and corrosion due to mechanical friction. This vulnerability underscores the need for reliable and automated bearing fault diagnosis technique. Moreover, the characteristic large torque ripple of SRMs complicates the application of conventional diagnosis methods, highlighting the necessity for specialized approaches. This paper presents a technical overview of traditional bearing fault diagnosis techniques and their inadequacy in dealing with complex and non-stationary conditions of SRMs. To overcome the problem, a novel compound neural network based intelligent fault diagnosis strategy is proposed which capitalizes on respective benefits of Convolutional Neural Networks and Long Short Memory Cells. The effectiveness of the proposed model is assessed via experiments carried out on a test rig containing defective bearings. It was observed that the proposed model was able to predict and classify the bearing defects with an exceptional accuracy of 95.16%. Additionally, t-distributed stochastic neighbor embedding (t-SNE) was employed to visualize and compare the learned feature distributions associated with various fault types.

Paper ID: 264

DYNAMIC ANALYSIS OF AN UNBALANCED AND CRACKED RIGID ROTOR WITH VISCOELASTIC SUPPORTED FOIL BEARINGS

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High-speed rotors are vulnerable to resonance and catastrophic failure. Managing coupled faults with enhanced damping mechanisms significantly boosts system reliability. In alignment with current research priorities in rotor dynamics, tribology, and adaptive material design, this study investigates the dynamic behavior of a rigid rotor system exhibiting both unbalance and transverse crack faults, supported by viscoelastic foil bearings. Building upon the numerical framework established in the referenced Jeffcott rotor study, the model incorporates switching crack mechanics and unbalance-induced forces to simulate fault interactions. The viscoelastic support structure enhances damping and mitigates stress concentrations compared to conventional bump-type foil bearings, offering improved operational reliability under high-speed conditions. The simulation reveals that unbalance faults dominate at higher spin speeds, while crack-induced harmonics manifest more prominently at lower speeds, leading to complex vibrational signatures including forward and backward whirl components. The viscoelastic layer effectively absorbs transient vibrations and suppresses amplitude escalation during startup and shutdown phases. Time domain analysis confirms the presence of a crack due to modulation in responses and eight-shaped orbits. The responses also illustrates asymmetric displacement patterns for a single speed rotation and ramp-up speed. Overall, the study highlights the superior fault-tolerant characteristics of viscoelastic-supported foil bearings, especially in managing coupled fault scenarios. The findings contribute to the development of robust rotor-bearing systems for advanced turbomachinery applications.

Paper ID: 268

AI-Assisted Crack Detection Using Modal Analysis and Frequency Response Data from FEA-Based Structural Simulations

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The early detection of structural cracks is critical in ensuring the operational safety and longevity of aerospace and mechanical components. In this study, a comprehensive methodology is developed that integrates finite element analysis (FEA) with machine learning techniques to identify the presence of cracks in aircraft wing-like structures. Using SolidWorks, detailed 3D models of healthy and cracked wing geometries are created and subjected to modal analysis in ANSYS to extract key vibration parameters such as natural frequencies and mode shapes. These parameters, which change subtly in response to structural degradation, serve as the primary features for AI model training. A supervised learning algorithm is then employed to distinguish between healthy and damaged states based on this frequency response data. The approach demonstrates promising accuracy in classifying cracked versus uncracked scenarios, showing potential for non-invasive structural health monitoring. This research develops a simulation-driven AI methodology for crack detection, providing a foundation for a future digital twin framework and enabling further exploration of predictive maintenance strategies in aerospace structures.

Paper ID: 272

LIGHTWEIGHT CLASSICAL MACHINE LEARNING FOR EDGE-READY BEARING FAULT DIAGNOSIS: A COMPARITIVE ANALYSIS OF RANDOM FOREST AND SVM ON STATISTICAL FEATURES

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A robust and lightweight machine learning pipeline is developed for bearing fault classification using high-resolution vibration data from the Case Western Reserve University dataset. Focusing on the 0 HP no-load condition and leveraging 48 kHz Drive End accelerometer signals, raw vibration data is segmented into overlapping windows and transformed into a compact set of handcrafted statistical and frequency-domain features. Two classical classifiers Random Forest and Support Vector Machine with an RBF kernel are evaluated on this feature space. With a classification accuracy of 98.5%, the Random Forest model outperforms the SVM in terms of both inference efficiency and prediction performance. Reliable detection across a range of fault kinds is confirmed by confusion matrices and classification reports. The findings highlight the usefulness of low-latency, interpretable models for real-time defect diagnosis and set the stage for further developments involving deep learning techniques, changing load scenarios, and embedded platform deployment.

Paper ID: 273

VARIATIONAL AUTOENCODER-BASED ANOMALY DETECTION IN VIBRATION SIGNALS FOR EARLY BEARING FAULT DIAGNOSTICS

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Reconstruction of bearing vibration signal using autoencoders is a powerful approach for anomaly detection and there by prediction of bearing faults. The proposed technique involves the use of variational autoencoder to encode and subsequently decode bearing vibration signal. After pre-processing of vibration data, a variational autoencoder architecture comprising of an encoder and a decoder is designed. The encoder reduces the dimensionality of the input signal to capture essential features, while the decoder aims to reconstruct the original signal from the compressed latent space representation. The objective of this work is to quantify the deviations of the reconstructed inner and outer race faulted bearing vibration signals with that of the healthy condition. The reconstruction error, indicative of the bearing's health enables fault detection. Through this approach, the deviations between the normal, inner and outer race faulted bearing vibrations have been determined using different types of auto-encoders, among which variational auto-encoder with an accuracy of 98% and threshold of .018 has shown its best performance for early anomaly detection. The approach allows for proactive maintenance and helps extend the operational life of bearings, making it suitable for real-time industrial settings where bearing failures can lead to costly downtime and damage.

Paper ID: 281

LATENT SPACE LEARNING FOR WIND TURBINE BLADE FAULT DIAGNOSIS USING 1D CONVOLUTIONAL VARIATIONAL AUTOENCODER

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This work presents a 1D Convolutional Variation Autoencoder (1D ConvVAE) for automated fault diagnosis of wind turbine blades using uniaxial vibration signals recorded under variable wind speed conditions. The model is trained on a benchmark dataset comprising five blade states including healthy, surface erosion, crack, mass imbalance and twist faults. Segmented and normalized vibration signals are encoded through convolutional layers into a low-dimensional latent space that facilitates both signal reconstruction and classification. A shared latent representation is used to reconstruct the input signal via a decoder while a parallel linear head performs fault classification. The network is optimized using a composite loss function that combines mean squared reconstruction error, Kullback--Leibler divergence for latent space regularization and cross-entropy loss for supervised classification. After 1000 training epochs, the model demonstrates strong capability in learning discriminative features directly from raw vibration data. Latent space visualization confirms clear separation between different fault types, emphasizing the model's interpretability and diagnostic accuracy. This approach is well suited for vibration-based condition monitoring in wind turbines and other rotating machinery applications where efficient representation learning and fault generalization are essential.

Paper ID: 282

Rapid and accurate "Life estimation" toolbox in MATLAB

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This research presents the development of a rapid and accurate MATLAB-based toolbox for life estimation of mechanical components subjected to cyclic loading. The methodology involves simulating stress distribution in a body without cracks under periodic loading, using a newly developed tool to evaluate stress intensity factors (SIF) in the presence of assumed flaws. The toolbox identifies cracks as elliptical, semi-elliptical, or quarter-elliptical based on where they are located and how close they are to the edge of the component. This classification allows the program to pick the correct method for calculating the stress intensity factor automatically. Computed SIFs are then integrated with Paris' law to estimate the number of cycles required for an initial flaw to grow and reach a critical size or the nearest edge, providing a practical life prediction for the component. The toolbox currently includes validated modules for three crack types and handles both constant and linearly varying loading conditions. The results confirm that the predicted stress intensity factors are highly consistent with both analytical calculations and finite element simulations performed in Abaqus for all tested crack geometries. This approach delivers a reliable and flexible solution for fracture analysis and lays the groundwork for future enhancement of the toolbox to accommodate additional crack shapes and more advanced loading conditions.

Paper ID: 285

Damping Characteristics of Auxetic Structures Made of Shape Memory Alloys

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Auxetic structures are class of structures that exhibits a negative Poisson's ratio and therefore, it undergoes lateral expansion when subjected to tension in longitudinal direction and lateral contraction under compression. Furthermore, the shape memory alloys (SMA) have also been proven to show better damping characteristics. The proposed work, investigates the combined effect of SMA based auxetic structures, particularly lozenge grid (LG), and to compare the damping characteristics of such structures with conventional auxetic structures. For the comparison, four different materials of uniform size plates are made: Nitinol (Ni45 Ti48), Mild Steel (MS), Stainless Steel 304 (UNS S30400), and Stainless Steel 316 (UNS S31600), among which Nitinol is SMA and others are conventional metals. A solid base plate (without the LG cut out) made of all four materials are also tested for the reference. The auxetic structures from these materials are fabricated using a laser cutting machine by considering optimized process parameters of the machine. The vibration response of the structures is captured using shaker testing rig by attaching two accelerometers. The frequency responses of the structures are compared and the damping factors are obtained using half power point method, which clearly demonstrates that auxetic structures possess good damping characteristics than solid plates made of the same material particularly at some specific modes and frequency ranges. As shown in the results section the damping factor is still enhanced when combined with NiTi which can be associated with superelastic property of the material.

Paper ID: 287

IMPACT OF STIFFNESS AND WEIGHT RATIO ON VIBRATION TRANSMISSION IN METALLIC PIPELINE COMPENSATORS

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When pipe systems are linked to pressure equipment such as boilers, pressure vessels, turbines, heat exchangers, and so on, the ends of movement compensators (bellows) may be exposed to fluid forces and different mounting weights. Pipe connections are less flexible than bellows connections. The vibrational behaviour is affected by end weights, mountings, and fluid forces. It is difficult to forecast resonance conditions. This work is focused on frequency analysis by securing one end and weighing the other. Natural frequency responses were studied using varied stiffness ratios (Tp) and weight ratios (1/α). For the first three vibration modes, Tp is 0.01 to 1.0 108 and 1/α is 0.1 to 1000. For 1/α > 100 and Tp > 103 , frequency response has no effect on higher modes. All three modes have more frequency responsiveness when Tp = 100 and 1/α

=0.1 to 1.0. Analytical (Timoshenko beam model) and experimental (FFT test) findings show that increasing weight lowers natural frequencies while increasing mode numbers enhances them. This study could assist for analysing and determining the flow-induced pipe vibrations and fluid-structure interactions (FSI) in given range of stiffness and weight ratio.

Paper ID: 294

INVESTIGATIONS ON RESONANCE EFFECT OF COMPENSATORS IN PIPING FOR VARYING END CONDITIONS

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Internal fluid pressures vary in most pipe constructions exposed to various important process equipment in power plants,
refineries, and numerous chemical and pharmaceutical industries. The U-shaped crowning bellows' flexibility, on the other hand, makes them vulnerable to induced dynamic changing membrane stresses caused by disruptions, internal fluid flow pressure, and external pressures. To maintain the structural integrity of the stress limits, it is necessary to identify the instability regions on the convolution surfaces in the bellows structure, which are causing the material to approach its yield limit due to various fluid factors. Bellows' flexibility is owing to their convoluted geometrical design, which renders them susceptible to vibration absorption. Internal or external pressure is induced by flow media in pipework or mechanical mechanisms. Metal bellows are used in situations where low amplitude and high frequency vibrations are desired. They, like reciprocating compressors, are not ideal for low frequency, large amplitude vibrations. In this paper, the effect of flexible convolution geometry on the frequencies generated by different boundary conditions in structures of varying stiffness is investigated. Fixedfree end, Fixed-Fixed, and Fixed-Fixed are the boundary conditions used in this study. One end is fixed (axially elastically constrained) while the other is connected to the weight. This is due to a variety of structural parts attached, such as flow control valve fittings, tie rods, hinge plates, anchors, and so on. As a result, the frequency and magnitude of mechanical external vibrations exerted on Expansion bellows must be predicted. It needs to be built to avoid resonance circumstances during fluid flow. For validation, a numerical simulation is run and the results are compared experimentally for the Fixed-Fixed end condition.

Paper ID: 296

MASS LOADING EFFECTS OF POLYMER COATING ON STRUCTURAL DYNAMICS AND ACOUSTIC RESPONSE OF THIN PLATES

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During acoustic testing of a thin-walled cylindrical structure of a launch vehicle, very high vibration responses were observed at multiple locations. This study investigates the effect of applying polymer (PC10) coating on structural vibration response. Comparative experiments were conducted on aluminium plates with and without PC10 coating, as well as with equivalent discrete masses to simulate the added mass of PC10. The added mass configuration was designed iteratively using Finite element analysis to ensure the stiffness of the plate is not affected. Acoustic excitation using white noise and impact hammer tests were employed to measure modal frequencies and damping. Results showed that while damping values remained largely unchanged, the PC10-coated plate and the plate with discrete masses both demonstrated nearly threefold reduction in grms levels compared to the bare plate. Finite element modelling validated the influence of mass distribution on modal characteristics. It is concluded that the observed reduction in vibration response with PC10 is primarily due to added mass rather than intrinsic damping properties. Further tests are required to generalize these findings across broader configurations and structures.

Paper ID: 300

ANALYTICAL AND NUMERICAL STUDY OF NOISE GENERATION FROM POWER LOOM BY CONSIDERING AS TWO MONOPOLES

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The sound pressure level (SPL) distribution in a power loom unit due to the noise generated by the reciprocating motion of the shuttle and its consequent impact is analysed in this paper. The investigation consists of field measurement, analytical method and numerical calculations. The loom is modelled as a set of two out-of-phase pulsating monopoles placed at its two extreme ends. Firstly, the sound powers of the monopoles for different octave frequencies are estimated from the measured SPL obtained using a sound level meter. These frequency dependent source powers, along with the room acoustic parameters, are used in the analytical method used to estimate the SPL due to a single monopole source in a free-field environment. It is compared with that obtained from the numerical method using COMSOL Multiphysics software. The simulation is then extended to the power loom model with two monopoles in an actual environment (with doors and windows opened) and the results (SPL) are validated with that estimated from the analytical method. Effects of sound absorption due to the walls, floor and roof materials are also studied. The main objective of the present work is to see the accuracy of the proposed two-monopole (out of phase) model in numerically estimating the SPL generated by a power loom. The proposed model can be used in estimating the optimal number of looms that can be accommodated in a given industrial space which causes minimum occupational noise level and provides maximum safety and comfort to the workers in power loom industries.

Paper ID: 301

Multi-DoF Model-Based Condition Monitoring of High-Speed Ball Bearings

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This paper presents a modelling and condition monitoring of ball bearings, emphasising on a high-fidelity mathematical model that incorporates five degrees of freedom in the bearing system. Unlike traditional models that typically limit analysis to two or three degrees of freedom, the suggested model includes axial, radial, and angular motions, thereby facilitating a more precise depiction of dynamic behaviour under operating conditions. The model rigorously incorporates high-speed rotating effects, including centrifugal forces, gyroscopic moments, and spin-induced instabilities, to accurately represent practical industrial applications. The equations of motion are formulated by incorporating time-dependent stiffness, nonlinear damping, and excitations caused by defects. Localised defects are introduced at the inner and outer races to evaluate their impact on typical vibration signatures across different speed regimes. This advanced model defect identification sensitivity offers a greater understanding of fault development in high-speed machinery.
Keywords: Vibration Analysis, Condition monitoring, Ball Bearings, High-speed effects, Mathematical modelling, Bearing defects, Fault diagnosis.

Paper ID: 303

SEVERITY DETECTION OF BONE FRACTURE THROUGH NON-INVASIVE SHOCK RESPONSE SPECTRUM ANALYSIS: EX VIVO STUDY

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This article presents a non-invasive, vibration-based shock response spectrum method to identify severity of fracture in bone. This method provides an alternative to radiation-based diagnostic methods, which are safer and simple to identify structure integrity. In this study, three goat metacarpal bones were collected from a local slaughterhouse and cleaned using formaldehyde solution: (1) Unfractured bone (B1) (2) Bone with lateral fracture (B2), and (3) Bone with longitudinal fracture (B3). Controlled artificial cracks were introduced on the external surface of specimens B2 and B3 bones. An acceleration sensor, an impact hammer and a data acquisition system were used to excite specimens and collect their vibrational data. The reference bone (B1) indicates that SRS peak at 655 Hz with an acceleration of 7.37 g, serving as baseline. The laterally fractured bone (B2) identifies a peak frequency of 831 Hz (26.87 % higher than B1) and an acceleration of 15.15 g (105.56 % higher than B1), indicating reduced stiffness and damping. In contrast, the longitudinal fractured bone (B3) identified a peak frequency of 867 Hz (32.37 % higher than B1) and moderate higher acceleration of 9.15 g (24.15 % greater than B1). The response showed multiple irregular peaks and troughs, reflecting disrupted energy transmission. These results clearly identify that laterally fractured bone found with most severe condition compared with longitudinal fractured bone. The study validates shock response spectrum analysis as alternative vibration-based method for non-invasive bone fracture assessment.

Paper ID: 305

IoT Based Vibrational Monitoring System For Predictive Maintainance of Industrial Equipment

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In industrial systems, predictive maintenance is essential for lowering operating expenses and downtime. Using the NASA C-MAPSS (Commercial Modular Aero-Propulsion System Simulation) dataset, this project suggests a hybrid deep learning model that combines Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks to improve remaining useful life (RUL) prediction for aircraft engines. While LSTMs capture temporal relationships and increase prediction accuracy over conventional single-model approaches, CNNs are used to extract spatial characteristics from sensor data. The CMAPSS sub-datasets (FD001-FD004) are used to train and validate the hybrid architecture, and performance metrics including Score Function and Root Mean Square Error (RMSE) are employed for assessment. The CNN-LSTM hybrid model works better than standalone CNN or LSTM models, according to experimental results, and achieves higher accuracy in RUL estimation.

Paper ID: 309

Dynamic Analysis of the Rotor Shaft in a Centrifugal Pump for Fighter Aircraft applications

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This study provides a thorough rotor dynamic assessment for the purpose of validating the design of an indigenous centrifugal pump rotor shaft intended for fighter aircraft applications. The pump is essential for ensuring the delivery of the correct fuel quantity at the appropriate pressure from the fuel feeder tank to the engine. This function is essential under diverse flight conditions, including altitude variations, abrupt acceleration or deceleration, and inverted maneuvers. The primary goal of the analysis is to assess the vibrational characteristics, pinpoint critical speeds and mode shapes, and confirm structural integrity. Along with this, a stack-up analysis for clearance calculation of the rotor during high-speed operations is performed, considering suitable bearing stiffness and damping coefficients. The finite element analysis was performed with the commercial software ANSYS to simulate the rotor system, including material characteristics, boundary conditions, and the effects of operational loading. The Modal, Harmonic response, and Space claim modules of ANSYS were employed for this investigation. This analysis focuses on calculating natural frequencies and mode shapes, as well as constructing the Campbell diagram to predict critical speeds and potential resonance conditions. The objective is to guarantee that the natural frequencies of the rotor shaft and pump are distinctly isolated from the operational frequency ranges. A parametric study was conducted to evaluate variations in parameters such as tolerances and design factors, including material deviations and machining errors. This analysis considers the worst-case deviations to predict the rotor shaft's critical speeds, which must be safely maintained beyond the operational range.

Paper ID: 318

Effect of Porosity and Geometrical Imperfection on Crack Propagation Analysis of S-FGM blade under Cyclic Cryogenic Thermal Shock

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The present research investigates the influence of porosity and geometric imperfections on the crack propagation analysis of a sigmoid functionally graded material (S-FGM) blade under cyclic cryogenic thermal shock using adaptive phase-field modeling. An adaptive phase-field method in conjunction with the finite element method is adopted to model the crack in the S-FGM blade. The front face of the blade, made of low-carbon steel, is exposed to cyclic thermal shock; however, the back metallic face, made of stainless steel, is maintained at a fixed cryogenic temperature. The material properties are assumed to be temperature-dependent and graded according to a power-law model across the height. The volume fraction of either constituent is estimated as per a sigmoid function. The results obtained are compared for a wide range of parameters to show the correctness of the present model. The thermal stress intensity factor is extracted using an energy method. Detailed numerical studies are conducted to investigate the effects of porosity and geometric imperfections on the thermal stress intensity factor.

Paper ID: 319

Auxetic Configuration-Based Blast Doors Panel: Numerical Investigation and Performance Characterization under Multiple Blast Loading Scenarios

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The blast door is a critical component of protective structures, often exposed to high-intensity shock waves and pressure loads. This research explores the use of auxetic-based structural panels for high-security applications such as bunkers, hospitals, embassies, banks, and military facilities, with the goal of enhancing blast resistance through advanced engineering design. Conventional blast doors, typically made of single-panel armored steel or sandwich constructions, frequently encounter limitations such as localized stress concentration, hinge failure, excessive weight, and reduced postblast operability. Moreover, flat-surfaced door designs tend to absorb rather than deflect blast waves, leading to significant structural deformation. In this study, auxetic geometries with a negative Poisson's ratio are integrated into a lightweight modular blast door system. Numerical simulations are performed to assess deformation behavior, energy absorption, and dynamic response under varying blast loads. Comparative analysis against conventional door systems demonstrates that the auxetic-based design reduces stress transfer, enhances energy dissipation, and improves operational reliability. The results highlight the potential of auxetic metamaterials to enable next-generation blast-resistant doors that are both resilient and efficient for critical infrastructure protection.

Paper ID: 321

DYNAMIC RESPONSE OF ELECTRICAL CONTROL PANELS UNDER WIND TURBINE VIBRATION

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Clean energy or renewable energy is need of any nation in the current environmental scenario. Indian power sector is also moving towards this sustainable approach. Wind energy is the major source of renewable energy in India after solar energy. In wind turbines, nacelle is the casing for generator, gearbox, and electrical control cabinet and other equipment. Nacelle is located at the top of the wind turbine tower. Electrical control panels mounted in nacelle are subjected to vibration generated due to heavy rotating machine and aerodynamic forces of turbines. Electrical control panels mounted in nacelle should be designed to withstand wind turbine vibrations. For vibration response analysis both mechanical integrity and functional capability of the electrical panels under vibration are important to determine its performance in the life time. In this study, dynamic response of electrical control panels under wind turbine vibration is discussed with case study. Electrical panels are subjected to site specific vibration levels and its vibration response and failure analysis is carried out for performance evaluation.

<u>Paper ID: 325</u>

Energy Harvesting from a Two Degrees-of-Freedom Vibratory System with Inertial Amplifier: Modeling, Analysis, and Biomedical Application

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This study presents a comprehensive mathematical modeling and performance analysis of energy harvesting from a two degrees-of-freedom (2-DOF) vibratory system, evaluated both with and without an inertial amplifier (IA), for potential biomedical applications. The work aims to enhance the efficiency of vibration-based power generation for implantable and wearable medical devices operating under low-frequency physiological motions such as heartbeat, respiration, and body movement. The coupled electromechanical system is formulated using second-order differential equations to capture both the mechanical and electrical dynamics. Frequency-domain analysis is performed to investigate the system's response and harvested power under harmonic base excitation representative of human-induced vibrations. Analytical solutions obtained through the harmonic balance method are validated using numerical simulations in MATLAB. The configuration without the inertial amplifier serves as a baseline to quantify the performance improvement achieved through IA integration. Results demonstrate that incorporating the IA leads to resonant frequency tuning, amplitude amplification, and bandwidth broadening, resulting in significantly enhanced harvested power across a wider low-frequency range. Parametric analysis identifies optimal design regions for maximizing power density while maintaining compactness suitable for biomedical deployment. The findings offer valuable insights for developing self-powered sensing and therapeutic systems capable of long-term operation without battery replacement in medical and healthcare applications.

Paper ID: 326

Multiphysics Simulation and Alt Reliability Assessment of PCB Copper Traces under Random Vibration Loading

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Printed Circuit Boards (PCBs) serve as the foundation of modern electronic systems, with their reliability being critically tested in high-vibration environments like automotive, aerospace, and industrial applications. The structural integrity of fine-pitch copper traces is particularly vulnerable to fatigue failure under random vibration loads. This study develops a Multiphysics simulation framework in COMSOL, integrating structural dynamics and fatigue modeling, to investigate the dynamic response and predict the fatigue life of PCB copper traces under accelerated random vibration conditions. The model quantifies key failure metrics, including stress distribution, plastic strain energy density, and cumulative damage, in accordance with Accelerated Life Testing (ALT) principles. The analysis identifies critical design parameters—specifically trace geometry, layout orientation, and substrate material properties—as dominant factors influencing vibration-induced fatigue resistance. This work provides a robust, simulation-driven methodology for prognosticating PCB reliability, offering a pathway to reduce reliance on costly physical testing and enabling the design of more resilient electronics for demanding applications.

Paper ID: 327

DYNAMIC ANALYSIS OF RE-ENTRANT AUXETIC HONEYCOMB STRUCTURES FOR IMPLEMENTATION IN HELMET LINER

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Re-entrant auxetic honeycomb structures, characterized by their negative Poisson's ratio, offer significant promise as advanced helmet liner materials due to their exceptional energy and impact absorption capabilities. This paper describes the computational investigation for re-entrant auxetic honeycomb structure, as a liner for a helmet. Using a foam liner model with PLA being chosen as the material, dynamic analysis is performed within ANSYS Mechanical, employing transient structural analysis to capture the time-dependent response of the liner under impact loading. A comprehensive parametric study is undertaken, systematically varying the strut thickness, and re-entrant angle in the honeycomb geometry to assess their influence on energy absorption

and stress distribution. Finite element analysis (FEA) is performed for each configuration, focusing on key parameters such as impact energy absorption, and stress transmission. The findings demonstrate effective force distribution and impact mitigation with the PLA-based re-entrant honeycomb liner, indicating the suitability of this design for enhanced helmet protection.

Paper ID: 328

Optimization of Geometric Parameters and Vibration Characteristics of Strip Plates

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The dynamic stability of machine tool systems plays a crucial role in ensuring the precision and reliability of micro-machining processes, as even minor vibrations can significantly affect surface quality and dimensional accuracy. This study utilised ANSYS 2025 R2 to conduct a systematic modal analysis of a mild steel plate used as the load-bearing element in a micro-machining setup. This finite element modelling endeavour encompassed the design of three distinct plate types: single-strip, double-strip and without strip plate. Establish rigid boundary conditions at eight through-holes and implement gravitational force while ensuring the spindle remains stationary. To improve the stiffness-to-mass ratio and reduce the likelihood of structural vibrations, geometric optimisation was investigated as well. The Multi-Objective Genetic Algorithm (MOGA) approach in ANSYS was used to optimise the geometric parameter. The aim was to maximise the natural frequency and minimise the deformation amplitude. The findings indicate that the single-strip plate exhibits elevated natural frequencies, suggesting increased stiffness; however, it is more susceptible to bending in specific modes. The double-strip plate exhibits marginally reduced frequencies while effectively distributing vibrational energy, minimising localised stresses, and enhancing the stability of the system during motion. Adjusting the geometric parameters demonstrated once more that the dimensions of the plate and the placement of the reinforcement significantly influence both the frequency response and the deformation amplitude. The double-strip layout is widely regarded as the most effective design for maintaining structural stability and minimising vibrations. The findings indicate that altering the design of machine tool plates can significantly enhance their ability to withstand vibration.

Paper ID: 329

INTEGRATED THERMODYNAMIC AND VIBRATION ANALYSIS OF MICRO TURBINES FOR AEROSPACE APPLICATIONS USING MATLAB

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Micro turbines are increasingly being adopted in aerospace applications due to their compact design, high power to weight ratio, and suitability for unmanned aerial vehicles (UAVs) and auxiliary power systems. The study aims to develop an integrated MATLAB based framework for analyzing both thermodynamic and vibration characteristics of micro turbines used in aerospace applications. The objective is to establish the relationship between cycle performance and structural stability to support reliable design of small scale jet engines. A Brayton cycle model was implemented in MATLAB to compute key performance parameters such as thrust, efficiency, and specific fuel consumption across varying pressure ratios and turbine inlet temperatures. In parallel, a rotor dynamic model was developed to simulate critical speeds, unbalance responses, and Campbell-style frequency characteristics using vibration equations. Simulation outcomes indicate that turbine efficiency and thrust are highly sensitive to pressure ratio, while rotor stiffness and unbalance mass significantly influence vibration amplitudes and operating stability. The combined analysis demonstrates that thermodynamic and structural behaviors are interdependent. The developed MATLAB framework provides a simple yet powerful platform for preliminary micro turbine design and optimization. The integrated approach enhances understanding of performance & stability interactions, supporting improved reliability and design accuracy in aerospace propulsion systems.

Paper ID: 331

Dynamic Shock Absorption Behavior of Closed-Cell Metallic Foams and Glass Fiber Composites: A Shock Tube Experimental Study

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In this study, a 4 m shock tube was used to inspect the shock absorption behavior of closed-cell metallic foams under dynamic shock loading at Mach 1.56 and 1.77. Three aluminum foam (AF) samples with densities of 0.69, 0.66, and 0.63 g/cc were tested. Experiments were conducted in two phases: (i) high-pressure shock loading on bare foam samples and a no-foam condition for comparison, and (ii) testing composite configurations – Foam + Glass fiber reinforced polymer (GFRP), GFRP + Foam, and GFRP + Foam + GFRP – to assess shock attenuation efficiency. High-density foams effectively limited the maximum pressure rise and diffused the shock wave, leading to attenuated propagation. The AF_01 sample (73.4% porosity, 0.266 relative density) showed a 16.10% reduction in reflected shock pressure and 42.27% reduction in peak pressure. The AF_03 sample (75.4% porosity, 0.246 relative density) achieved the highest reductions – 26.76% in reflected pressure and 34.40% in peak pressure. An anomaly was observed in the AF_02 sample, possibly due to microstructural defects affecting its performance. Composite sandwich structures exhibited superior load-reducing performance, with lower pressure ratios than bare foams. Among these, the GFRP + Foam + GFRP arrangement most effectively minimized pressure rise and delayed peak pressure, demonstrating enhanced shock absorption. Overall, the study confirms that closed-cell metallic foams, particularly in sandwich configurations, provide significant attenuation of dynamic loads, making them promising materials for aerospace, defense, and automotive applications requiring efficient shock mitigation.

Paper ID: 332

Design and Development of a Shape Memory Alloy Wire Actuated Active Morphing Airfoil

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This study presents the design, fabrication, and experimental validation of a Shape Memory Alloy (SMA) wire–actuated morphing airfoil based on the NACA 4421 profile. The system enables continuous camber variation through trailing-edge deflection using an antagonistic arrangement of SMA wire as actuators. A functional prototype is fabricated to understand the challenges and assess both static and dynamic performances. Primarily the trailing-edge deflection of the airfoil, while the SMA wires are alternately activated, is quantified in absence of aerodynamic forces and is found to be around 10% of the camber in both directions. Its aerodynamic performance is measured through a subsonic wind tunnel test at free-stream velocities of up to 12 m/s. Substantial improvement in aerodynamic efficiency is observed. Results confirm that SMA-based actuation provides smooth, controllable, and energy-efficient morphing suitable for low-speed UAV applications.

Paper ID: 336

Active Control of Rotor Vibrations Due to Parallel Type of Misalignment in an Induction Motor with Built-in Bridge Configured Force Actuator

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This study investigates the force-current relationship in a three-phase induction motor featuring a novel bridge-configured force actuator within its stator. Unlike conventional induction motors, this specialized design can generate controllable dynamic forces alongside torque for motion transmission. An analytical model is developed to describe the force production mechanism, with validation provided through both finite element method (FEM) simulations and experimental measurements. The actuator's unique winding arrangement enables directional force generation, though direct measurement remains challenging due to the absence of suitable force sensors. To overcome this limitation, the research employs FEM-based analysis combined with phased current excitation. By sequentially energizing individual phases, the study determines both the magnitude and direction of resultant forces arising from the interaction between phase currents and the actuator's specialized winding configuration. Furthermore, the rotor dynamics are integrated with an electrodynamic model, enabling formulation of force-displacement characteristics through FEM analysis and experimental verification. Results confirm that the induction motor generates measurable forces when energized, demonstrating the feasibility of this integrated force-actuator design. The findings provide valuable insights for applications requiring combined torque and controlled force generation in electric drive systems.
Keywords: Induction motor, force actuator, bridge configuration, force-current relationship, finite element analysis, electrodynamic modelling, smart actuators, etc.

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