Modern Practice in Stress & Vibration Analysis

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Dear Delegates,

Welcome to the 2022 Modern Practice in Stress and Vibration Analysis conference. It is my privilege and great pleasure on behalf of the Applied Mechanics group of the Institute of Physics to welcome you.

The International Conference on Modern Practice in Stress and Vibration Analysis (MPSVA 2022) is the 10th conference in this series with the first event held in Liverpool in 1989.

In this conference we aim to bring together physicists, mathematicians, materials scientists, and engineers from academia and industry, and to provide a platform for the presentation of creative and novel research findings facilitating an interchange of ideas and providing guidance for future research direction. The scope of the conference is broad and covers the full range of fundamental, experimental and applied research in stress and vibration analysis.

We have a series of exciting keynote speakers, Professor John Mottershead, Alexander Elder Professor in Applied Mechanics at the University of Liverpool, Professor David Hills, from our host University, the University of Oxford and Professor Beverley Inkson from the University of Sheffield.

And for the first time – we have the winners of our Early Career Researchers prize Adolphus Lye, from the University of Liverpool and Alessandra Vizzaccaro from the University of Bristol. These researchers have made outstanding contributions in their careers so far.

And since as scientists and engineers we look to solve the challenges currently facing our planet with innovative solutions and technologies we are delighted to hear from, for the first time industry partners Adrian Jones from Rolls Royce and Mauro Caresta from Schlumberger to tell us about industrial challenges in stress and vibration.

All this alongside hearing about your work and your recent research successes promises I hope you will agree to set the scene for a fascinating and exciting event.

Carol Featherston

Chair MPSVA conference

Chair Applied Mechanics Group

We are grateful for the help of the minisymposium organisers for helping us coordinate this exciting MPSVA programme, the Applied Mechanics Group Committee, the local organising committee and the IoP conference team.

The first Modern Practice Conference was held in Liverpool in 1989: What have we learnt sine then?

John Mottershead

University of Liverpool, UK

The presentation will cover selected achievements within the modal vibrations domain. With reference to basic principles and in line with the modern-practice theme of the conference, emphasis will be placed on applications close to practical application in industry. Topics covered will include the following:

1. Modal testing of Civil Engineering structures, particularly methods based on output-only (ambient-excitation) techniques, which fall into broadly two classes: (i) those based on conventional system identification techniques including the fitting of a modal model and the application of stabilisation diagrams; and (ii) and those based on Bayesian inference.
2. Camera-based optical techniques by point-tracking and digital image correlation (DIC), which enable the acquisition of full-field operational modes. Advantages of using the frequency domain (noise spreading) and the condensation of large volumes of highly redundant data will be considered.
3. Receptance-based modelling of structures composed of multiple components and the blocked-force method in transfer path analysis (TPA) when external forces are difficult (or impossible) to measure directly. The measurement of not only translational, but also rotational receptances (rotational displacement/applied moment) is generally required.
4. Finite element model updating (also known as FE model calibration) based on local eigendata sensitivity, now in widespread use in the aerospace and automotive industries. Regularisation of ill-posed systems and well-established validation procedures help to provide confidence in the updated model. More recent Bayesian techniques provide a formal quantification of uncertainty in model updating.
5. Active vibration control using receptances, typically from a modal test, offers an alternative to classical state-space methods, with the advantage that there is no need to know or to determine the M, C, K system matrices. Recent developments include minimum norm and H_2 (minimum control energy) formulations.

Brief comments will be made on future scientific research opportunities for the modal vibrations community.

Influence of Contact and Friction on Vibration Assessments in Gas Turbines

Adrian Jones

Rolls-Royce, UK

One of the main failure modes to be avoided in Gas Turbine component design is high cycle fatigue (HCF) and contact fatigue. The stresses and strains that cause HCF are due to vibration of the component, as a result of excitation forces that occur within an engine or as a result of component flutter. The assessment of a design's HCF integrity requires knowledge of the levels of vibration, which is based on the level of excitation and damping within the system, which affects the non-linear behaviour. The drive for ever higher product efficiency is increasing the Mechanical difficulty in designing Gas Turbine components, with the need for weight reduction, higher temperatures and increased time on wing. With current tools and methods, designs are becoming constrained by existing criteria, and higher fidelity analytical tools in determining dynamic contact behaviour are needed to improve optimisation and assess robustness.

The impact of dynamic contact and friction behaviour in Gas Turbines are seen in a range of areas, including high loaded contacts and non-linear damping. Being able to more accurately model contact interfaces, will allow the generation of improved and efficient designs capable of operating safely for the full design life of the component. This keynote covers some of the key areas in Gas Turbine design where an improved understanding is required, and the impact in service, along with current areas of research.

The costs and time delays associated with dynamic issues can be extreme. From the need to re-run strain gauge tests, up to in service issues, the costs range from £millions to £billions, highlighting the need for accurate predictions to prevent such problems. There are other substantial benefits that can be derived from the ability to accurately predict non-linear contact and friction behaviour.

Current Challenges to Improve Reliability of Downhole Drilling Equipment

Mauro Caresta

Schlumberger Cambridge Research, UK

In recent years there has been a substantial increase in the rate of penetration in drilling operations with the aim of reducing costs. This has aggravated the already challenging downhole environment which is characterized by severe shocks and vibrations, the main cause of both mechanical and electronics failures. One of the main causes of fatigue failures are high frequency torsional oscillations (HFTO) which are self-excited because of the frictional interaction of the drillstring and the bit with the borehole. On the other hand, electronics failures seem to be more related to local amplifications inside the tools. This talk will give an overview of these two problems and will focus on nonlinear dynamics.

An investigation towards the Uncertainty Model calibration approaches for NASA-Langley UQ Challenge 2019

Adolphus Lye[1], Alice Cicirello[2], and Edoardo Patelli[3]

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The paper presents a series of follow-up analysis from the recent NASA-Langley Uncertainty Quantification Challenge 2019. In this research, 4 alternative Uncertainty Models are being proposed to investigate the following factors which contribute to the lowest degree of uncertainty over the aleatory and epistemic uncertain model parameters: 1) the choice of distribution of the aleatory model parameters; 2) the choice of the stochastic distance metric within the likelihood function to model the data variability; and 3) the choice of data type used within the likelihood function for the Bayesian model updating approach. To model the distribution of the aleatory model parameters, 2 distribution functions are considered: Beta vs Staircase Density Function. To quantify the variability of the input data used for model calibration, 2 types of stochastic distances are considered: Wasserstein's distance vs Bhattacharyya's distance. For the input data used for model calibration, 2 data types are considered: Time-domain vs Frequency domain. Based on the results, it was found that the Uncertainty Model incorporating the Beta distribution to model the aleatory model parameters, the Bhattacharyya's distance as the stochastic metric, and the time-based data as the input data, yielded P-box estimates of the aleatory distribution and probabilistic estimates of the epistemic model parameters with the lowest degree of uncertainty

Probabilistic surrogate modelling for real-time structural health monitoring: application to Neath Swing Bridge

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Cardiff University, UK

Structural health monitoring (SHM) requires a complex data acquisition and structural analysis process especially for the historical structures with more than 100 years history where complete information about the material and geometric properties are limited, and the structure is suffering accumulative degradation and damage due to operational and environmental conditions. Traditional bridge inspection is presently undertaken manually which is intrusive, time consuming and poses health and safety risks associated with working around live infrastructure assets. Additionally, such a method is not able to capture the exact structural degradation and there are significant uncertainties associated with this. As a result, many simplifications and assumptions have to be made during structural analysis leading to inaccurate simulation which potentially be detrimental for bridge maintenance. On the other hand, as the structure is dynamically evolving over its operational lifetime, capturing real-time structural performance with traditional method is challenging. Machine learning methods offer a highly efficient way of mapping performance data to the structural properties which allow structural monitoring to happen in real-time. This paper presents a novel method using probabilistic surrogate modelling techniques, like Gaussian process, to map the structure's vibration response to damage/degradation parameters. The Latin hypercube sampling is adopted to generate the samples and is fed into the finite element analysis to form a structural response database. With such a method, the uncertainties of the bridge can be efficiently displayed and resolved by calibrating the vibration sensors installed on the bridge. The machine learning surrogate model can therefore provide an accurate and nearly real-time structural analysis for vibration based SHM.

Keywords: Structural health monitoring, machine learning, vibration, structural analysis, gaussian process regression

Population-based wind farm monitoring based on a spatial autoregressive approach

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An important challenge faced by wind farm operators is to reduce operation and maintenance cost. Structural health monitoring provides a means of cost reduction through minimising unnecessary maintenance trips as well as prolonging turbine service life. Population-based structural health monitoring can further reduce the cost of health monitoring system by implementing one system for multiple structures (i.e. turbines). At the same time, shared data within a population of structures may improve the predictions of structural behaviour. To monitor turbine performance at a population/farm level, an important initial step is to construct a model that describes the behaviour of all turbines under normal conditions. This paper proposes a population-level model that explicitly captures the spatial and temporal correlations (between turbines) induced by the wake effect. The proposed model is a Gaussian process-based spatial autoregressive model, named here a GP-SPARX model. This approach is developed since (a) it reflects our physical understanding of the wake effect, and (b) it benefits from a stochastic data-based learner. A case study is provided to demonstrate the capability of the GP-SPARX model in capturing spatial and temporal variations as well as its potential applicability in a health monitoring system.

Stress Analysis of Bone Tissue Scaffolds Composed of Piezoelectric Materials

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The increase in life expectancy over the past few decades has been accompanied with an increase in age related disorders such as osteoporosis and higher risk of fractures, which has given rise to higher demand for mechanically and biologically reliable bone substitutes (Badilatti et al. 2015). Previous research has established the importance of scaffold geometry, and its influence on bone healing and regeneration (Zadpoor 2015). Due to high expenses of experimental testing and complexity of biological processes, achieving robust, consistent, and economic production of tissue scaffolds on an industrial scale is challenging. Computational modelling techniques are a strong tool for prediction and optimization of the mechanical behavior of tissue scaffolds (Olivares and Damien 2013). In this study, a series of geometries were designed with the Taguchi method in order to obtain the most optimal combination of process parameters. To assess the potential of the designs as bone substitutes, finite element analysis were carried out on polylactic acid (PLA) and polyvinylidine fluoride (PVDF) geometries to study their stress distribution after mechanical load application. Stress analysis results indicated that cylindrical and cubic constructs possess higher mechanical strength compared to pentagonal prism structures, and are hence more suitable for bone tissue engineering applications. The obtained results were within the acceptable range of stiffness reported in literature for trabecular bone (Hollinger et al. 2004).

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Finite element analysis of synthetic, functionally graded coronary artery grafts

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Coronary artery disease is the most prevalent cause of death worldwide, accounting for 32% of global fatalities in 2019[1]. Bypass surgery is the gold standard in modern clinical practice, with autologous, allogeneic, and synthetic grafts being the most commonly used conduits[2].

Due to hemodynamic stress, these grafts can cause complications such as an abnormal proliferation of cells known as intimal hyperplasia[3]. Furthermore, the mismatch between fabricated implants and host tissue is well documented. Both incidences can induce graft malfunction[4]. Additive manufacturing (AM) offers design flexibility when manufacturing patient-specific synthetic grafts. However, the performance of AM grafts has not yet been thoroughly investigated. Poly vinyl(alcohol) (PVA) cryogel is a versatile biomaterial that has been used to imitate arterial tissue and can bioprinted at sub-zero temperatures[5].

This research intends to design, validate, and prototype mechanically viable cardiovascular grafts to allow healthy endothelial mechanotransduction. This is accomplished through variation of biomaterial composition along the length of the graft wall, which is in contrast to geometric manipulation. PVA/gelatin grafts with varying axial spatial material properties are simulated using finite element analysis. The impact of this variation on transmural stress is subsequently analysed.

This method highlights the importance of functional grading in implant design. The proposed design technique is not specific to PVA or cardiovascular applications. In future, it could be used for designing functionally graded materials via AM.

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Patient-Specific Fluid-Solid Interaction Modelling of the Mitral Valve

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Introduction

Cardiac valve function depends on a delicate balance between haemodynamics and cardiac muscle motion. This study characterised the effects of papillary muscle and mitral valve annulus motion on the stress distribution of FSI patient-specific mitral valve (MV) models. Hypertension (hypMV), decellularization (decMV), augmentation (augMV) and chordae rapture (rctMV) were considered in parametric studies, with a view towards personalised cardiac models assisting in pre-operative planning and medical device design.

Materials and Methods

Computed tomography (CT) images of the native mitral valve apparatus were collected from a 65-year-old patient and pre-processed. Biaxial tensile data of fresh and decellularised porcine samples were fitted to the Puso-Weiss transversely isotropic model. Valves were embedded in a cylindrical fluid domain with physiological atrioventricular pressure at the boundary. Six FSI models were created, in LS-DYNA (Ansys), using the partitioned approach; fixed mitral valve apparatus (fMV), prescribed motion of apparatus (pmMV) and four parametric studies. Anterior/posterior leaflet landmarks; edge and belly and chordae were used for stress/strain comparison.

Results

The fMV anterior leaflet appeared more billowed during valve closure compared to the pmMV. Anterior leaflet edge, belly and chordae stress decreased (3.5%,4% and 9% respectively) for the pmMV model and increased for the posterior leaflet (24%,3.5% and 6% respectively) indicating redistribution of stress. hypMV resulted in 7-9% increased stress in both leaflets, whilst decMV a maximum increase of 21% compared to the fMV model. rctMV led to an increase in proximal chordae stress and a redistribution of leaflet stress and augMV, to 255% increase in the augmented region stress compared to the fMV.

Conclusion

Cardiac motion and haemodynamics affect mitral valve function by redistributing stress, while chemical treatment and surgical repair affect mechanical properties leading to high-stress concentrations. Accounting for these parameters can improve patient-specific model accuracy and allow for improvements in mitral valve implant design.

A two-level framework for model reduction and stochastic updating of a dynamic system

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The paper will present a two-level framework for stochastic model updating. This becomes necessary due to the extended use of composite materials in aircraft structures that lead to unexpected dynamic behaviours of assembled structures. Moreover, their dynamic response is probabilistic because the behaviour of their interfaces is intrinsically uncertain. However, many industries continue to rely on linear and deterministic design methods that may not correctly describe the dynamic behaviour of the real-world system. The probabilistic approach of the framework brings the advantage of providing a measure of confidence in the updated model.

The framework consists of two levels (Figure 1). The first level is based on global sensitivity, with indices computed using the polynomial chaos expansion. The first level aims to reduce the number of inputs and select the parameters to update, which is a significant issue to overcome in all model updating schemes. The global sensitivities application requires an accurate choice of the quantities of interest (measurable outputs – eigenvalues of the system) and a critical evaluation of the results.

In the second level, the reduced-order metamodel is built based on the inputs selected from the global sensitivity analysis. The unselected parameters are considered deterministic and are assigned nominal values. Then using the reduced-order metamodel, the correlation between the experimental data and analytical model is improved. The Bayesian model updating is applied; it is probabilistic and based on Bayes' rule. The outputs (posterior distribution) are probability distributions in the space of the selected parameters. Its application makes use of an algorithm that applies the Markov chain Monte Carlo method. The posterior distributions, obtained with kernel smoothing, describe the uncertainties of the updated parameters

Cyclical VBMC for multi-stage damage detection

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In engineering, it is common to find structures that are composed of structural elements coupled together in such a manner that some of their elements cannot be directly observed. However, changes/damages on those inaccessible elements may compromise the overall performance of the structure, causing unexpected failure during operating conditions. The layout of these structures introduces a limited availability of the number of observations that may be taken from them, their locations, and the time periods between those observations. In some cases, during an observation period, two different states of damage might occur. This implies two different periods with different values of modal parameters and associated physical parameters. Therefore, a method able to account for a multi-modal distribution on the physical parameters is required.

In this paper, the cyclical Variational Bayesian Monte Carlo (cyclical VBMC) method [1] is compared with the Transitional Ensemble Markov Chain Monte Carlo (TEMCMC) [2] for the purpose of dealing with multi-modal statistical model updating problems for damage detection. This method produces a non-parametric estimation of the posterior distribution of the identified parameters.

A simplified model of a coupled beam system modelled by two beams connected using translational, rotational and shear spring is investigated. From data of this model, a simulated case where the modal parameters are calculated for two different states in an observation period is created. The rotational and shear spring stiffnesses of the model are decreased, so changes in the modal parameters occur.

Results from the cyclical VBMC algorithm and the TEMCMC algorithm are compared, and it is shown that less runs of the model are required compared to state-of-the-art sampling method TEMCMC. The superiority of the proposed VBCM algorithm over TEMCMC for producing an accurate resulting posterior in multimodal problems is also shown.

A physics-enhanced Gaussian process for the quantification of localised nonlinearities in structures

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Nonlinear dynamic phenomena are encountered in a wide range of engineering structures under operating conditions. The unpredicted nonlinear behaviour of a system can lead to undesired phenomena such as noise or excessive oscillations, or even to serious consequences, e.g. a reduction of the fatigue life and unexpected failures. Nonetheless, despite the ongoing research efforts, the development of efficient monitoring strategies for nonlinear structures is still hindered by the difficulties related to the modelling and identification of nonlinear systems.

This contribution presents an approach for quantifying the parameters of a localised nonlinearity in dynamic structural systems without direct measurements of the nonlinear element. This approach enhances the applicability of monitoring strategies to the characterisation of contact properties by accounting for the misfit between the data and the physics-based model under limited information. In particular, the parameters of the nonlinearity are estimated by combining of a physics-based Gaussian process (GP) with a zero-mean measurements-driven GP and a noise term. The proposed approach is applied to numerical case-study involving a randomly excited multi-degree of freedom system with a frictional contact, showing a very good accuracy. Furthermore, it is shown how the addition of physics-based knowledge of the nonlinear system to data-driven models can lead to significant improvement in the prediction of the dynamic response.

Bayesian data-driven learning of vector-valued functions with invariant kernels

David Walton, Abhishek Kundu, Carol Featherston, and David Kennedy

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Data-driven learning in the context of design under uncertainty is associated with the challenge of creating optimal high-dimensional maps of input parameters to vector-valued output quantities. This work focuses on an approach of compressing multi-output vector and modelling it within a Bayesian framework. Three models are compared, a brute force learning of all output vectors, learning of reduced dimensioned approximation of the vector-valued output, and a compressed model with log standardisation applied. Gaussian process regression with a squared exponential kernel function is used to learn the maps. Compression is applied using principal component analysis. Log transformation of the data is applied to reduce bias in the PCA. Both the compression and standardisation introduce uncertainty which is quantified and propagated through the models along with the mixed uncertainty of the vector-valued output. The data-driven learning is performed with a practical high-dimensional industrial problem aimed at a specifically parametrized aircraft wing configuration. The input is made up of ten parameters over 201 uniformly distributed design of experiment points. The targets are the responses at points along the wingspan when it experiences prescribed loading conditions producing an 8556 dimensioned vector-valued output. It is found that the compressed model can reduce computational expense by up to 98% while incurring an increase of 5% in the relative error compared to the brute force and standardised model, where the relative error is of the order $\times 10^{-4}$. The use of an isotropic kernel enables the creation of response surfaces for input parameters of interest while retaining information on the predictive uncertainty at every sampled point in the surface, this is important as this framework lays the foundation for further work into design optimisation under uncertainty. The methods used here are not dependent on demonstration application and can be applied to any high dimensional machine learning task.

Explainable and Interpretable Machine Learning for problems in Applied Mechanics

Alice Cicirello

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The past 20 years have seen the widespread use of machine learning based techniques in applied mechanics to learn from data, to reduce computational cost of expensive-to-evaluate physics-based models and to make predictions. However, two important characteristics of these approaches have been often overlooked: Interpretability and Explainability. While Interpretability focuses on how a prediction was made, and in particular if a human can understand how a prediction was made and why the model would succeed/fail, Explainability focuses on how the results are presented, and if they are presented in a format that is understandable by humans. Interpretability and Explainability are critical in engineering to support decision making because: (i) humans would trust more predictions made by an interpretable model, and (ii) critical decisions need to be presented in a format that is comprehensible by the decision maker. This contribution discusses how domain expertise and the availability of a causal model would enable one to move from accurate-but-wrong predictions, to explainable and interpretable inferences fully exploiting machine learning techniques in applied mechanics. In particular, two examples are presented

Keynote: Frictional Elastic Contacts– their taxonomy and properties - with application to Fretting

David Hills

University of Oxford, UK

In the absence of body forces, all components in any engineering assembly receive their loads *only* by contact with other components. There are actually only a very small number of geometric classes into which elastic contacts of all kinds can fall, and which will be defined. Each has its own kind of characteristic behaviour and, in particular, it's own kind of frictional response, and these vary quite considerably. In this talk I will try to bring out the different behaviour one can expect, and show what are often quite surprising effects. For example, if a 'square edged' block is pressed onto another piece of similar, flat-faced material, if the coefficient of friction exceeds about 0.4, no what how hard or in what way one pushes it along, the trailing edge will always separate, and may not be held in intimate contact. There are a number results of this general kind which one can establish, and which are not widely known, which will be discussed in a way which is accessible and of general interest.

Damped nonlinear modal analysis of complex aero-engine assembles with friction interfaces

Jie Yuan[1], Loic Salles[2], and Christoph Schwingshackl[3]

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Blased disk are regarded as one of the fundamental factors in aeroengines that determine the overall performance of both civil and military engines. It contributes to more than 30% of the overall weight of a gas turbine engine but also is critical on the efficiency and reliability of an aeroengine. Fan blade systems is known as the first stage of compressors providing over 60% thrust of modern jet engines. It consists of large metal or composite blades that are commonly attached to a disk via curved or straight dovetail roots. This design ensures easy assembly and safe load distribution, and also provides essential damping to the system that is critical to mitigate flutter and high cycle fatigue failures. It is still a computationally challenging task to accurately predict the damping levels from the dovetail joints. In this study, we will introduce an efficient method based the concept of damped nonlinear modes to obtain the nonlinear damping from the fan blade systems. Damped nonlinear modes is an extension of linear modes of a linear system, which can give an insight into the response of a nonlinear system such as energy dependent damping. The damped nonlinear modal analysis can be effectively performed using harmonic balance methods with numerical continuation techniques. In this study, we have applied this method to two case studies: the first one is an industrial-scale finite element fan blade system with dovetail joints and the second one is a high fidelity finite element model of "Dogbone" test rig for fan blade systems. The obtained nonlinear dynamic behaviours from damped nonlinear modal analysis are validated against the directly computed forced frequency functions. A parametric study is also carried out to assess the influence of the contact parameters on the damping of the fan blade systems

Low interference clamping of aero-engine blades for dynamic testing

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A turbine blade consists of a streamlined aerofoil and the blade root. The root is designed such that it can be inserted into a similar yet marginally bigger slot on the disk. The most common root designs include dovetail and firtree roots, where friction affects the blade dynamics. To predict correct amplitude under dynamic loads, we need to measure the damping that comes from the friction on blade root, which is achieved by dynamic testing of blades under realistic conditions.

During normal engine operation, turbine blades are fixed to their discs by centrifugal forces. In the case of rotating tests, this is automatically provided and purely depends on the rotational speed. Unfortunately, rotating tests can lead to many other challenges, and hence static tests are consequently widely used. However, if the root fixing is not carefully designed in an experiment, the dynamic characteristics of the blade can strongly be impacted by the clamp itself and deviate from its real operation, making the test results less relevant. The particular challenge in the static blade root testing is the recreation of realistic blade root loading conditions, without the introduction of significant levels of parasitic stiffness or damping via the loading system.

This work presents the analysis of a novel loading system design to apply the centrifugal loads with minimum dynamical interaction. Initially, several loading systems were considered and the most successful one was selected. To determine the expected nonlinear dynamic response, the blade was modelled using FORSE (FOrced Response SuitE) to ensure reliable operation. This included: i) linear blade and holding block dynamics; ii) nonlinear friction between the blade and the slot; and iii) the loading system dynamics. Using the nonlinear nonlinear model, a loading system was designed that is expected to have a minimum impact on the damping and natural frequencies.

Developing an Approach for Predicting Friction Management Product Influence on the Wheel/Rail Contact

Roger Lewis[1], Klaus Six[2], Gerald Trummer[2], Alexander Meierhofer[2], and Zing Lee[3]

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Friction in the wheel/rail interface is critical to the safe and efficient operation of a railway network. Low friction due to leaf layers or the "wet-rail" phenomenon can cause safety issues and delays. High friction can lead to increased energy consumption and possibly accelerated wheel and rail damage.

Management of friction in the wheel/rail contact is achieved through application of different products either from wayside devices or systems onboard the train. For example, lubricants are applied at curves to reduce friction and wear; top-of-rail products are applied on the rail head or wheel tread to give an intermediate level of friction for reducing energy used; wheel and rail damage and suppressing noise and traction enhancers are applied to overcome low adhesion problems.

Monitoring friction in the actual wheel/rail interface is challenging, although new approaches are emerging, so the performance of friction management products is mainly based on small-scale laboratory studies. It is critical that the outcomes of these tests can be taken and applied in the context of field use of the products.

This presentation will give details of a framework for parameterising creep force models using small scale data on friction management product performance to enable predictions to be made for their behaviour in a full-scale contact. Validation approaches are also detailed based on the use of full-scale rigs, actual locomotives and measurements made on the rail head/gauge corner.

First steps in an investigation of physical effects during wheel-rail sanding

Klaus Six[1], Bettina Suhr[1], William Skipper[2], and Roger Lewis[2]

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Sanding systems are used to increase friction in the wheel-rail interface under low adhesion conditions caused, for example, by leaves or the “wet-rail phenomenon”. Although the positive effect of sand is proven, the underlying physical effects regarding the interaction of sand grains with wheel-rail surfaces and other contaminants are still not fully understood. In an on-going project funded by the Austrian Science Fund (FWF) these phenomena are now investigated in detail. Experimental investigations have been carried out at The University of Sheffield and the results will be used to develop, calibrate and validate models at Virtual Vehicle Research GmbH.

It is known that sand particles reaching the wheel-rail contact get crushed. After the first crushing – several centimeters in front of the contact patch due to the narrowing gap between wheel and rail – some of the resulting smaller particles are expelled from the running band, while others stay inside and get crushed again. Finally, some of them reach the contact, forming clusters of highly compacted powder which interact with the wheel-rail surfaces and positively affect adhesion.

In this project an attempt has been made to separate the relevant effects occurring in the contact region. In stage 1, effects during the initial breakage of sand grains are investigated on a UMT (Universal Mechanical Tester) machine where single sand grains are vertically loaded between two plates. The breakage forces are used to calculate Weibull statistics describing the relationship between particle stress and breakage probability. Additionally, the size and position of the smaller particles after breakage are investigated. Two different types of sand are tested under dry and wet conditions.

These stage 1 experiments provide valuable information regarding particle breakage and the amount of material which finally reaches the contact and is therefore important for understanding and modelling of the relevant effects.

High Performance Experimentation - Design of a spinning rig for study of combined LCF and HCF characteristics

Ibrahim Sever

Rolls-Royce, UK

As part of a High Performance Experimentation (HiPE) drive, a spinning rig that allows well-planned, intelligent testing that is representative of the actual physics and boundary conditions at play in operating conditions is designed. The HiPE rig combines LCF and HCF stress states to provide insights into dynamic behaviours for engine-representative conditions up to maximum operating speeds. With a full set of blades installed and instrumented on a full size civil large aircraft engine compressor drum under rotation, most significant sources of uncertainty are eliminated. In engine forcing characteristics and patterns are achieved via a distributed number of air jets. The position and the direction of the jets are adjusted based on the mode of interest with a range of intensities to generate the desired response amplitudes. The rig setup provisions integration of fast acting valves for generation of nonsynchronous excitations. A digital model of the rig facility is constructed to help with optimisation of test campaigns. The results produced provide gold standard evidence for validation of vibration simulation tools at system level as well as understanding of complex vibration phenomena that are not yet fully explored. With this capability, explorations that once required test-bed running with full engines, are possible in a controlled rig environment featuring only the stages of interest

Development and Application of Non-linear Friction Damping Analysis for Turbomachinery Blades and Vanes

Davendu Kulkarni

Rolls-Royce Plc, UK

The aeromechanical behaviour of turbomachinery blades and vanes are dependent on the total damping in the structure. The mechanical friction damping generated at various non-linear joints of blades and vanes forms a significant component of the total damping; however, it is difficult to accurately determine the damping magnitude and the system-level distribution. Moreover, the sensitivity and the scaling properties of friction damping are known to vary for each component and therefore, at present, friction damping cannot be robustly designed into a structure to control its aeromechanical behaviour.

In view of these challenges, this presentation provides an overview of the prediction and application aspects of friction damping to turbomachinery blades and vanes. Initially, the dependency and sensitivity of mechanical friction damping on various independent parameters are discussed using an example of a core compressor outlet guide vane (OGV). The study reveals the variation of friction damping with the combined variation of two independent parameters. Further, the integration of friction damping into the aeromechanical assessment of OGV is discussed.

Next, the presentation deliberates on the current friction damping assessment methodologies using an example of a compressor rotor blade. It uncovers a formulation developed to normalise the blade loading and the scaling of the predicted blade-root friction damping with friction coefficient, rotational speed and blade-root geometry. This methodology is developed to generate the characteristic curves of friction damping, which are useful to extrapolate the predicted damping to other engine operating conditions around the flight cycle.

Finally, the presentation elaborates on the friction damping validation studies, wherein the blade-root friction damping is predicted for multiple vibration modes of a real compressor rotor blade. These results are compared to the measured friction damping data obtained from a vacuum spin test rig. The presentation also provides a view on the future work.

Analysis of periodic nonlinear vibrations of structures considering heat generation by rubbing at friction contact interfaces

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The structures of gas-turbine engines and most of the other machinery are assembled structures having a multitude of friction contact interfaces. The forced response caused by a periodic excitation is often also periodic for such structures, even interaction forces at friction contact interfaces are significantly nonlinear. The friction damping is one of the major mechanisms of reducing the forced response levels, which is performed by the dissipation of the vibration energy in heat. The heat generated by the micro- or macro-slip motion at the contact interfaces can significantly change the temperature at contact interfaces and, therefore, the major friction contact parameters: friction coefficient and contact stiffness. The effect of heat generation at the contact interfaces is especially important when the contacting components have large relative motion between components: such as in rotating bladed disk-casing rubbing contacts and rubbing in rotor bearing and labyrinth seals.

In the paper, a methodology is developed for a coupled thermal and nonlinear structural dynamics analysis of structures with rubbing at contact interfaces. The methodology is based on the multiharmonic representation of the periodic structural vibrations, analytical formulation of the friction contact elements allowing large rubbing motion and evaluating the heat generation. The detailed finite element models are used for the description of the dynamic properties of the structure and the solution of the thermal conductivity problem required for the determination of the temperature at the contact interfaces.

Numerical examples of the application of the developed methodology are provided.

Investigation of fretting wear of misaligned spline couplings

Yuen-ling Kong

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Involute spline couplings are used for the transfer of torque between adjacent shafts with a high torque capacity, which are frequently used in gas-turbine aeroengines. Due to operating, manufacturing and assembly errors, spline couplings can become misaligned between the shaft and the sleeve, which causes small relative movement between the contacting tooth surfaces. This leads to fretting wear, which can reduce the functionality of the spline coupling and may mean that it needs to be replaced. Due to the expensive nature in cost and time associated with experimental testing, the understanding of fretting wear behaviour of misaligned spline couplings is limited. This talk will present the development of modelling methods to address this, which incorporate representative operating conditions and various spline geometries to create a tool to aid the design of spline couplings to minimise fretting wear. This involved a computationally efficient spline contact model to solve for the contact pressure distribution across each tooth under torsion and misalignment; a shaft bending model that considers shaft flexibility to calculate unknown misalignments; and a spline fretting wear model that determines the evolution of fretting wear under the gross slip regime according to the Archard wear relationship. The evolution of contact pressure distribution, unknown misalignments, reaction loads and wear distribution can be found for a representative number of cycles, where many cases can be compared to improve spline design. The talk will also cover progress on the development of an experimental facility designed to test misaligned spline couplings with the goal of validation/verification of the model and the assumptions therein, including the Archard wear relationship.

Discrete Element Modelling of Particle Entrainment in Wheel-Rail Interface Using an Open-Source

Sadaf Marami, and Sadegh Nadimi

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The traction between train wheel and rail plays a significant role in train kinematics. It influences the acceleration and deceleration of the train, and it poses safety issues for railway transportation when the traction is not sufficient. To increase the wheel-rail traction to an adequate level, rail-sanding has been employed in which sand particles are deposited on the rail ahead of the wheel. The efficiency of particle deposition (entrainment efficiency) dictates the value of rail-wheel traction and thus affects the risks of railway transportation [1-2].

Computational simulation of rail-sanding can be utilised to investigate and to find solutions for increasing the particle entrainment efficiency. In this work, DEM simulations of rail-sanding are performed for different values of sand particle size and velocity using the open-source DEM software MUSEN (version 1.71.5) [3]. Since the high fidelity CFD-DEM coupling has a high computational cost, the aim is to investigate if the DEM-only simulation can provide accurate data for particle entrainment efficiency.

The results of entrainment efficiency produced in this study are compared to the results of the coupled CFD-DEM simulations presented by Gautam and Green [4] (Figure-1). Numerical results show that such assumption is possible in some conditions, which reduces the computational cost of rail-sanding simulation. The reduction of computation resources foresees future larger-scale simulations with more realistic particle shapes and the presence of leaf contamination.

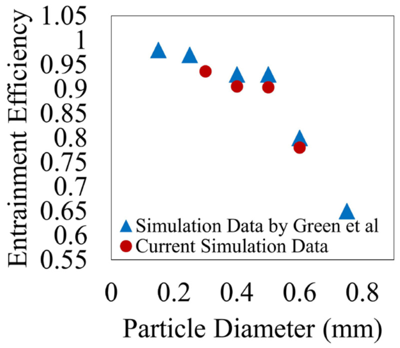

Figure-1 Particle entrainment efficiency versus particle diameter.

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Using the Extended Creep Force Model to Predict Full-Scale Sanded Creep Curves

William Skipper[1], Alexander Meierhofer[2], Anup Chalisey[3], Klaus Six[2], and Roger Lewis[1]

[1]University of Sheffield, UK, [2]Virtual Vehicle Research, UK, [3]Rail Safety and Standards Board UK

A newly developed method for assessing friction in the wheel/rail interface is the high pressure torsion (HPT) method. HPT data can be used to parameterise the extended creep force (ECF) model, which can then generate accurate predictions of full-scale traction behaviour. This work aimed to extend the ECF model to predict behaviour of two different rail sands (British & Austrian), as well as two low adhesion contaminants (sycamore leaf and graphite).

The modelling approach of the ECF model is as follows: from experimental observations it can be surmised that a third body layer (3BL), comprising “actual” 3BLs (e.g. wear debris) and near-surface, deformed, wheel/rail layers, is always present. It is assumed that the wheel and the rail behave elastically, while the 3BL is assumed to have an elastic-plastic behaviour. To describe this elastic-plastic behaviour of the 3BL, Voce’s hardening law was used, where the model parameters are contact pressure and temperature dependency. For parameterisation of the pressure dependency, data from the HPT can be used, whereas the temperature dependency of the parameters has been determined by vehicle tests. Finally, the 3BL model has been implemented into a brush model for rolling contacts to predict the creep force characteristic.

The ECF model, parameterised with HPT data, predicted higher traction for British rail sand compared to Austrian rail sand in dry conditions, with this becoming less pronounced in wet conditions, and practically non-existent in leaf contaminated conditions. Regarding low adhesion contaminants, both graphite and sycamore leaf were predicted to create low adhesion, with graphite producing markedly lower traction of the two. The predictions of leaf behaviour compare well with full-scale measurements and field data.

The Effect of Roughness on Friction in the Wheel/Rail Interface

Harry Shackleton, and Roger Lewis

The University of Sheffield, UK

Friction in the wheel/rail interface is critical to the safe and efficient operation of a railway network. Low friction due to leaf layers or the "wet-rail" phenomenon can cause safety issues and delays. High friction can lead to increased energy consumption, accelerated wheel and rail damage and is now thought to play a role in wheel climb derailments. These have been noted to occur after wheel turning or rail grinding operations which inevitably increase the roughness of wheel and rail surfaces. Although the roughness wears in relatively quickly, there is a period where the risk of an accident is raised.

Effects of roughness on friction, particularly for the wheel/rail interface, have not been extensively studied. Part of the reason for this is the difficulty in measuring the evolution of roughness during a test.

In this work friction measurements were taken using a high pressure torsion test approach. Specimens made from wheel and rail materials were used and the different initial roughness' imposed on the rail materials. Friction was recorded cycle by cycle and roughness measured using a replica approach. Dry tests were run as well as tests with the addition of a third body layer. Relationships between friction and roughness have been determined that could now be integrated into models designed to predict wheel/rail interface behaviour.

A Micro Finite Element Modelling of Particle Breakage in Wheel-Rail Interface

Bin Zhang, and Sadegh Nadimi

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Adhesion in the wheel-rail interface significantly influences the braking distance and train traction [1]. Poor adhesion causes longer stopping distance and reduced train acceleration. When the loss of adhesion occurs, sand particles are rapidly discharged at the interface from an on-board device to enhance the adhesion level. Operational experience has shown that a coarse particle size is more suitable for braking while fine particle size is more suitable for traction [2]. Additionally, the magnitude of adhesion enhancement is correlated to particle size [3]. In this study, a wheel-rail model is developed using the micro finite-element methodology proposed in [4] to study the influence of sand particle breakage on wheel traction systematically. Four different particle sizes are selected based on the Rail Safety and Standards Board (RSSB) standard GMRT2461 [2] and used to observe the influence of fracture behaviour on the traction in the wheel-rail interface before and after the particle breakage. A full-scale wheel is created with boundary conditions assigned to reproduce real wheel-rail interface conditions. The coefficient of traction from four tests is calculated and analysed. This study provides new insights into the effect of particle size and its fracture behaviour for railway sanding systems.

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On the identification of compliant rate-and-state friction laws to predict friction-induced vibration

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Various challenging case studies of rate-and-state dependent friction were presented in an earlier study [1] concerning tests performed with different polymers pins, sliding against glass and steel disks. The dynamic component of the friction force was quantified by means of a frictional frequency response function, which was modelled by using an enhanced rate-and-state friction model, “borrowed” from the geomechanic community. It was shown that the key ingredient in the model to match the experimental results was the inclusion of a “homogenized” tangential contact stiffness. The latter elastic contribution was assumed to be composed of two components placed in series: a bulk stiffness and a tangential contact stiffness representing the elastic contribution of the interface asperities. Apart from highlighting the need of a “homogenized” tangential stiffness, the measurements reported in the previous study [1] were unsuitable to uniquely identify and discriminate the single stiffness contributions. Therefore, this study aims to propose a new metric, and hence a hypothetical experimental identification procedure, to uniquely identify the different stiffness contributions affecting the dynamic friction during a perturbed sliding process. As a first proof of concept, the analysis in this study will be limited to a perturbed classic mass-spring system sliding on a moving belt, for which the contact interaction is assumed to follow different versions of a compliant rate-and-state friction constitutive law. Subsequently, the case will be extended to a bi-directional rate-and-state friction law, including effects due to normal force variations.

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Parametric Analysis of Tooth Contact Stress for a non-standard Spur Gear Pair

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Gear load carrying capacity is limited by maximum contact stress and its correlated failure modes. Contact stress magnitude is the main criteria to characterise the load carrying capacity of a tooth flank, through its contribution to surface failure. This paper presents a quasi-static contact stress analysis for a pair of spur gears, for low-speed, high-torque applications. Contact stress is evaluated for different relative contact positions within a full mesh contact cycle, using a finite element model of a gear pair, to consider the stress fluctuation due to the alternation of single and double tooth pairs of teeth in contact. Models are firstly generated in KISSsoft, and exported as 3d profiles into a CAD environment, prior to modelling in ANSYS using contact mechanics loading cases. The influence of gear proportions such as generating pressure angle, profile shift and addendum factor, on maximum contact stress is studied extensively, through the exploration of a feasible parameter space, and moving away from standard gear proportions. Results are compared with those from gears with standard proportions. The correlation between contact stress and tooth flank geometry is explained through an analysis of the generated contact area. Also the influence of tooth proportion on contact ratio, and on the time interval of maximum contact stress, is evaluated. From this parametric study, suitable suggestions for enhancing the load carrying capacity of the tooth flank are made. The study shows that the use of non-standard geometric parameters can improve the performance of gears, particularly for low-speed, high torque applications.

Decoupling slip and stress in contacts for the prediction of fretting fatigue life

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One of the key applications of contact mechanics solutions is in the understanding of a damage mechanism in contacting metal components known as fretting fatigue. Cracks initiate in these contacts due to some combination of local slip and the cyclic state of stress, however the classical experimental methods used to quantify the life of such components are not capable of decoupling these effects, as changes to any load component or to the contact geometry will result in significant changes to both slip and stress. This paper describes novel experiments in which changes to the path through load space (rather than the more typical changes to the end points) are used to isolate the effects of slip. Here we can maintain a very similar stress range between experiments, but vary, significantly, the size of the slip zone, and so isolate the effect of slip alone. The results of these experiments are then discussed. The various effects of the slip (calculated analytically and numerically) such as dissipated energy, slip direction, wear damage, oxide production and traction distribution, are considered to better understand the effect of slip on fretting crack nucleation.

A Numerical Model for Investigating the Effects of Viscoelasticity on the Partial Slip Solution

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The problem of coupled normal and tangential loading has always been an area of interest to determine the frictional behaviour of dissimilar materials in contact. Considering the wide application of viscoelastic materials in engineering fields, a boundary element model replicating the partial slip contact of two viscoelastically dissimilar materials is developed in this study. The ratio of retardation time to relaxation time is employed to characterize the rheological property of a viscoelastic material. Although the exact boundary value is not known, materials with high ratios are found to exhibit more fluid-like contact behaviours while those with low ratios perform more like solid. No matter what rheological model is used, it is the ratio that dominates the shape of contact tractions. When a constant normal load is applied, the stick ratio is found to be insensitive to the viscoelasticity of materials under a fixed load or displacement in the lateral direction. However, the separation patterns of the stick and slip regions vary with time when stress relaxation is encountered in the lateral direction. Unlike the elastic response, the transition from partial slip to gross sliding of viscoelastic materials tends to be abrupt under fully coupled conditions. A more abrupt transition can be achieved when it comes to a more fluid-like material. The effects of the partial slip period on the later frictional sliding contact solutions are investigated as well in the study. Compared with the frictionless sliding contact solutions, the peak pressure is lower and the contacting area is shifted in the direction opposite to the sliding motion when contact friction is considered. The later the gross sliding happens, the longer time it requires for the viscoelastic contact to be in the steady-state.

Study of two-dimensional acoustic structures involving structural and material discontinuities

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Structural acoustics has gained significant intention towards the development of many engineering and applied mathematics problems alike. The major part of these contributions includes designing structures with the aim to control noise emanated from multiple sources. These naturally involve the wave scattering features at a discontinuity both in material properties and structures as investigated in the literature while studying the dissipative devices that are modelled for computational purpose. We study a mode-matching analysis of a two-dimensional waveguide problem subject to wave bearing boundaries. The underlying mathematical model characterizes the system to be non Sturm-Liouville whose solution suggests that how a choice of structure involving wave bearing boundaries is handled computationally. We aim to discuss the performance of reflected and transmitted regions of trifurcated lined waveguide backed by a line walled cavity involving multiple step discontinuities. Precisely we analyze the viability of the mode-matching technique and support our results with apposite numerical experiments. While performing the power balance the expressions for energy fluxes in different regimes are also the key finding for this study.

On the effect of the different sources of energy dissipation involved in shape memory alloys on their damping capacity

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Due to the phenomenon of superelasticity, shape memory alloys (SMA) exhibit significant damping properties, as evidenced by their increasing use as part of damping devices to control the vibrations of various engineering structures. In the absence of well identified procedures, the experimental characterisation of these damping properties is often carried out using cyclic tensile tests performed under quasi-static conditions. Furthermore, the state of the art mentions different relationships between the hysteretic mechanical behaviour associated with superelasticity and the induced damping capacity, without one of them being clearly established.

Thus, a numerical model was used to explicitly relate the energy dissipation measured at the material scale (via the stress field) to the intrinsic damping capacity determined at the structure scale (via the vibration of the structure). To this end, the transient response of a simple clamped-free SMA beam was obtained using a finite element model and analysed using an original vibration signal processing methodology.

Finally, the damping capacity of such a material was tested in a damping device dedicated to the protection of structural civil engineering cables against vibratory loads. The results from a numerical model were compared with experimental results from a full-scale bridge cable. In this study, emphasis is placed on the need to take into account all sources of energy dissipation involved in SMA, such as thermomechanical couplings, multi-phase transformations and propagation of transformation fronts, in order to correctly predict the effectiveness of the device.

A finite element analysis of a vibrating beam resting on a Winkler elastic foundation

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Jouf University, Saudi Arabia, COMSATS University Islamabad, Pakistan, COMSATS University, Islamabad

Vibration of continuous system plays a very important role in structural, mechanical and civil engineering which also helps to understand the phenomenon of soil structure interactions and predict contact pressure distribution and deformation within a medium. The Winkler approach is considered to be the most common theory of beams considering the spring-based modeling. In this study, we are interested to present a finite element analysis together with analytical results for the dynamics of a vibrating beam resting on a Winkler elastic foundation. The analytical and numerical techniques in terms of root finding techniques will be utilized to compute the normal frequencies of beams subject to various boundary conditions and hence getting the mode shapes for comparing the normal frequencies. Beams deflection depends upon its length, its cross-sectional region and material properties, where the deflecting force is applied by the support of the beam at different ends. Deformation and frequency behavior of beam will too be analyzed graphically by defining the finite element algorithm for both consistent and lamped mass matrices. Further, the behavior of achieved mode shapes comparing to normal frequencies will be drawn and investigated numerically.

A Novel Finite Element Formulation for the Analysis of FG Timoshenko Curved Tapered Beams

Hugo Santos[1], and Vadim Silberschmidt[2]

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Due to their excellent performance, functionally graded materials (FGMs) have been extensively used in the last years in different engineering applications, such as airspace, automotive, energy, defense, etc. FGMs are a class of composites that have a smooth and continuous variation of material properties in any desired direction.

The large number of works available in the literature dealing with the modelling, analysis and optimization of FG beams demonstrates a continuing interest of the research community in the development of simple and efficient mathematical models to predict their structural response. However, their complex geometries pose challenges to the development of robust approaches for the modelling of their response. Approaches based on the finite element method have proven to be the most successful ones, particularly thanks to their versatility. Nonetheless, when applied to Timoshenko structural models, some of these approaches are prone to shear locking when the elements become slender, and to membrane locking when the curvature of the elements increase [1].

The aim of this contribution is to introduce a novel, simple and effective finite element formulation for the analysis of FG Timoshenko curved tapered beams. This formulation relies on a complementary variational approach based on a set of approximations that satisfy in a strong form all equilibrium conditions of the boundary-value problem [2], resulting thus in a formulation that is naturally free from both shear and membrane locking phenomena. The effectiveness of the formulation is numerically demonstrated through its application to benchmark problems, and the obtained results are analyzed and discussed.

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Experimental Modal Analysis for a Nonlinear Structure

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An impulse method may be used for experimental modal analysis in which the vibration decay following the impulse is used to determine structural parameters such as natural frequency and damping ratio. For a linear structure there are well developed methods for modelling this data based on spectral analysis. This is possible because a linear structure has a simple spectrum which may be easily modelled. When the structure is nonlinear there is no simple equation representing the spectrum.

This paper examines the use of a Laurent series to represent the frequency spectrum. A Laurent series is very general and can be used to represent almost all singularities on the complex plain. Furthermore, the first term is the same as that found in a linear structure. Consequently, this should be a good method for modelling nonlinear systems. However, there are difficulties with the use of Laurent series. First, the impulse method usually excites several resonant modes and consequently these must not be allowed to interfere with the mode of interest. Also, the Laurent series is difficult to handle since higher order terms can become numerically unstable.

The approach taken is to use filtering to remove the unwanted modes and then to fit the Laurent series to part of the filtered spectrum. The spectrum is then inverse Fourier transformed to give a time history. Finally, a differential equation with time dependent coefficients is fitted to the data. This produces time dependent natural frequencies and damping ratios. This model can then be used in, for example, a computer code to represent the nonlinear system.

Analytical and Experimental Modal Analysis of a Flexible Robot

Viet-Hung Vu, Marc Thomas, Zhaoheng Liu, Quoc Cuong Nguyen, and Thanh Trung Do

Ecole de Technologie Superieure, Quebec, Canada

New modern methods are presented on the analytical and experimental modal analysis of a robot with flexible joints. On the analytical approach, a linearization of the dynamic equations is employed to solve the eigen value problems taking into account the controlled parameters and the manipulator's configuration. The method offers a continuous modal analysis in the whole workspace and at any location of the end-effector. On the experimental approach, a state space model is developed from the times series representation. The method allows a rapid, accurate experimental modal analysis of the robot and in addition, an ability to estimate the force at the end-effector. Both methods are applied on a portable flexible robot at Hydro Quebec with great vibration analysis outcomes.

Long timescale dynamic testing of a jointed interface

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What is the interface's dynamic behaviour under long-timescale continuous vibration loading? The answer might not be as straightforward as one might think. Dynamic tests are typically carried out for as much vibration cycle as required to estimate dynamic characteristics, such as damping. Therefore, one shall assume that a damping value, likely amplitude-dependent, might be valid (plus or minus the effect of wear) for a long timescale. How much do we know about the high harmonic characteristics under a long timescale?

Furthermore, how much do we know how frictional interface and surface heating during long timescale vibration loading? Again, not much. One of the reasons is that the duration of such tests is very long. Furthermore, it is a multiphysics because some of the mechanical responses drive the frictional heat developed at the interfaces. This presentation will show ad-hoc experiments executed on jointed interfaces to observe the dynamics under a long number of excitation cycles.

A double cantilever beam was designed to have two lap joints on either side. The lap joint is designed as a hinge type, where a bolt forces the interface together. The centre part of the double cantilever beam is connected to a shaker, which vibrates the structure to its first bending motion. The bending motion allows the interfaces of the hinged lap joints to slide. Basically, we allow shear force to create frictional heat under a long timescale. The vibration amplitude of the beam's tip is maintained constant throughout a long time of testing by using a PID controller. A thermal camera is positioned right above the two hinges and is used to measure the surface temperature as a function of the excitation cycles. The results are pretty interesting and will be presented

Evaluation of a massively parallel laser RADAR for structural experimental testing of a lightweight FRP footbridge

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Non-contact techniques for static and dynamic characterization of structures simplify data collection and have the potential to expand the scope of structural analysis and structural health monitoring to situations where fixed instrumentation is too cumbersome or costly, or undesirable on conservation grounds. Laser RADAR is a novel 3D metrology technique that offers long-range vibrometry information in any lighting condition.

Methods:

Measurements were carried out on a 10m long Fibre-Reinforced Polymer (FRP) footbridge with the goal of comparing two measuring techniques under ambient and forced excitations: a well-stablished accelerometry-based system and the new Laser RADAR.

The accelerometry set up used B12 piezoelectric sensors with nominal sensitivity of 10 V/g, a frequency range of 0.15 to 1000 Hz and resolution of $8 \cdot 10^{-6}$ g rms. Data was read with a 24bit cRIO acquisition board from National Instruments.

Measurements were also carried out using a novel massively parallel laser RADAR. The system, working at a wavelength of 1.55μm, makes use of the Doppler effect to extract instantaneous velocity from the light reflected from 128 spots projected on the structure. An integrated optical sensor allows simultaneous readout of all 128 locations.

Several tests were conducted, including operational modal analyses (OMA) with ambient and forced vibration, sinusoidal excitation and several representative load conditions such as low and high frequency impacts.

Results:

OMA results from the accelerometers and the laser RADAR were comparable, revealing the expected fundamental mode resonance. Frequencies and damping factors were 7.684Hz and 0.998% with accelerometers versus 7.506Hz and 0.352% with the laser RADAR.

Conclusion:

Measurements conducted with a parallel Laser RADAR correlated well with those obtained from a well-consolidated equipment for structural dynamic testing. The obtained data was suitable to carry out a consistent modal parameter extraction. The laser RADAR has significant potential for non-contact dynamic characterization of civil engineering structures.

Modal identification and validation of unknown aircraft structure – simple fixed wing mockup plane case - for flutter prediction

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Flight flutter test is an important process for aircraft airworthiness certification. The process could be very costly and time consuming. Flutter predictions can reduce the resources consumption during flight flutter test. However, low accuracy models can cause large deviations in flutter prediction results. The accuracy can be improved by having a proper structural model. In this study, we carried out both simulations and experiments for obtaining structural model with enhanced accuracy. Structural model is constructed and analysed by using finite element method and normal modes analysis, respectively. The analysis results then compared with the experimental results (ground vibration test). The comparison is used as the basis for updating model. The model is updated by direct and parametric methods. The advantage of using the direct method is the flexibility in modifying mass and stiffness matrices. However, it is very time consuming due to selection process on those matrices which done manually. In the other hand, parametric method has an easy approach on updating model by performing model optimization. Moreover, changes to the mass and stiffness matrices using parametric methods are carried out thoroughly. The frequency difference between simulation and experiment in the first mode are 0.04 Hz and 2.035 Hz for direct and parametric model updates methods, respectively. Furthermore, the frequency difference in the second mode for direct and parametric methods are 0.249 Hz and 0.182 Hz, respectively. By referring to the frequency difference between simulation and experiment, the direct method has a higher level of accuracy than the parametric method but unable to retain structure information thoroughly, opposed to parametric method. The updated structural model is then developed for reference on aerodynamic models which will be used for flutter prediction.

Finite Element Analyses of Soil Effects on Substructure and Soil Performances of 15 MW Offshore Wind Turbine: A Comparative Study

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[1]Nottingham Trent University, UK [2]Cyprus University of Technology, Cyprus

The focus on renewable energy development has led to increase in the number of offshore wind turbines (OWT). As these structures are subjected to harsh environmental conditions in deep seas and different locations, there is a need to consider the structural integrity of their support structure. Thus, numerical analyses are employed in this study to access the effects of the soil profiles on the stresses, deformations (soil and tower) and natural frequency in the support structure of a 15 MW large-diameter offshore wind turbine in peak power production conditions. Material model representing real soil profile parameters obtained from in-situ soil tests in the North Sea, East China Sea, and Irish Sea has been applied in the finite element model. The inclusion of soil model provided realistic conditions where the natural frequency in different soils was found to be within the expected frequency band of 0.1-0.38 Hz defined in design code for wind turbines. The maximum deformation was found to be 2.8 m at the tower top. The predicted stresses in all models showed a maximum difference of 9.5 % with compressive stresses being dominant in the splash zone of the transition piece of the OWT. It was found that the soil profile of medium to dense sand located in the North Sea is suitable for installation of a 15 MW large-diameter horizontal-axis OWT meeting the design code requirements for proof analyses, deformations at the soil and natural frequency of the OWT.

Approximating Loads in Kick Scooters with Measured Strain

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University of Oxford, UK

Kick scooters are rapidly becoming a mainstream mode of urban transport that reduces inner-city congestion and pollution. They also receive widespread recreational use. Despite comprising a multi-billion-dollar industry, there is no published research on the loading of kick scooters. Understanding the loading scooters face in real-world use can help design lighter and stronger scooters.

This research investigates the loading scooters face and uses this information to optimize their design. There are three main components to the load investigation. First, an appropriate experimental setup is necessary. A lightweight data acquisition system capable of capturing eight channels of strain data at 62.5 kHz has been made.

In the case of static loads, the possible basis loads must be assumed. Their strain output can be simulated with FE analysis and confirmed with experimental measurement. Each basis load will produce a unique strain distribution that results in a measured strain at each strain measurement point. The basis loads form an orthonormal set. Consequently, the loading can be approximated by the measured strain. The approach can be extended to the dynamic case, where instead of basis loads, basis impulses are used, and the strain history is used, rather than strain measurements at one instance in time. Each basis impulse will produce a strain at distribution that varies with time.

The variation in the magnitude and distribution of the loads the scooter faces can be used to optimize the design. Techniques such as shape and topology optimization can help achieve improved geometries

The mechanobiological link between micro-cracks and lacunae: a multi-scale fracture mechanics approach

Federica Buccino, and Laura Maria Vergani

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The increase in fragility fractures and the related dramatic impact on the healthcare and financial system, raise a big red flag in the approach to the clinical treatment. With the rise in life expectancy, the prevalence of chronic conditions, such as osteoporosis, is also set to escalate. All these contributing factors highlight the urgency to address the fragility fracture crisis with a critical eye on the intricate bone multi-scale arrangement. Indeed, bone damage comprehension is still limited to macro- and meso-scale level, where its occurrence is catastrophic. It is still unclear what befalls at the micro-scale and what is the role of microscopic bone porosities, named lacunae, during the damage processes. More in depth, there exists a dualism behind the role of lacunae: they seem to play an antithetical mechanical contribution, having an effect on both strength and toughness.

For these reasons, recent studies address the issue from a multi-scale perspective, elevating the micro-scale phenomena as the key for detecting early damage occurrence. However, several limitations arise specifically for defining a quantitative framework to assess the contribution of lacunar micro-pores to fracture initiation and propagation. Moreover, the need for high resolution imaging imposes time-demanding post-processing phases.

To overcome these issues, we exploit synchrotron scans in combination with micro-mechanical tests, to offer a fracture mechanics-based approach for quantifying the critical stress intensification in healthy and osteoporotic trabecular human bones. This is paired with a morphological and densitometric framework for capturing lacunar network differences in presence of pathological alterations. To address the current time-consuming and computationally expensive manual/semi-automatic segmenting steps, we implement convolutional neural network to detect the initiation and propagation of micro-scale damages. The results highlight the intimate cross talks between toughening and weakening phenomena at micro-scale as a fundamental aspect for fracture prevention.

Keynote: *In situ* analysis of friction and wear mechanisms at single asperity contacts

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The University of Sheffield, UK, Institute for Future Transport & Cities, UK, Henry Royce Institute, UK

Friction between moving contacts is a significant problem in many industrial systems, leading to significant energy transfer, heating and structural change, all of which change the properties of the system. Friction mechanisms are length-scale dependent, with structural damage and wear being the superposition of spatially heterogeneous events occurring in different volumes and at different timescales.

Here we will discuss the analysis of nano-to-micro friction and wear mechanisms using in situ electron microscopy. Scratch testing inside electron microscopes has been applied to a range of industrially relevant ceramics and metals, to evaluate their dynamical interfacial friction and wear behaviour. Specifically, in-situ imaging of tribological tests with electron beams can be used to generate videos of moving single asperity contacts, enabling analysis of microstructural change in inhomogeneous microstructures during non-linear loading.

Applications of the methodology will be demonstrated including evaluation of the mechanisms of degradation of low friction coatings, microabrasion of metal matrix composites, and behaviour of self-healing materials. Future possibilities for vibrational testing and methodology limitations will be discussed.

Hybrid-hybrid turning of micro-SiCp/AA2124 composites

Anish Roy, and Jin Kim

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Two distinct hybrid machining processes –ultrasonic-assisted turning (UAT) and laser-ultrasonic-assisted turning (LUAT) were performed on three types of micro-SiC/AA2124 composites with different volume fractions and particle sizes and compared to a conventional machining process to determine the effectiveness of the hybrid machining processes. Carbide tools are determined to be unsuitable for long-term cutting in LUAT but yield excellent machining outcomes in UAT. Studies in LUAT indicate that an optimum laser power exists for each of the composite materials yielding benefits in terms of machining force reduction, surface topology improvement and potentially tool life improvement.

In this talk, we discuss some of the pros and cons of using hybrid machining and explore the future direction of using vibro-impact assisted machining for improved machining efficiency.

Hybrid manufacture of aerospace-grade materials: instrument design

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The hybrid machining technique combining ultrasonically and electrically assisted material removal process on aerospace-grade materials is presented in this study. The machining process exploits the piezoelectric and electro-plastic phenomena via a bespoke shaped transducer that vibrates at high frequencies coupled with a pulsed high current passing through the workpiece which in turn softens the material to be removed enhancing the ductility and machinability of the part.

The ultrasonic transducer employs piezoelectric elements (rings) that when excited produce high-frequency mechanical motion. In a traditional Langevin-type transducer, the piezoelectric rings are sandwiched between the back and front driver via a precompressed bolt. To favour the longitudinal motion, the transducer has axial symmetry.

For this work, a parametric finite element model has been developed to simulate the modal vibration of the transducer. The effect of geometric parameters of the transducer back and front drivers on vibration frequency has been investigated. In particular, the front driver - responsible for the transducer holding position and for the vibration amplitude magnification - has been divided into two parts separated by an insulating insert so that the piezoelectric elements are protected by the pulsed current passing through the workpiece.

The transducer design has been optimised using modal analysis simulation to achieve maximum longitudinal vibrations within the bandwidth of the ultrasonic generator (20-21 kHz) and having more than 1 kHz of frequency separation to the next adjacent vibration modes.

The optimised transducer has eventually been manufactured and tested. Comparison between simulations and experimental results are reported along with its enhanced manufacturing performance resulting in cutting force reduction and improved surface finish of the machined aerospace-grade materials.

Electrically assisted deformation of aerospace grade materials

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Manufacturing with aerospace grade materials remains a challenge due to their outstanding material properties. Electrically assisted deformation technique has been practiced and researched to be a more efficient, less time consuming and environmentally friendly solution to increase the deformability of these aerospace grade materials.

The research works carried out attempt to determine the suitable conditions for carrying out the electroplastic deformation process particularly compression and tension process on Ti-6Al-4V and mild steel. The samples were subjected to different value of current densities ranging between 10 – 40 A/mm^2 at low and high current frequencies between 5 Hz – 6 kHz throughout the elastic and plastic deformation process. The temperature rise was also recorded for all the specimen tested to investigate and verify the independency of material softening to increasing heat and to exhibit the influence of electric current on the deformation process.

The microstructural aspect of the deformed materials was also examined using optical microscopy (OM) and scanning electron microscopy (SEM) to assess for any microstructural alteration or modifications as a result of application of electric current flow.

Results obtained agreed with theoretical prediction which showed reduced flow stresses at different current densities and at low and high frequencies in comparison to conventional method. The temperature variation showed increasing values as current was increasingly applied at lower frequencies. The grain structure for the compressed samples experienced slight changes which goes to show that the electrically assisted deformation method did not alter the basic grain structure of the tested material hence preserving the original qualities of deformed materials.

The study presented here showed that electrically assisted deformation process is a potential alternative to conventional methods and promises flow stress reductions when deforming aerospace grade materials while maintaining the microstructural integrity of the material being deformed.

Trial of a randomised lattice bone scaffold implant

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This work tests the proposal that a random lattice scaffold for bone repair should be superior to a regular lattice because that is the form that nature has evolved for the interior of structural bones.

2-dimensional lattices are constructed, nominally rectangular but with varying degrees of randomisation superimposed. These were obtained from just three 4-bit numbers defining the average density, the relative density at the core and edges, and the degree of superimposed randomness. The cross-sectional dimensions of the various lattice links were optimised for moderate loading in one direction only.

The lattices were tested for fracture strength in different loading directions. The robustness of the lattice was obtained from the loss of strength and stiffness of the structure loaded in the ideal design direction, to that when loaded in the direction normal to it.

A genetic algorithm (GA) is used to optimise the lattice using as genes the three lattice definition numbers. The fitness of a lattice was taken as this robustness less a cost function obtained from added mass and reduced strength and stiffness with respect to the equivalent non-randomised lattice. Results are presented to show that the GA selects for lattices that are dense at the edges and sparse in the interior, similar to natural cortical bone, and with a moderate degree of randomness.

Analysis of intragranular stress in NiTi Shape Memory Alloy during Superelasticity

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To explore an effective route of customising the Superelasticity (SE) of NiTi Shape Memory Alloys via modifying the grain structure, binary $Ni_{55}Ti_{45}$ (wt.%) alloys were fabricated in As Cast, Hot Swaged and Hot Rolled conditions, presenting contrasting grain sizes and grain boundary types. *In situ* synchrotron X-ray Laue micro-diffraction and *in situ* synchrotron X-ray powder diffraction techniques have been employed to unravel the underlying grain structure mechanisms that causes the diversity of SE performance among the three materials. Evolution of lattice rotation, strain field and phase transformation has been revealed at micro- and mesoscale, and the effect of grain structure on SE performance has been quantified. It was found that (i) The Ni_4Ti_3 and $NiTi_2$ precipitate is similar among the three materials in terms of morphology, size, and orientation distribution; (ii) phase transformation happens preferentially near High Angle Grain Boundaries (HAGBs), yet randomly in Low Angle Grain Boundaries (LAGBs) structure; (iii) the smaller the grain size, the higher the phase transformation nucleation kinetics, and the lower the propagation kinetics; (iv) stress concentration happens near HAGBs while no obvious stress concentration can be observed in LAGB grain structure during loading; (v) the statistical strain distribution of the three materials becomes asymmetric during loading; (vi) three grain lattice rotation modes are identified and termed for the first time, namely multi-extension rotation, rigid rotation and non-dispersive rotation; (vii) texture evolution of B2 austenite and B19’ martensite is not strongly dependent on the grain structure.

Sample Gripping for Material Characterisation

Shabarish Sriraman, and Hugh Goyder

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Material characterisation is a fundamental part of modern engineering, and its need has increased with the advent of new materials and applications. Property data is also the first step in any simulation and thus, ensuring accuracy is critical. The nature of sample gripping is dictated by the interface between a material sample and the surrounding apparatus. Ensuring a well gripped sample allows for confidence in the characterisation results. If sample gripping is not considered, the material may be prone to localised slippage in static or dynamic loading conditions. This introduces false displacements and friction at the contact interface and may even manifest as separation between the sample and apparatus. Friction is difficult to account for during measurements due to its non-linear nature and thus can have a significant impact on the characterised results, especially when material damping is considered.

Contact interfaces of material samples in a characterisation apparatus are considered in this paper. Two rigs have been developed as part of a novel approach to characterise the high-frequency vibration properties (Young's modulus and damping) of non-metallic materials. One rig uses cuboidal samples, similar to ones used in industrial methods, and the other uses axisymmetric cylindrical samples with a central hole.

Simulated stress distributions were considered for several test cases. Variations in sample geometry, loading conditions and material properties were evaluated and it was found that:

- Sample geometry is formative in determining the stress distribution at the contact interface, and uniform gripping may only be achieved with careful tuning.
- Edges can be used to introduce stress in low stress regions.
- The relative difference of material properties between the sample and the rig impacts the stress distribution.
- Static loading input locations impact the stresses in the sample.
- A non-linearity test was developed for experimental results to validate the elimination of sample slippage.

Experimental Vabration Characterization of Laser-machined Bi-stable Piezoelectric Energy Harvester

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Vibration-based energy harvesting has gained considerable interest in recent decades due to its potential application for the self-powered sensor. The piezoelectric energy harvesting devices are designed to provide the required electrical power for the wireless sensor which can work without the limitation of battery life. Traditional vibration-based piezoelectric energy harvesters are mostly linear oscillators which are only suitable for static and narrowband excitations near their resonant frequencies. If the vibration frequency is distributed over a wide spectrum, the linear harvesters become less efficient because the power generation drops dramatically and is too low when the vibration frequency is away from the resonant frequency. Bistable energy harvester which has double-well restoring force potentials and strong nonlinearities during vibration has been recognized as a potential candidate to broaden the bandwidth. The most common mechanism of making the beam bi-stable is by pre-loading. In this paper, a bistable piezoelectric harvester is developed for broadband vibration-based energy harvesting at low frequencies (<30 Hz). The energy harvester is developed by using a laser-machined bistable structure consisted of two supported beams and a wider main buckled beam. Unlike other energy harvester based on buckled beam, this device can work like a cantilever because the boundary conditions for post-buckling are integrated with the piezoelectric beam. This harvester is capable of snapping through between two equilibriums when it is excited. An experimental setup is established to measure the voltage responses of frequency-sweep when the harvester is actuated under different acceleration levels. The strong nonlinear response of this bi-stable harvester caused by inter-well snap-through motion is beneficial for energy harvesting to broaden the frequency bandwidth with high output. The different oscillation modes are captured in the experiments, and the output power is measured further. The output power under the inter-well oscillation is 126 μW at 1.5g and 17.5 Hz.

A novel design of vibration isolator with high and adaptive damping characteristics based on a Large Negative Poisson's Ratio (LNPR) metastructure

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In this paper, a vibration isolator with adaptive damping characteristics based on an integrated design of large value of negative Poisson's ratio (NPR) metastructure and viscoelastic materials is designed and analyzed. The negative Poisson's ratio of the metastructure leads to its amplified lateral deformation, making this new isolator exhibit high damping properties at low frequencies and low damping properties at high frequencies. This novel vibration isolator can achieve large damping characteristics and low vibration transmissibility, particularly, when applying for micro-level vibration isolation. The damping and dynamic characteristics of this new type of negative Poisson's ratio vibration isolator were analyzed by ABAQUS software, the hyperelastic and viscoelastic properties of damping rubber were established by using the two-parameter Mooney-Rivlin model and Prony series, and the properties of damping materials were verified by finite element simulation. The vibration isolation performance of the NPR metastructure vibration isolator and the linear spring vibration isolator with the same stiffness under free vibration was analyzed by implicit dynamics, and then the response and vibration transfer rate of the two vibration isolators at different frequencies were analyzed by sweep frequency. Finally, a vibration isolation platform with 40 NPR metastructure vibration isolators is analyzed by finite element analysis, and the vibration isolation effect of NPR metastructure is approved.

Multi-Frequency Vibration Correlation Technique for Predicting Critical Buckling Loads of Plates and Stiffened Panels

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Plates and stiffened panels provide low mass solutions in many engineering applications. Critical buckling is an important consideration but may be affected by damage or initial imperfections. Buckling tests for built-up structures are impractical, while predictions from models are imprecise due to difficulties in detecting the location and extent of damage.

Using the Vibration Correlation Technique (VCT) (Singer et al., 2002), Kennedy and Lo (2018) established a straight line relationship between the square of natural frequency and applied compressive load for simply supported plates having identical sinusoidal mode shapes for unloaded vibration, critical buckling, and the intermediate cases of vibration under light loads. For stiffened panels, discrete changes in mode shape result in intersecting straight line relationships. For plates and panels loaded in shear, the mode shape becomes increasingly skewed as the loading is increased, yielding intersecting non-linear curves.

This paper presents a least squares technique in which multiple natural frequencies are recorded at each load level. The data is fitted to a family of intersecting straight lines or polynomial curves, using special ordered sets (Beale and Forrest, 1976) in the mixed integer linear programming solver LPSOLVE (SourceForge, 2020).

Accurate critical buckling predictions for a longitudinally compressed stiffened panel are made following the identification of intersections of intersecting straight lines. Critical buckling in shear is also predicted to an accuracy of 1% by identifying the intersections of fourth order polynomial curves.

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Three-dimensional modelling and analysis of high-speed train-induced building vibration considering different soil types

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The problems such as train-induced ground vibration and its dynamic effects on nearby structures have become a major environmental concern in urban areas with the rapid increase and development of high-speed trains (HSTs). Ground-born vibrations produced by high-speed trains pose a great challenge for engineers to build structures in such areas that is applicable to residents. This study evaluates the effect of HST-induced environmental vibrations using the developed computational model and validates the test results in full-scale field conditions. Experimental investigations were performed at the Istanbul-Ankara high-speed railway section to examine the effect of ground vibrations from HSTs on the surrounding residential lands. The experimental results of vertical and horizontal ground vibration accelerations induced by HSTs with a velocity of 250 km/h were analyzed. In order to study the effects of train-induced vibration on nearby buildings, an advanced 3D finite element model has been developed using Plaxis 3D. The measured and analyzed results were compared for validation using the peak acceleration values. An in-depth analysis was achieved to investigate the effect of different soil properties on the train-induced building vibration by using the verified model. Based on the dynamic analysis results, the relative vibration response curves in all directions for different soil conditions were obtained comparatively. Results show that the peak acceleration values of train-induced vibrations at soft soil sites increased dramatically when compared to the rock site. The vibration analysis results are discussed to figure out some useful conclusions.

Application of Low energy, High Frequency Laser Shock Peening to Diamond

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Ultra-hard materials such as polycrystalline diamond (PCD) is typically used as a cutting tool for the precision machining of automotive and aerospace components. It provides optimum balance between tool performance, which reduces costs for end users; and abrasive resistance, which leads to increase in tool life. Due to the inherent attributes of PCD materials, it has become almost impossible to machine PCD materials conventionally. As cutting tools, these materials are subjected to severe wear environments at high temperature. Thus, improving their mechanical properties is a major element in the design of new materials. This study investigated the effect of low energy, high frequency laser shock peening (LE/HF-LSP) with and without coatings technique on the change in microstructural behaviour and improvement in mechanical properties of PCD composites. Proposing a characterisation methodology for the evaluation of the change in surface integrity and microhardness with respect to the laser fluence. The results showed an increase in hardness with the increase in number of peening from one to four times. In particular, the laser manufactured PCD composites proved to perform 50% better than the as-received specimen in terms of mechanical performances. The results showed a correlation between the surface roughness and microhardness to the thermal response of this LE/HF-LSP technique with variation in laser fluence. This could expand the use of low energy laser shock peening for manufacture of PCD and other composites which have complex thermal response to an energy beam due to their arrangement of chemicals and grain structures.

Stress field analysis near a grain boundary of a Ni-base superalloy during the micropillar compression

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Grain boundary plays a significant role to dislocation transmission and therefore the overall plasticity. Dislocation pile-ups at the grain boundary during the mechanical loading result in inhomogeneous stress distribution. Grain boundaries inevitably yield a local heterogeneous stress field and can be the damage nucleation sites. In this context, the stress field and deformation constraint across the grain boundary in Ni-base superalloy was measured during the micropillar compression using high angular resolution electron backscatter diffraction. A quantitative stress field analysis is carried out and the results will be discussed with regards to the crystallographic and morphological features of the grain boundary. The change of the grain boundary features during compression will also be discussed.

Key Word: Local stress, Grain boundary, EBSD, Micropillar compression

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Visco-elastic characterisation of additively manufactured nylon polymer

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Research in additive manufacturing (AM) of polymers has increased significantly in recent years; however, the application of AM materials remains limited. This is due to their weaker performance compared to that of their bulk counterparts, which outweighs the advantage of fabricating complex structures with reduced material waste. On the other hand, most research focuses on the quasi-static performance of AM materials, while their dynamic performance has not yet been fully explored. Few studies have investigated the dynamic characteristics of AM polymers at different temperatures using dynamic mechanical analysis (DMA). In this study, DMA is employed to explore the dynamic performance of AM polymers at different frequencies.

Rectangular specimens of AM nylon polymer manufactured using fused deposition modelling (FDM) were investigated. DMA was carried out under 3-point bending for a frequency range of 1 – 150 Hz at 5 Hz intervals. The values of storage modulus, loss modulus, and tan-delta of the material were obtained at different frequencies. The storage modulus was found almost an order of magnitude higher than the loss modulus for corresponding frequencies, yielding a very low value of tan delta. The overall tan delta decreased with increasing frequency, with the highest value being 0.15 at 1 Hz and the lowest being 0.05 at 150 Hz. The results indicated that the material exhibited more elastic than viscous behaviour, which was dominant at higher frequencies. The experimental results were used to determine the Prony-series parameters in the frequency domain, which would be useful in future numerical studies.

Assessment of the Cellularisation Potential of the HeartWare HVAD™

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Introduction

Left ventricular assist devices (LVAD) have been used clinically as bridge to transplantation for end-stage heart failure patients. The blood contact with the surfaces of the LVAD has been reported to cause complications, including thrombogenicity and haemolysis. Endothelialisation of the blood contacting surfaces of the LVAD has been suggested as a solution for improving their haemocompatibility. This study assessed the surface material properties of the HeartWare HVAD™ impeller, with a view to establishing its potential for endothelialisation.

Methods

TiN-coated impellers (n=4) were isolated from HeartWare HVADs that were obtained post-explantation from Royal Papworth Hospital. The surface properties of the impellers were assessed under non-destructive methods; x-ray photoelectron spectroscopy (XPS; elemental composition), profilometry (non-contact; roughness), and contact angle (CA; wettability).

Results & Discussion

XPS revealed that the impellers featured similar spectra with evident oxidised TiN (Fig. 1) [1]. No significant differences were found in the CA of the different impellers tested. The CA measurements were within the range of 45°-65° (Fig. 2), which has been reported to be suitable for EC adhesion [2].

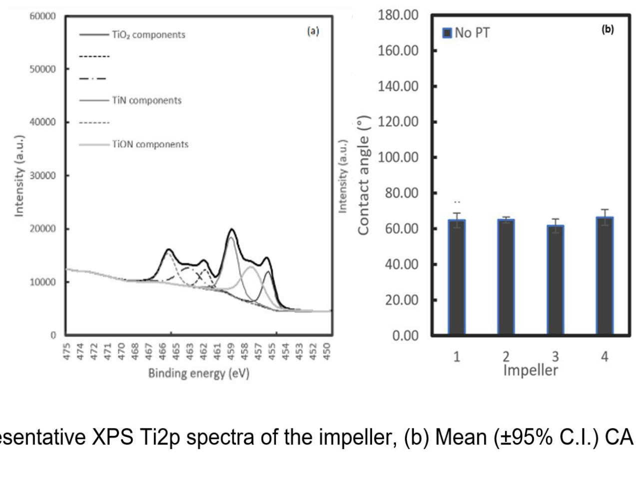

Fig. 1 (a) Representative XPS Ti2p spectra of the impeller, (b) Mean (±95% C.I.) CA of the impellers.

The Sa values obtained from different regions of the impeller (Fig. 2) were between 0.123-0.266 μm (Fig. 3); along with the wave-like topography, Sa values within this range have been reported to support cell adhesion and proliferation [2].

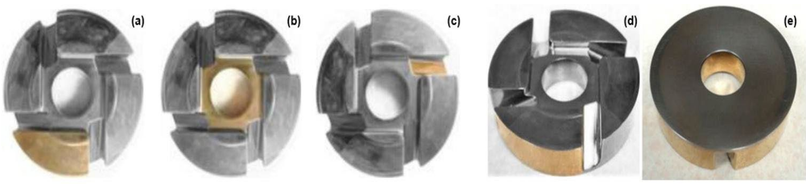

Fig. *2* Surface properties characterisation of different regions of the impeller (a) 1, (b) 2, (c) 3, (d) 4, and (e) 5.

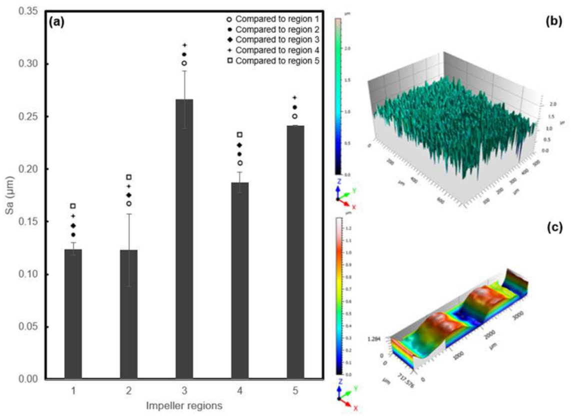

Fig. 3 (a) Mean (±95% C.I.) Non-contact profilometry Sa values from different regions of the impeller. Representative 3D (b) roughness and (c) waviness map of the impeller.

Conclusion

The results suggested that the LVAD surfaces are susceptible to cell adhesion, including thrombocytes. This aptitude can be exploited to seed ECs to increase the haemocompatibility of the LVAD.

Acknowledgements

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Experimental Detection of Shock Waves by Exploiting the Electromechanic Effect

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Our research group had developed a method with which the properties of the mechanical contact between metallic bodies can be evaluated by conducting a constant current through the contact area and measuring the voltage between nearby points [1]. It was found that voltage signals can be detected even if the bodies are not connected to any voltage or current source, but the metal specimens are subjected to shock-like force impulses. Indeed, as was discussed in [2], mechanical deformation may lead to the spatial variation of both the free electron density and the Fermi energy in metals, resulting in an electric potential difference between points of the body. To estimate the magnitude of the measurable voltage, an explicit formula was derived that takes both effects into account and can be considered as an extension of the theory in [2]. In order to exclude the influence of all possible external electromagnetic noises and thermo-electric effects, a special steel specimen was manufactured (Figure 1) and the voltage was measured between the prepared attachment points when the body was struck by a hammer. The details of the measurement technique will be given in the presentation. We believe that this electromechanical effect may have several applications in measurement technology, e.g., it can be exploited for the detection or characterization of shock waves in metals.

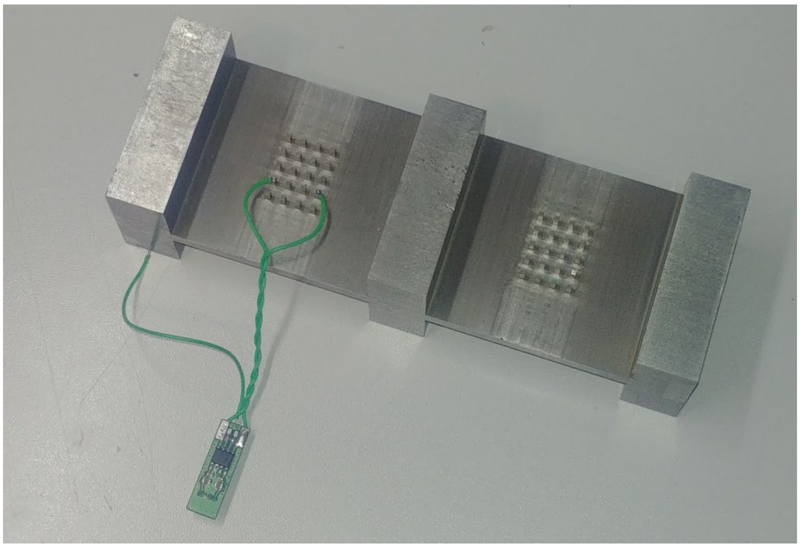

Figure 1. Steel specimen used for the preliminary experiments

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Robust Backstepping Control of a Quadrotor Unmanned Aerial Vehicle under Pink Noise

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Technological developments in sensors, actuators and energy storage devices have allowed the development of quadrotor unmanned aerial vehicles (UAVs). Quadrotor UAVs are used in sensitive tasks such as surveillance, search and rescue, mapping, mining, cargo carriage, agricultural spraying, firefighting and photography. Quadrotor UAVs are exposed to effects such as noise and vibration while performing these sensitive tasks. Therefore, robust controller design that is resistant to noise and vibration gains a great importance. Noise and vibration can be caused by the sensors, actuator and propellers of the quadrotor. Background noise in electronic devices is called pink noise. The primary sources of pink noise in electronic devices are generally slow fluctuations of the properties of the condensed matter materials of the devices. These contain fluctuating defect configurations in metals, fluctuating trap occupancy in semiconductors, and fluctuating field structures in magnetic materials. In this study, a robust backstepping controller is designed for a quadrotor that can follow altitude and attitude references under pink noise. The rise time, overshoot and settling time of the proposed backstepping controller and classical PID controller were compared. It has been proven by simulations that the designed backstepping controller performs more successfully than the classical PID controller.

Investigation of structural intensity analysis based on point cloud data from camera measurements for curved, plate-like structures

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Structural intensity (SI) describes the transport of vibrational energy through a structure and can be utilized as a design tool next to modal analysis. Thereby, information about the dynamics of the structural excitation mechanism, the location of energy sources and sinks as well as the energy transfer paths can be revealed. In this contribution we consider an experimental method to measure SI in flat and curved plates, which may be described by the Kirchhoff-Love plate theory.

A challenge for an experimental SI analysis, especially for curved plates, lies in the requirement of accurate full-field representations of both the surface geometry as well as the 3D vibrational field. To this extent we employ a stereo camera system and Lukas-Kanade optical flow. We propose to process the resulting dynamic point cloud data with a point-wise, low order polynomial fitting approach. Principal coordinates and the required spatial displacement gradients for the evaluation of SI are obtained. Furthermore, repeated application of the fitting procedure can be used to mitigate noise on the measurement data (cf. Savitzky-Golay filter).

Contrary to methods based on numerical models, the proposed approach does not require assumptions about the structural boundary conditions. The method is validated experimentally against Finite Element results on a flat plate excited by two out-of-phase shakers. Next, the performance for curved plates is studied based on numerically generated data resulting in guidelines for the minimal spatial density of the point cloud and robustness to measurement noise.

An Approach to Morphing Structure Control based on Real-time Displacement Reconstruction

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Shape morphing structures can be considered a key technology for the next generation of aerospace vehicles, facilitating adaptive performance based on their operational environment. This paper introduces a framework for morphing monitoring and control based on the inverse problem of real-time reconstruction of structural displacements using in-situ strain sensor data, referred to as shape sensing. The inverse Finite Element Method (iFEM) is the inverse methodology employed, where the structure is discretized using a series of finite elements and the displacements are calculated by minimizing a functional defined as the least-squares error between experimental and analytically defined strains. Subsequently, the morphing actuation load at each time step is calculated by minimizing the least-squares error between the desired and iFEM reconstructed nodal displacements. Real-time assessment of shape or displacement over the entire structural domain is expected to produce more accurate and efficient morphing performance. This novel control strategy is demonstrated numerically for the case of a morphing wing aircraft, where the shape of the wing profile is controlled using a distributed set of actuators. The morphing performance in controlling the wing camber is investigated and the effect of the number of actuators used is also studied. These preliminary numerical results demonstrate efficient control performance with a potential for further improvement.

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